Abstract of EP2124069 (A1)

An imaging system (29) is installed in the propagation paths of the radiation wave and reflected wave for covering the detection region at the transmission side and the receiving side. A rotary wedge-shape optical element (31) identifies the reflected wave regarding the reflective position. An independent claim is included for usage method of imaging system.

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(54) Omnidirektionales Lidar system

(57) Die Erfindung betrifft eine Vorrichtung zur ortsaufgelösten Erfassung von in einem Überwachungsbereich befindlichen Gegenständen, mit einer Sendeeinrichtung zur Aussendung von elektromagnetischer Strahlung in einem Sendebereich, mit einer Empfangseinrichtung zum Empfang von aus einem Empfangsbereich reflektierter Strahlung, wobei sich der Sendebereich und der Empfangsbereich in einem innerhalb des Überwachungsbereiches gelegenen und einen Erfassungswinkel abdeckenden Erfassungsbereich überlappen oder schneiden, in welchem die ausgesandte Strahlung von Gegenständen reflektiert wird, mit einer im Ausbreitungsweg der ausgesandten Strahlung und/oder der reflektierten Strahlung gelegenen Abbildungsanordnung, die zu jedem Zeitpunkt den gesamten Erfassungsbereich sendeseitig und/oder empfangsseitig abdeckt, und mit Ortsauflösungsmitteln zur Unterscheidung der reflektierten Strahlung hinsichtlich des Reflexionsortes.

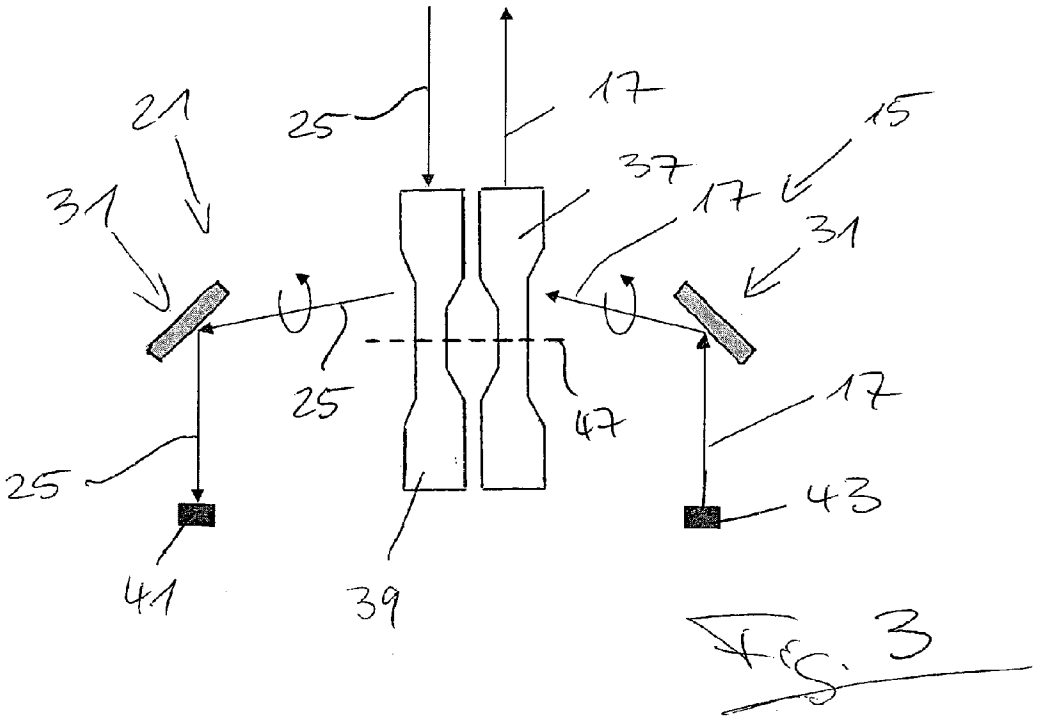


Fig. 3

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Beschreibung

[0001] Die Erfindung betrifft eine Vorrichtung zur ortsaufgelösten Erfassung von in einem Überwachungsbereich befindlichen Gegenständen mit einer Sendeeinrichtung zur Aussendung von elektromagnetischer Strahlung in einem Sendebereich und mit einer Empfangseinrichtung zum Empfang von aus einem Empfangsbereich reflektierter Strahlung, wobei sich der Sendebereich und der Empfangsbereich in einem innerhalb des Überwachungsbereichs gelegenen und einen Erfassungswinkel abdeckenden Erfassungsbereich überlappen oder schneiden, in welchem die ausgesandte Strahlung von Gegenständen reflektiert wird.

[0002] Derartige Erfassungsvorrichtungen sind grundsätzlich bekannt, z.B. in Form von Laserscannern, die als scannende Laserentfernungsmesser ausgebildet sind und den Erfassungsbereich mit einem Laserstrahl zeitlich gepulst oder kontinuierlich abtasten. Die Entfernungsmessung erfolgt dabei z.B. nach einem Laufzeitmessprinzip ("time of flight", TOF) oder einem Phasenmessprinzip.

[0003] Derartige Erfassungsvorrichtungen werden z.B. an Fahrzeugen montiert, um die Fahrzeugumgebung abzutasten und hierdurch in Sichtweite der Vorrichtung befindliche Gegenstände, wie beispielsweise andere Verkehrsteilnehmer, zu erkennen. Hierdurch ist das Fahrzeug gewissermaßen in der Lage, sich ein ortsaufgelöstes und - aufgrund der Möglichkeit zur Messung von Entfernungen - außerdem tiefenaufgelöstes Bild von seiner Umgebung zu machen, wobei diese Umgebungserfassung in Echtzeit erfolgt. Vielfältige Anwendungen sind mit den auf diese Weise gewonnenen Umgebungsdaten möglich. Derartige Erfassungsvorrichtungen werden auch in industriellen Anwendungen eingesetzt.

[0004] Insbesondere für scannende TOF-Laserentfernungsmesser, die einen vergleichsweise großen Winkelbereich von bis zu 360° in wenigstens einer Sende- oder Erfassungsebene überwachen sollen, ist es bekannt, den im Prinzip eindimensionalen Abtastlaserstrahl, also die ausgesandte Strahlung, innerhalb dieser Ebene mit einer vorgegebenen, die Ortsauflösung mit bestimmenden Winkelauflösung auszulenken. Hierzu ist es bekannt, in den - auch einfach als Sensoren bezeichneten - Erfassungsvorrichtungen den - auch als Mess- oder Fahrstrahl bezeichneten - Abtaststrahl mittels eines motorisch bewegten rotierenden Prismas oder mittels eines z.B. um 45° zur optischen Achse gekippten rotierenden Spiegels auszulenken. In diesen Fällen verlaufen die Rotationsachse des Primas bzw. des Spiegels und die optische Achse des Sensors parallel zueinander. In einer alternativen Ausgestaltung kann die gesamte elektrooptische Einheit des Sensors zur Rotation gebracht werden. Hierbei werden sowohl die Sendeals auch die Empfangsapertur auf einer Kreisbahn bewegt, um dafür zu sorgen, dass der Abtaststrahl des Sensors den gewünschten Winkelbereich von bis zu 360° überstreicht.

[0005] Die vorstehend genannten Lösungen haben den Nachteil, dass vergleichsweise große Massen bewegt, insbesondere in Rotation versetzt, werden müssen. Die hierzu erforderliche elektrische Leistung trägt in einem nicht unerheblichen Umfang zur gesamten Leistungsaufnahme des Sensors bei. Von Nachteil ist ferner, dass die erforderliche Lagerung der rotierenden Bauteile die Lebensdauer des Sensors signifikant begrenzt.

[0006] Aufgabe der Erfindung ist es, eine Erfassungsvorrichtung der eingangs genannten Art derart weiterzubilden, dass die vorstehend erwähnten Nachteile vermieden werden, wobei insbesondere bei möglichst einfachem, störunanfälligem und eine möglichst lange Lebensdauer sicherstellendem Aufbau eine zuverlässige Erfassung von in einem Überwachungsbereich befindlichen Gegenständen über einen möglichst großen Winkelbereich von insbesondere bis zu 360° erzielbar sein soll.

[0007] Die Lösung dieser Aufgabe erfolgt durch die Merkmale des Anspruchs 1.

[0008] Insbesondere ist erfindungsgemäß vorgesehen, dass die Vorrichtung eine im Ausbreitungsweg der ausgesandten Strahlung und/oder der reflektierten Strahlung gelegene Abbildungsanordnung umfasst, die zu jedem Zeitpunkt den gesamten Erfassungsbereich sendeseitig und/oder empfangsseitig abdeckt, wobei die Vorrichtung, insbesondere zusätzlich zu der Abbildungsanordnung, Ortsauflösungsmittel zur Unterscheidung der reflektierten Strahlung hinsichtlich des Reflexionsortes umfasst.

[0009] Bei dem Erfassungsbereich handelt es sich um denjenigen Bereich des Überwachungsbereiches, in den die Vorrichtung gewissermaßen sowohl mit der Sendeeinrichtung als auch mit der Empfangseinrichtung "blickt". Mit anderen Worten ist der Erfassungsbereich derjenige Bereich in der Umgebung der Vorrichtung, in welchem Gegenstände von der Vorrichtung detektiert, d.h. "gesehen", werden können. Prinzipiell ist es möglich, dass der Sendebereich und der Empfangsbereich mehr oder weniger zusammenfallen. Dies ist beispielsweise bei einer so genannten koaxialen Anordnung eines Senders der Sendeeinrichtung und eines Empfängers der Empfangseinrichtung bzw. der entsprechenden Optiken der Fall. Bei einer so genannten biaxialen Anordnung dagegen "blicken" der Sender und der Empfänger aus unterschiedlichen Richtungen auf den Erfassungsbereich. In einer solchen Anordnung kann insbesondere eine Überlappung von Sendebereich und Empfangsbereich in einem Nahbereich der Erfassungsvorrichtung verhindert werden.

[0010] Die Ortsauflösung der erfindungsgemäßen Vorrichtung ist auch durch die Größe des Querschnitts bestimmt, die ein in den Erfassungsbereich ausgesandter Strahl auf einem Gegenstand besitzt, an welchem der Strahl reflektiert wird. Insofern kann die Ortsauflösung von der Entfernung zwischen Erfassungsvorrichtung und Gegenstand abhängig sein, wenn der ausgesandte Strahl eine Divergenz aufweist, d.h. sich aufweitet. Eine

Rolle spielen hier auch die Abbildungseigenschaften der verwendeten optischen Einrichtungen der Sendeeinrichtung, insbesondere der erfindungsgemäßen Abbildungsanordnung, sofern diese sendeseitig wirksam ist.

[0011] Indem erfindungsgemäß die Abbildungsanordnung den gesamten Erfassungsbereich abdeckt, "sieht" die Abbildungsanordnung zu jedem Zeitpunkt eine Mehrzahl von (möglichen) Reflexionsorten, wobei "möglich" hier so zu verstehen ist, dass von einem Reflexionsort tatsächlich nur dann gesprochen werden kann, wenn sich im Erfassungsbereich ein Gegenstand befindet, an dem eine Reflexion stattfinden kann. Mit anderen Worten ist die Abbildungsanordnung dazu in der Lage, gleichzeitig eine Mehrzahl von Reflexionsorten auf einem im Erfassungsbereich befindlichen Gegenstand zu erzeugen (sendeseitige Abdeckung) und/oder eine Mehrzahl von Reflexionsorten zu "sehen" und auf der Empfangseinrichtung abzubilden (empfangsseitige Abdeckung).

[0012] Gewissermaßen als "Ausgleich" für eine derartige gleichzeitige Abdeckung des gesamten Erfassungsbereiches sind mit dem Ziel einer ortsaufgelösten Erfassung der im Überwachungsbereich befindlichen Gegenstände die Ortsauflösungsmittel vorgesehen. Diese Mittel sind zur Unterscheidung der reflektierten Strahlung hinsichtlich des Reflexionsortes ausgebildet.

[0013] Die Erfindung hat den Vorteil, dass die Abbildungsanordnung nicht bewegt zu werden braucht, da sie dazu in der Lage ist, zu jedem Zeitpunkt den gesamten Erfassungsbereich abzudecken. Die Ortsauflösungsmittel können in vielfältiger Weise realisiert werden. Insbesondere ermöglicht es die Erfindung, für die gewünschte Ortsauflösung auf eine Bewegung von Bauteilen ganz zu verzichten oder die für die gewünschte Ortsauflösung zu bewegenden Massen auf ein Minimum zu reduzieren.

[0014] Der von der Abbildungsanordnung abgedeckte, d.h. "gesehene", Erfassungswinkel kann grundsätzlich beliebig groß gewählt werden. So ist es möglich, dass die Abbildungsanordnung einen Erfassungswinkel von wenigstens 90°, vorzugsweise von wenigstens 180° und insbesondere bevorzugt von 360° abdeckt. In letzterem Fall liegt ein Sensor mit "Rundumsicht" vor.

[0015] Vorzugsweise ist die Erfassungsvorrichtung als Entfernungsmesser ausgebildet. Insbesondere ist für jeden (möglichen) Reflexionsort ein Entfernungswert bestimmbar. Die Vorrichtung kann zur Entfernungsmessung nach dem Laufzeitmessprinzip und/oder nach dem Phasenmessprinzip ausgebildet sein. Insbesondere ist die Vorrichtung als ein Laserscanner ausgebildet, der den Erfassungsbereich zeitlich gepulst oder kontinuierlich mit wenigstens einem ausgesandten Laserstrahl abtastet.

[0016] Des Weiteren kann erfindungsgemäß vorgesehen sein, dass die Sendeeinrichtung zur Aussendung der Strahlung in wenigstens einer Sendeebene ausgebildet ist. Bei einem Erfassungswinkel von 360° beispielsweise erfolgt die Erfassung der Umgebung der Vorrichtung somit auf einem Kreiszylinder, dessen Höhe von der Größe des Querschnitts der ausgesandten Strahlung in der jeweiligen Entfernung von der Vorrichtung abhängt.

[0017] Vorzugsweise ist die Abbildungsanordnung zur Umlenkung der ausgesandten Strahlung und/oder der reflektierten Strahlung ausgebildet. Beispielsweise erfolgt eine Umlenkung um 90°. Bei einer Anordnung der Sendeeinrichtung oberhalb oder unterhalb der Abbildungsanordnung und Aussendung der Strahlung in Richtung der Abbildungsanordnung in vertikaler Richtung erfolgt somit eine Umgebungserfassung in einer horizontalen Sendeebene.

[0018] Des Weiteren kann erfindungsgemäß vorgesehen sein, dass die Abbildungsanordnung wenigstens ein optisch wirksames Element umfasst. Bei diesem Element handelt es sich insbesondere um eine Linse, bevorzugt um eine so genannte Panoramalinse oder omnidirektionale Linse, oder um eine Strahlungsreflexionsfläche, bevorzugt um einen zumindest teilkegelförmigen Spiegel.

[0019] Derartige optisch wirksame Elemente, insbesondere die erwähnten Panoramalinsen bzw. omnidirektionalen Linsen, sind grundsätzlich bekannt. Der Einsatz derartiger Linsen erfolgt im Bereich von Videoanwendungen. Die Erfindung nutzt in vorteilhafter Weise die Eigenschaft derartiger optisch wirksamer Elemente dazu aus, einen großen Erfassungsbereich, der insbesondere einen Erfassungswinkel von bis zu 360° umfasst, auf einmal abdecken zu können, ohne die Elemente hierfür bewegen, insbesondere drehen, zu müssen. Die Erfindung ermöglicht somit erstmals den Einsatz derartiger optisch wirksamer Elemente in einer Vorrichtung zur ortsaufgelösten Umgebungserfassung, insbesondere von Panoramalinsen bzw. omnidirektionalen Linsen in Verbindung mit einem Laserscanner. Da erfindungsgemäß keine Notwendigkeit mehr besteht, eine vergleichsweise große Masse aufweisende Komponenten zu bewegen, insbesondere in Rotation zu versetzen, wird die Lebensdauer der erfindungsgemäßen Erfassungsvorrichtungen im Vergleich zu bislang bekannten Vorrichtungen signifikant erhöht. Des Weiteren sorgt die Erfindung für eine relevante Reduzierung der Leistungsaufnahme der Erfassungsvorrichtung.

[0020] In einem möglichen Ausführungsbeispiel der Erfindung umfasst die Abbildungsanordnung eine gemeinsame Abbildungseinrichtung, die sowohl sendeseitig als auch empfangsseitig wirksam ist. Dies ist jedoch nicht zwingend. Es ist auch möglich, dass die Abbildungsanordnung sowohl sendeseitig als auch empfangsseitig jeweils eine separate Abbildungseinrichtung umfasst. Diese beiden Abbildungseinrichtungen können insbesondere baugleich, bevorzugt identisch, ausgeführt sein. Hierdurch wird ein gemäß einer weiteren Ausführungsform vorgesehener, hinsichtlich zumindest der prinzipiellen Anordnung und Wirkungsweise der optischen Bauteile symmetrischer Grundaufbau der erfindungsgemäßen Erfassungsvorrichtung ermöglicht, wobei die Symmetrie bezüglich einer die Sendeseite von der Empfangsseite trennenden Ebene gegeben ist. Hier-

bei ist "symmetrisch" nicht zu eng auszulegen. Vielmehr sollen Unterschiede zwischen der Empfangsseite und der Sendeseite, die in Bezug auf die spezifischen Funktionen der Sendeeinrichtung einerseits und der Empfangseinrichtung andererseits erforderlich oder vorteilhaft sind (z.B. Unterschiede in der Größe der wirksamen Empfangsfläche einerseits und der wirksamen Sendefläche andererseits), an dem symmetrischen Grundaufbau an sich aber nichts ändern, von dem Begriff "Symmetrie" mit umfasst sein. So ist man naturgemäß bestrebt, in Abhängigkeit von der Größe des Empfängers die Empfangsoptik derart und insbesondere möglichst großflächig auszulegen, dass die empfangene Leistung möglichst hoch ist. Gleichzeitig kann sendeseitig dagegen eine deutlich kleinere Sendeoptik ausreichend sein.

[0021] In einem weiteren Ausführungsbeispiel können die Ortsauflösungsmittel empfangsseitig wirksam sein. Dabei kann insbesondere vorgesehen sein, dass die Sendeeinrichtung dazu ausgebildet ist, zu einem Zeitpunkt den gesamten Erfassungsbereich mit ausgesandter Strahlung zu beaufschlagen.

[0022] Hierbei ist es insbesondere möglich, die gesamte wirksame Fläche der Abbildungsanordnung mittels eines Senders der Sendeeinrichtung, beispielsweise einer Laserquelle, zu "beleuchten", d.h. mit der Abtaststrahlung zu beaufschlagen. Hierdurch breitet sich die Abtaststrahlung in alle vorgesehenen Richtungen aus. Bei einem Erfassungswinkel von 360° kann die Abtaststrahlung folglich von allen Gegenständen, die sich um die Vorrichtung herum und innerhalb der Reichweite der Vorrichtung befinden, gleichzeitig reflektiert werden. Für die gewünschte Ortsauflösung wird hierbei auf der Empfangsseite gesorgt. Hierzu kann beispielsweise die Empfangseinrichtung einen Empfänger umfassen, der in eine Mehrzahl von Einzelempfängern unterteilt ist, die jeweils wenigstens einem (möglichen) Reflexionsort zugeordnet sind. Es kann beispielsweise ein Empfänger-Array vorgesehen sein, wobei die einzelnen Array-Elemente beispielsweise kreisförmig angeordnet sind. Mittels dieses Empfänger-Arrays erfolgt eine Unterscheidung der verschiedenen Reflexionsorte, an denen die ausgesandte Strahlung im Erfassungsbereich reflektiert wird oder - genauer gesagt - reflektiert werden kann, sofern sich an der betreffenden Stelle im Erfassungsbereich ein die Abtaststrahlung reflektierender Gegenstand befindet. Hierbei sorgt die Abbildungsanordnung, beispielsweise eine Panoramalinse, folglich zu jedem Zeitpunkt für eine Abbildung des gesamten Erfassungsbereiches auf das Empfänger-Array. Beispielsweise zeitlich nacheinander in Richtung der Abbildungsanordnung ausgesandte Laserpulse werden somit jeweils über 360° verteilt in den Überwachungsbereich ausgesandt. Diese "Rundumsicht" der Erfassungsvorrichtung ermöglicht es, gleichzeitig die Entfernung von um die Erfassungsvorrichtung herum befindlichen Gegenständen zu messen, beispielsweise nach dem Lichtlaufzeitprinzip, wobei die Ortsauflösung durch das Empfänger-Array sichergestellt ist.

[0023] Bei einer solchen empfangsseitig wirksamen Ortsauflösung kann alternativ anstelle des beschriebenen Empfänger-Arrays ein einziger Strahlungsempfänger vorgesehen sein, der ausreichend groß ausgebildet und derart angeordnet ist, dass die Abbildungsanordnung den gesamten Erfassungsbereich auf dem Empfänger abbilden kann. Zur Unterscheidung der verschiedenen Reflexionsorte bzw. Erfassungsrichtungen, aus denen die im Erfassungsbereich reflektierte Strahlung einfällt, kann beispielsweise eine rotierende Blende vorgesehen sein, die zu jedem Zeitpunkt ausschließlich von dem jeweiligen Reflexionsort stammende bzw. unter dem jeweiligen Winkel einfallende reflektierte Strahlung durchlässt.

[0024] Eine weitere Möglichkeit zur Unterscheidung zwischen den einzelnen Reflexionsorten, also gewissermaßen zur "Ausblendung" aller zu einem bestimmten Zeitpunkt jeweils gerade nicht zu erfassenden Reflexionsorte und auch zur Ausblendung von Stör- bzw. Hintergrundstrahlung, besteht darin, empfangsseitig die Ausbreitungsrichtung der Strahlung zu beeinflussen. Hierzu ist insbesondere vorgesehen, dass die Empfangseinrichtung Beeinflussungsmittel zur zeitlich variierenden Beeinflussung der Ausbreitungsrichtung der Strahlung umfasst. Bevorzugt sind die Beeinflussungsmittel im Ausbreitungsweg der Strahlung zwischen der Abbildungsanordnung und einem Empfänger der Empfangseinrichtung angeordnet. Auf konkrete Möglichkeiten zur Ausgestaltung derartiger Strahlungsbeeinflussungsmittel wird nachstehend näher eingegangen.

[0025] Während vorstehend erwähnt wurde, dass in einer Variante der Erfindung der Erfassungsbereich zu einem Zeitpunkt vollständig mit der ausgesandten Strahlung beaufschlagt wird, indem beispielsweise die gesamte wirksame Fläche der Abbildungsanordnung "beleuchtet" wird, so dass für die gewünschte Ortsauflösung auf der Empfangsseite zu sorgen ist, kann in einer weiteren Variante der Erfindung zusätzlich oder alternativ auf der Sendeseite für die gewünschte Unterscheidung zwischen den verschiedenen Reflexionsorten gesorgt werden, d.h. die Ortsauflösungsmittel können sendeseitig wirksam sein.

[0026] Es kann eine Einrichtung vorgesehen sein, die in Bezug auf die Reflexionsorte zur selektiven Aussendung der Strahlung mittels der Sendeeinrichtung dient. Die Abbildungsanordnung wird hierbei folglich nicht mehr vollständig mit der Abtaststrahlung beaufschlagt. Vielmehr kann vorgesehen sein, insbesondere nach dem Prinzip eines herkömmlichen Scanners, die Abbildungsanordnung zu jedem Zeitpunkt mit lediglich einem einzigen Sendestrahl zu beaufschlagen, wobei die Richtung, unter welcher dieser Sendestrahl auf die Abbildungsanordnung trifft, zeitlich variiert wird.

[0027] Die Sendeeinrichtung kann Beeinflussungsmittel zur zeitlich variierenden Beeinflussung der Ausbreitungsrichtung der Strahlung umfassen. Insbesondere sind die Beeinflussungsmittel im Ausbreitungsweg der Strahlung zwischen einem Sender der Sendeeinrichtung

und der Abbildungsanordnung angeordnet.

[0028] Bei den vorstehend erwähnten Beeinflussungsmitteln, die sendeseitig und/oder empfangsseitig vorgesehen sein können, kann es sich insbesondere um zur Ausführung von Ablenkbewegungen ansteuerbare bewegliche, insbesondere rotierbare, optische Elemente handeln. Derartige optische Elemente sind beispielsweise Spiegel, Prismen oder Keile. Bei den Beeinflussungsmitteln kann es sich auch um diffraktive Optiken handeln, die beispielsweise zur Veränderung ihres strahlungsbrechenden Verhaltens elektrisch ansteuerbar sind.

[0029] Derartige Beeinflussungsmittel sind grundsätzlich bekannt. In einem besonders bevorzugten Ausführungsbeispiel wird sendeseitig und/oder empfangsseitig jeweils wenigstens ein so genannter mikromechanischer Spiegel (MEMS) eingesetzt.

[0030] Die Erfindung ermöglicht es folglich, die für die Umgebungserfassung zu bewegenden Massen zu minimieren. Ein Sender, beispielsweise eine Laserquelle, der Sendeeinrichtung, ein Empfänger, beispielsweise ein oder mehrere Fotodioden, der Empfangseinrichtung sowie die Abbildungsanordnung, die beispielsweise zwei Panoramalinsen oder omnidirektionale Linsen umfasst, von denen die eine der Sendeeinrichtung und die andere der Empfangseinrichtung zugeordnet ist, können in Bezug auf eine Basis der Erfassungsvorrichtung, d.h. bezüglich eines fest mit der Erfassungsvorrichtung verbundenen Koordinatensystems, unbeweglich angeordnet sein.

[0031] Gemäß einem weiteren Aspekt betrifft die Erfindung die Verwendung einer Abbildungsanordnung, die zu jedem Zeitpunkt einen Erfassungsbereich sendeseitig und/oder empfangsseitig vollständig abdeckt, insbesondere einer Panoramalinse, einer omnidirektionalen Linse oder eines zumindest teilkegelförmigen Spiegels, in einer Vorrichtung zur ortsaufgelösten Erfassung von in einem Überwachungsbereich befindlichen Gegenständen, insbesondere eine Vorrichtung der vorstehend erläuterten Art, wobei die Vorrichtung eine Sendeeinrichtung zur Aussendung von elektromagnetischer Strahlung in einem Sendebereich und eine Empfangseinrichtung zum Empfang von aus einem Empfangsbereich reflektierter Strahlung umfasst, wobei sich der Sendebereich und der Empfangsbereich in dem innerhalb des Überwachungsbereichs liegenden und einen Erfassungswinkel abdeckenden Erfassungsbereich überlappen oder schneiden, in welchem die ausgesandte Strahlung von Gegenständen reflektiert wird bzw. reflektiert werden kann, wobei die Abbildungsanordnung im Ausbreitungsweg der ausgesandten Strahlung und/oder der reflektierten Strahlung gelegen ist, und wobei die Vorrichtung Ortsauflösungsmittel zur Unterscheidung der reflektierten Strahlung hinsichtlich des Reflexionsortes umfasst.

[0032] Generell ist die Erfindung in vielfältiger Weise einsetzbar, beispielsweise in Fahrzeuganwendungen und in industriellen Anwendungen.

[0033] Mögliche Ausführungsformen der Erfindung sind vorstehend bereits erläutert worden und auch in den abhängigen Ansprüchen, der Beschreibung sowie der Zeichnung angegeben.

[0034] Die Erfindung wird im Folgenden beispielhaft unter Bezugnahme auf die Zeichnung beschrieben. Es zeigen:

Fig. 1a und 1b	schematisch verschiedene Ansichten eines Ausführungsbeispiels einer Abbildungseinrichtung für eine erfindungsgemäße Erfassungsvorrichtung, und
Fig. 2 bis 5	schematisch unterschiedliche Ausführungsformen einer erfindungsgemäßen Erfassungsvorrichtung.

[0035] Die in den Fig. 1a und 1b schematisch dargestellte Panoramalinse 37, die als eine Abbildungseinrichtung in einer erfindungsgemäßen Erfassungsvorrichtung zum Einsatz kommen kann, ist bezüglich einer Achse 47 rotationssymmetrisch ausgebildet. Über eine Strahlungseintrittsfläche 51, die einem nicht dargestellten Sender, beispielsweise einer Laserquelle, zugewandt ist, einfallende Strahlung 17 wird innerhalb der Linse 37 zunächst an einer ersten Fläche 49 und dann an einer zweiten Fläche 49 reflektiert. Die Strahlung 17 tritt über einen Winkelbereich von 360° (Fig. 1b) aus der Linse 37 über eine umlaufende Austrittsfläche 53 aus. Der Strahlungsverlauf ist in Fig. 1a lediglich angedeutet und nicht physikalisch korrekt wiedergegeben. Die erwähnten Flächen sind in Fig. 1b durch gestrichelte bzw. strichpunktierte Linien lediglich angedeutet.

[0036] Folglich wird mit der Panoramalinse 37 der Sender bzw. die ausgesandte Strahlung 17 auf einen 360° umfassenden Sendebereich abgebildet. Es erfolgt eine Umlenkung der ausgesandten Strahlung 17 um 90°. Die die Linse 37 verlassende Strahlung 17 breitet sich in einer Sendeebene 35 aus, die senkrecht zur optischen Achse 47 der Linse 39 verläuft.

[0037] Gestrichelt ist in Fig. 1a der umgekehrte Strahlungsverlauf angedeutet.

Die Panoramalinse 37 ist dann empfangsseitig wirksam, wobei aus einem 360° umfassenden Empfangsbereich einfallende Strahlung 25 auf einen nicht dargestellten Empfänger abgebildet werden kann.

[0038] Die in den Fig. 2 bis 5 dargestellten Ausführungsbeispiele einer erfindungsgemäßen Erfassungsanordnung haben gemeinsam, dass jeweils zwei Panoramalinsen 37, 39, wie sie in Fig. 1a und 1b gezeigt sind, vorgesehen sind. Eine erste Linse 37 ist einer einen Sender 43, beispielsweise eine Laserquelle, umfassenden Sendeeinrichtung 15 zugeordnet, während eine zweite Linse 39 einer Empfangseinrichtung 21 zugeordnet ist, die einen Empfänger 41 z.B. in Form einer Fotodiode umfasst.

[0039] Die Ausführungsformen der Fig. 2 bis 5 unterscheiden sich durch die Ausgestaltung von Strahlungs-

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beeinflussungsmitteln 31, worauf nachstehend näher eingegangen wird.

[0040] Im Ausführungsbeispiel der Fig. 2 ist die Funktionsweise der erfindungsgemäßen Erfassungsvorrichtung näher angedeutet. In einem Überwachungsbereich 11 befindet sich ein Gegenstand 13. Unter anderem aufgrund der Abbildungseigenschaften der Sendelinse 37 erfolgt eine Aufweitung der ausgesandten Strahlung 17. Die Linse 37 besitzt beispielsweise einen austrittsseitig wirksamen Öffnungswinkel von etwa 30°. Die Aussendung der Strahlung 17 erfolgt somit in einem sich in radialer Richtung aufweitenden, 360° um die Sendelinse 37 herum abdeckenden Sendebereich 19. Dabei liegt die Sendestrahlung 17 in einer Sendeebene 35, die senkrecht zu einer gemeinsamen optischen Achse 47 der von den beiden Linsen 37, 39 gebildeten Abbildungsanordnung 29 verläuft. Entsprechend besitzt die zur Sendelinse 37 baugleiche Empfangslinse 39 einen Empfangsbereich 23. Die Anordnung der beiden Linsen 37, 39 ist derart gewählt, dass ab einer gewünschten Messentfernung der Sendebereich 19 und der Empfangsbereich 23 einander überlappen bzw. schneiden. Hierdurch ergibt sich ein gestrichelt dargestellter Erfassungsbereich 27, in welchem die erfindungsgemäße Erfassungsvorrichtung Gegenstände 13 detektieren kann.

[0041] Diese Situation ist in Fig. 2 schematisch in einer Ebene dargestellt, welche die gemeinsame optische Achse 47 der beiden Linsen 37, 39 enthält. Bei dem Erfassungsbereich 27 handelt es sich folglich um einen bezüglich der Achse 47 rotationssymmetrischen Bereich der Umgebung der Erfassungsvorrichtung, der sich um 360° um die Abbildungsanordnung 29 bzw. deren Achse 47 herum erstreckt. Die ausgesandte Strahlung 17 wird von dem Gegenstand 13 an so genannten Reflexionsorten 33 reflektiert, von denen in Fig. 2 lediglich einer dargestellt ist.

[0042] Die Empfangslinse 39 ist in umgekehrter Strahlungsausbreitungsrichtung wirksam. Die aus den Erfassungsbereich 27 in einer Empfangsebene 55 reflektierte Strahlung 25 wird von der Empfangslinse 39 auf den Empfänger 41 abgebildet. In optischer Hinsicht ist die Erfassungsvorrichtung somit hinsichtlich des generellen Grundaufbaus symmetrisch bezüglich einer die Sendeseite von der Empfangsseite trennenden Ebene 45 ausgelegt, die senkrecht zur Achse 47 verläuft.

[0043] Um mittels der Sendelinse 37 die Strahlung 17 in unterschiedliche Richtungen auszusenden, ist im Ausbreitungsweg der Strahlung 17 zwischen dem Sender 43 und der Sendelinse 37 ein optisch wirksames Element 31 angeordnet. Im Ausführungsbeispiel der Fig. 2 handelt es sich hierbei um einen rotierenden optischen Keil. Der aus dem Keil 31 austretende Laserstrahl 17 bewegt sich auf einem Kegelmantel, so dass der aus der Sendelinse 37 austretende Laserstrahl 17 um die Achse 47 rotiert und folglich den gesamten Erfassungsbereich 27 überstreicht.

[0044] Sendeseitig ist somit ein Laserscanner realisiert, wobei allerdings die für die Ablenkung in den Erfassungsbereich 27 sorgende Linse 37 stationär angeordnet ist. Es ist lediglich erforderlich, den optischen Keil 31 in Rotation zu versetzen. Durch dieses sendeseitige Scannen ist die gewünschte Ortsauflösung trotz der zu jedem Zeitpunkt gegebenen vollständigen Abdeckung des Erfassungsbereiches 27 durch die Sendelinse 37 gewährleistet.

[0045] Aufgrund der vorstehend erwähnten prinzipiellen symmetrischen Ausgestaltung der Erfassungsvorrichtung ist auch empfangsseitig im Ausbreitungsweg der reflektierten Strahlung 25 zwischen der Empfangslinse 39 und dem Empfänger 41 ein rotierender optischer Keil 31 angeordnet. Der sendeseitige Keil 31 und der empfangsseitige Keil 41 sind derart hinsichtlich ihrer Rotationsbewegungen miteinander synchronisiert, dass jeweils ein in den Erfassungsbereich 27 ausgesandter Laserstrahl nach Reflexion an einem Gegenstand 13 mittels der Empfangslinse 39 auf dem Empfänger 41 abgebildet wird. Diese empfangsseitige Selektivität stellt in vorteilhafter Weise sicher, dass auf die Empfangslinse 39 treffende Störstrahlung ausgeblendet wird, d.h. nicht auf den Empfänger 41 gelangt. Diese Hintergrundausblendung ist nicht zwingend. Alternativ ist es möglich, auf die empfangsseitig vorgesehene zeitlich variierende Beeinflussung der Ausbreitungsrichtung der reflektierten Strahlung 25 mittels des rotierenden Keils 31 zu verzichten. Es kann stattdessen z.B. ein großflächigerer Empfänger vorgesehen sein, auf den zu jedem Zeitpunkt der gesamte Erfassungsbereich 27 mittels der Empfangslinse 39 abgebildet wird. Aufgrund der erwähnten Störstrahlung oder Hintergrundstrahlung könnte sich allerdings ein gegenüber der in Fig. 2 dargestellten Anordnung verschlechterter Rausch-/Signalabstand ergeben.

[0046] Zur Bestimmung der Entfernung des Gegenstands 13 von der Erfassungsvorrichtung ist beispielsweise eine Einrichtung zur Laufzeitmessung vorgesehen. Hierbei wird die Zeit gemessen, welche die Laserstrahlung benötigt, um den Weg von der Sendeeinrichtung 15 zum Gegenstand 13 und als reflektierte Strahlung 25 zurück zur Empfangseinrichtung 21 zurückzulegen. Insofern können für die erfindungsgemäße Erfassungsvorrichtung grundsätzlich alle herkömmlichen Methoden zur Entfernungsmessung eingesetzt werden, wie sie z.B. in Bezug auf existierende Laserscanner bekannt sind. Auf die eigentliche Entfernungsmessung, die dem Fachmann somit bekannt ist, braucht daher nicht näher eingegangen zu werden.

[0047] Das sendeseitige Scannen und die empfangsseitige Hintergrundausblendung sind auch in den Ausführungsbeispielen der Fig. 3, 4 und 5 vorgesehen, wobei hierfür aber jeweils unterschiedliche Mittel eingesetzt werden.

[0048] In dem Ausführungsbeispiel der Fig. 3 sind der Sender 43 und der Empfänger 41 außerhalb der gemeinsamen optischen Achse 47 der Sendelinse 37 und der Empfangslinse 39 angeordnet. Die hier anstelle der rotierenden optischen Keile gemäß Fig. 2 vorgesehenen Strahlungsbeeinflussungsmittel in Form der Ablenkein-

richtungen 31 sorgen nicht nur für die Rotation der ausgesandten Strahlung 17 bzw. reflektierten Strahlung 25, sondern korrigieren außerdem die erwähnte Abweichung von der optischen Achse 47. Als Ablenkeinrichtungen können hier beispielsweise die bereits erwähnten mikromechanischen Spiegel 31 (MEMS) eingesetzt werden. Als Alternative zu diesen beweglichen Spiegeln 31 können auch elektrisch steuerbare diffraktive Optiken verwendet werden, wie sie ebenfalls grundsätzlich bekannt sind. Des Weiteren sind auch motorisch angetriebene taumelnde Spiegel als Beeinflussungsmittel 31 einsetzbar.

[0049] Bei der zentralen Anordnung der optischen Komponenten gemäß Fig. 4 existiert sowohl sendeseitig als auch empfangsseitig jeweils ein so genannter "blinder Fleck", der für die jeweilige Abbildung nicht benötigt wird. Dieser Umstand wird hier dazu genutzt, den Sender 43 und den Empfänger 41 auf der optischen Achse nahe der jeweiligen Linse 37 bzw. Linse 39 anzuordnen. Hierdurch sind die aktiven Flächen des Senders 43 und des Empfängers 41 von der jeweiligen Linse 37 bzw. Linse 39 abgewandt. Die Brennweite des von den Linsen 37, 39 gebildeten optischen Systems bestimmt den Abstand, in welchem die Strahlungsbeeinflussungsmittel 31 angeordnet sind. Bei diesen kann es sich beispielsweise um die bereits erwähnten mikromechanischen Spiegel (MEMS) handeln. Diese sorgen dafür, dass der Sendestrahl 17 bzw. das Blickfeld, aus welchem die reflektierte Strahlung 25 einfällt, kreisförmig auf den relevanten Bereich der jeweiligen Linse 37 bzw. Linse 39 abgelenkt wird.

[0050] Das Ausführungsbeispiel der Fig. 5 zeigt ebenfalls eine zentrale Anordnung der optoelektronischen Bauteile. Die Ablenkung der Senderichtung bzw. Blickrichtung erfolgt hierbei durch elektrisch steuerbare diffraktive Optiken 31, wie sie ebenfalls bereits erwähnt wurden. In dieser Anordnung befinden sich der Sender 43 und der Empfänger 41 jeweils im Brennpunkt der zugehörigen Linse 37 bzw. Linse 39.

Bezugszeichenliste

[0051]

11	Überwachungsbereich
13	Gegenstand
15	Sendeeinrichtung
17	ausgesandte Strahlung
19	Sendebereich
21	Empfangseinrichtung
23	Empfangsbereich
25	reflektierte Strahlung
27	Erfassungsbereich
29	Abbildungsanordnung
31	Ortsauflösungsmittel
33	Reflexionsort
35	Sendeebene
37	Abbildungseinrichtung
39	Abbildungseinrichtung
41	Empfänger
43	Sender
45	Symmetrieebene
47	Achse der Abbildungsanordnung
49	Reflexionsfläche
51	Eintrittsfläche
53	Austrittsfläche
55	Empfangsebene

Patentansprüche

1. Vorrichtung zur ortsaufgelösten Erfassung von in einem Überwachungsbereich (11) befindlichen Gegenständen (13),
mit einer Sendeeinrichtung (15) zur Aussendung von elektromagnetischer Strahlung (17) in einem Sendebereich (19),
mit einer Empfangseinrichtung (21) zum Empfang von aus einem Empfangsbereich (23) reflektierter Strahlung (25),
wobei sich der Sendebereich (19) und der Empfangsbereich (23) in einem innerhalb des Überwachungsbereiches (11) gelegenen und einen Erfassungswinkel abdekkenden Erfassungsbereich (27) überlappen oder schneiden, in welchem die ausgesandte Strahlung (17) von Gegenständen (13) reflektiert wird,
mit einer im Ausbreitungsweg der ausgesandten Strahlung (17) und/oder der reflektierten Strahlung (25) gelegenen Abbildungsanordnung (29), die zu jedem Zeitpunkt den gesamten Erfassungsbereich (27) sendeseitig und/oder empfangsseitig abdeckt,
und mit Ortsauflösungsmitteln (31) zur Unterscheidung der reflektierten Strahlung (25) hinsichtlich des Reflexionsortes (33).

2. Vorrichtung nach Anspruch 1,
dadurch gekennzeichnet,
dass der Erfassungsbereich (27) eine Mehrzahl von möglichen Reflexionsorten (33) umfasst.

3. Vorrichtung nach Anspruch 1 oder 2,
dadurch gekennzeichnet,
dass der Erfassungswinkel zumindest in einer Sendeebene (35) wenigstens 90°, vorzugsweise wenigstens 180° und insbesondere bevorzugt 360° beträgt.

4. Vorrichtung nach einem der vorhergehenden Ansprüche,
dadurch gekennzeichnet,
dass sie als Entfernungsmesser ausgebildet ist, wobei insbesondere für jeden Reflexionsort (33) ein Entfernungswert bestimmbar ist.

5. Vorrichtung nach einem der vorhergehenden An-

sprüche,
dadurch gekennzeichnet,
dass sie zur Entfernungsmessung nach dem Laufzeitmessprinzip und/oder nach dem Phasenmessprinzip ausgebildet ist.

6. Vorrichtung nach einem der vorhergehenden Ansprüche,
dadurch gekennzeichnet,
dass sie als ein Laserscanner ausgebildet ist, der den Empfangsbereich (27) zeitlich gepulst oder kontinuierlich abtastet.

7. Vorrichtung nach einem der vorhergehenden Ansprüche,
dadurch gekennzeichnet,
dass die Sendeeinrichtung (15) zur Aussendung der Strahlung (17) in wenigstens einer Sendeebene (35) ausgebildet ist.

8. Vorrichtung nach einem der vorhergehenden Ansprüche,
dadurch gekennzeichnet,
dass die Abbildungsanordnung (29) zur Umlenkung der ausgesandten Strahlung (17) und/oder der reflektierten Strahlung (25) ausgebildet ist.

9. Vorrichtung nach einem der vorhergehenden Ansprüche,
dadurch gekennzeichnet,
dass die Abbildungsanordnung (29) wenigstens ein optisch wirksames Element umfasst, insbesondere eine Linse, bevorzugt eine Panoramalinse und/oder eine omnidirektionale Linse, oder eine Strahlungsreflexionsfläche, bevorzugt einen zumindest teilkegelförmigen Spiegel.

10. Vorrichtung nach einem der vorhergehenden Ansprüche,
dadurch gekennzeichnet,
dass die Abbildungsanordnung (29) eine gemeinsame Abbildungseinrichtung umfasst, die sowohl sendeseitig als auch empfangsseitig wirksam ist.

11. Vorrichtung nach einem der Ansprüche 1 bis 9,
dadurch gekennzeichnet,
dass die Abbildungsanordnung (29) sowohl sendeseitig als auch empfangsseitig jeweils eine separate Abbildungseinrichtung (37, 39) umfasst, wobei insbesondere die Abbildungseinrichtungen (37, 39) baugleich sind.

12. Vorrichtung nach einem der vorhergehenden Ansprüche,
dadurch gekennzeichnet,
dass die Ortsauflösungsmittel (31) empfangsseitig wirksam sind,
wobei insbesondere die Sendeeinrichtung (15) dazu ausgebildet ist, zu einem Zeitpunkt den gesamten Erfassungsbereich (27) mit ausgesandter Strahlung (17) zu beaufschlagen, insbesondere mittels der Abbildungsanordnung (29).

13. Vorrichtung nach einem der vorhergehenden Ansprüche,
dadurch gekennzeichnet,
dass die Empfangseinrichtung (21) einen Empfänger (41) umfasst, der in eine Mehrzahl von Einzelempfängern unterteilt ist, die jeweils wenigstens einem Reflexionsort (33) zugeordnet sind.

14. Vorrichtung nach einem der vorhergehenden Ansprüche,
dadurch gekennzeichnet,
dass eine Einrichtung vorgesehen ist, die in bezug auf die Reflexionsorte (33) zur selektiven Erfassung der reflektierten Strahlung (25) mittels der Empfangseinrichtung (21) dient.

15. Vorrichtung nach einem der vorhergehenden Ansprüche,
dadurch gekennzeichnet,
dass im Ausbreitungsweg der reflektierten Strahlung (25) zwischen der Abbildungsanordnung (29) und einem Empfänger (41) der Empfangseinrichtung (21) eine bewegliche Blende angeordnet ist.

16. Vorrichtung nach einem der vorhergehenden Ansprüche,
dadurch gekennzeichnet,
dass die Empfangseinrichtung (21) Beeinflussungsmittel (31) zur zeitlich variierenden Beeinflussung der Ausbreitungsrichtung der reflektierten Strahlung (25) umfasst, wobei insbesondere die Beeinflussungsmittel (31) im Ausbreitungsweg der Strahlung (25) zwischen der Abbildungsanordnung (29) und einem Empfänger (41) der Empfangseinrichtung (21) angeordnet sind.

17. Vorrichtung nach einem der vorhergehenden Ansprüche,
dadurch gekennzeichnet,
dass die Ortsauflösungsmittel (31) sendeseitig wirksam sind.

18. Vorrichtung nach einem der vorhergehenden Ansprüche,
dadurch gekennzeichnet,
dass eine Einrichtung (31) vorgesehen ist, die in Bezug auf die Reflexionsorte (33) zur selektiven Aussendung der Strahlung (17) mittels der Sendeeinrichtung (15) dient.

19. Vorrichtung nach einem der vorhergehenden Ansprüche,
dadurch gekennzeichnet,

dass die Sendeeinrichtung (15) Beeinflussungsmittel (31) zur zeitlich variierenden Beeinflussung der Ausbreitungsrichtung der Strahlung (17) umfasst, wobei insbesondere die Beeinflussungsmittel (31) im Ausbreitungsweg der Strahlung (17) zwischen einem Sender (43) der Sendeeinrichtung (15) und der Abbildungsanordnung (29) angeordnet sind.

20. Vorrichtung nach einem der Ansprüche 16 bis 19,
dadurch gekennzeichnet,
dass die Beeinflussungsmittel (31) wenigstens ein zur Ausführung von Ablenkbewegungen ansteuerbares bewegliches optisches Element, insbesondere einen Spiegel, ein Prisma oder einen Keil, und/oder zumindest eine zur Veränderung des strahlungsbrechenden Verhaltens ansteuerbare diffraktive Optik umfassen.

21. Vorrichtung nach einem der vorhergehenden Ansprüche,
dadurch gekennzeichnet,
dass sie in Bezug auf eine die Sendeseite von der Empfangsseite trennende Ebene (45) zumindest hinsichtlich der prinzipiellen Funktionsweise symmetrisch aufgebaut ist.

22. Verwendung einer Abbildungsanordnung (29),
die zu jedem Zeitpunkt einen Erfassungsbereich (27) sendeseitig und/oder empfangsseitig vollständig abdeckt,
insbesondere einer Panoramalinse, einer omnidirektionalen Linse oder eines zumindest teilkegelförmigen Spiegels,
in einer Vorrichtung zur ortsaufgelösten Erfassung von in einem Überwachungsbereich (11) befindlichen Gegenständen (13), insbesondere einer Vorrichtung nach einem der vorhergehenden Ansprüche,
wobei die Vorrichtung eine Sendeeinrichtung (15) zur Aussendung von elektromagnetischer Strahlung (17) in einem Sendebereich (19) und eine Empfangseinrichtung (21) zum Empfang von aus einem Empfangsbereich (23) reflektierter Strahlung (25) umfasst, wobei sich der Sendebereich (19) und der Empfangsbereich (23) in dem innerhalb des Überwachungsbereiches (11) gelegenen und einen Erfassungswinkel abdeckenden Erfassungsbereich (27) überlappen oder schneiden, in welchem die ausgesandte Strahlung (17) von Gegenständen (13) reflektiert wird,
wobei die Abbildungsanordnung (29) im Ausbreitungsweg der ausgesandten Strahlung (17) und/oder der reflektierten Strahlung (25) gelegen ist, und
wobei die Vorrichtung Ortsauflösungsmittel (31) zur Unterscheidung der reflektierten Strahlung (25) hinsichtlich des Reflexionsortes (33) umfasst.

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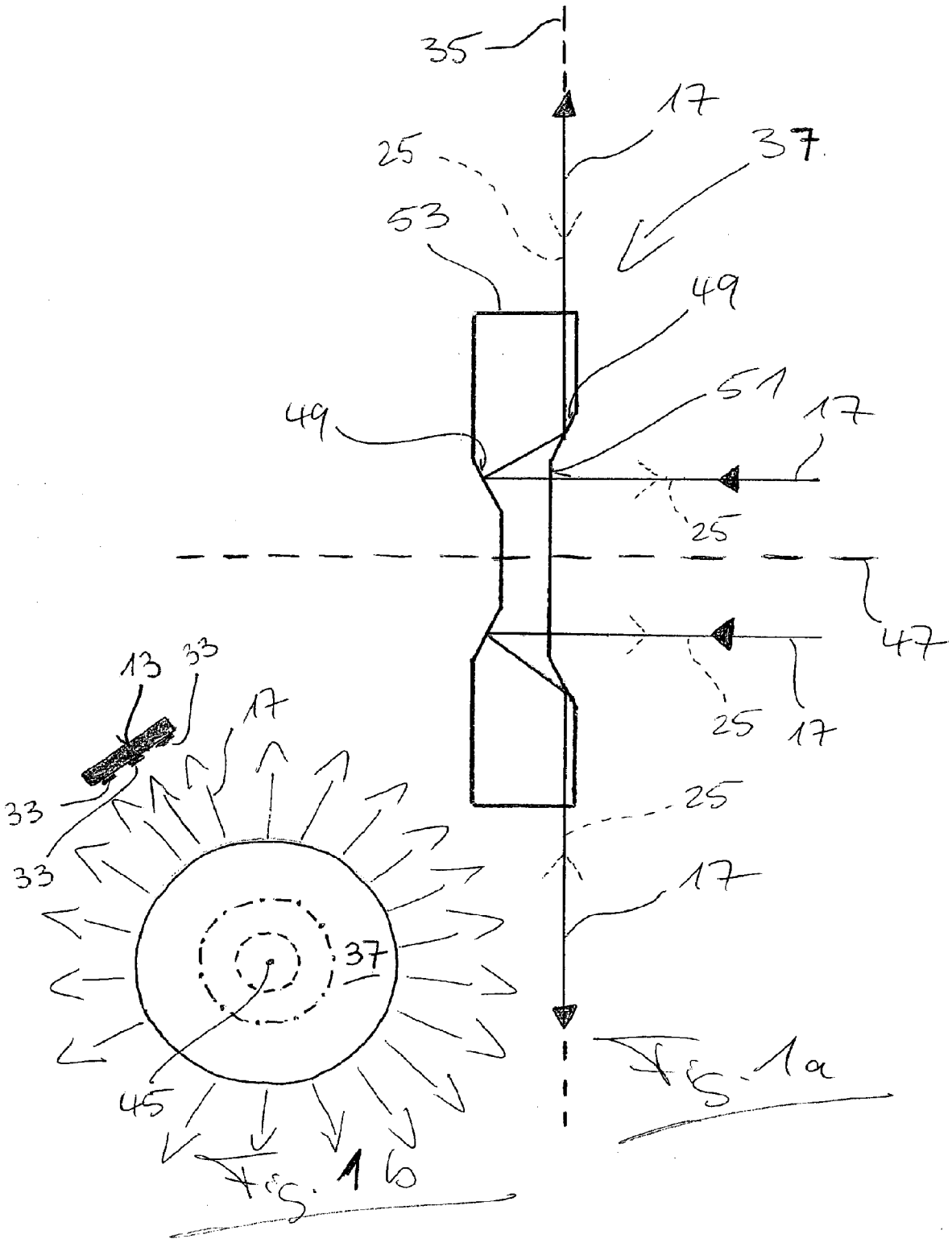


FIG. 1a

FIG. 1b

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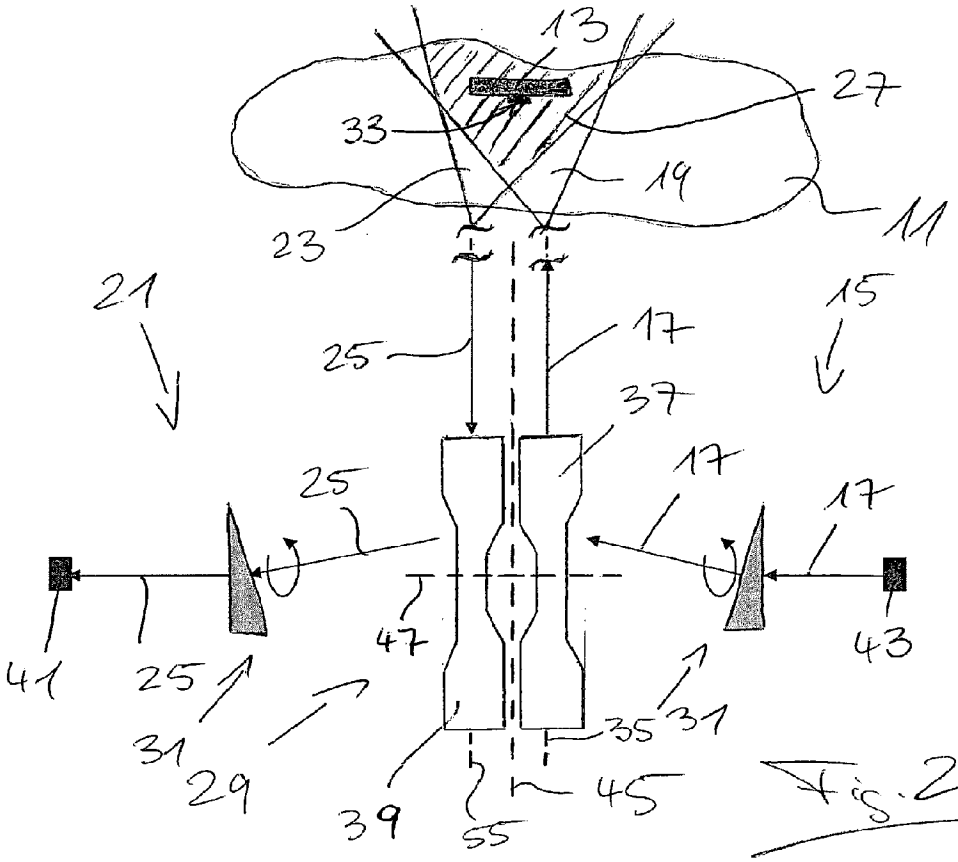


Fig. 2

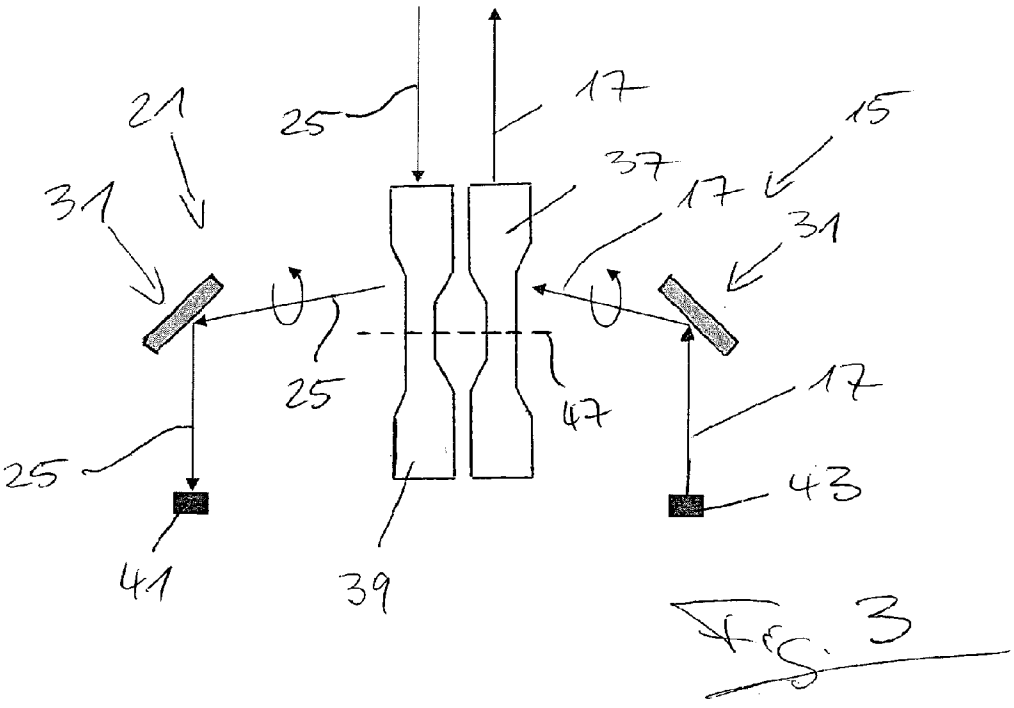


Fig. 3

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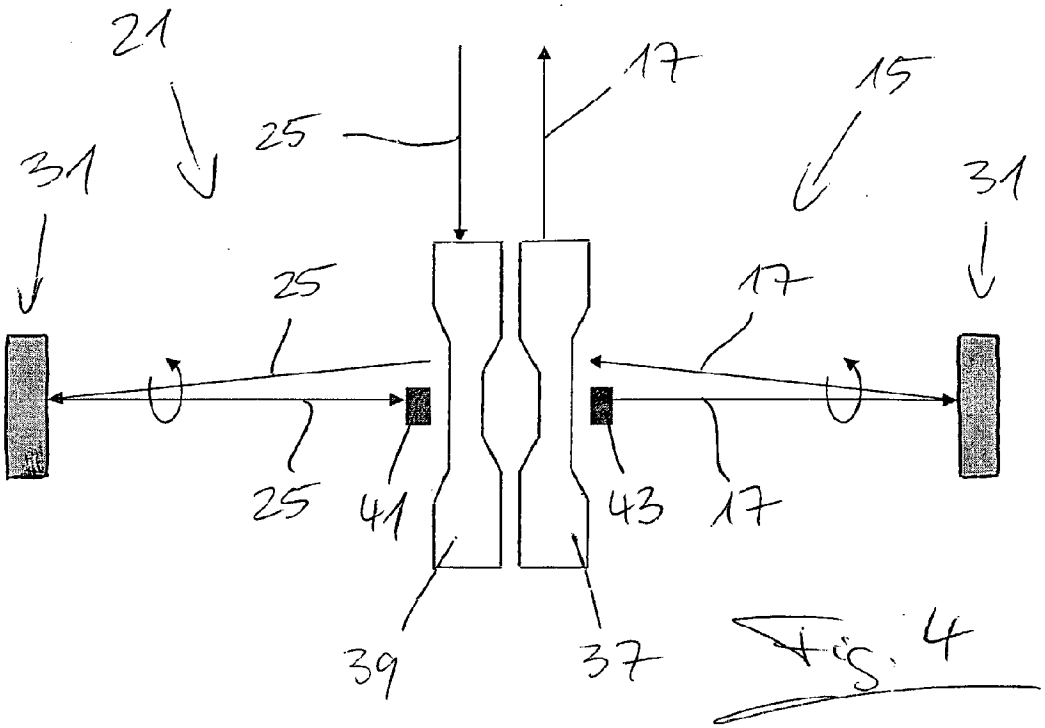


Fig. 4

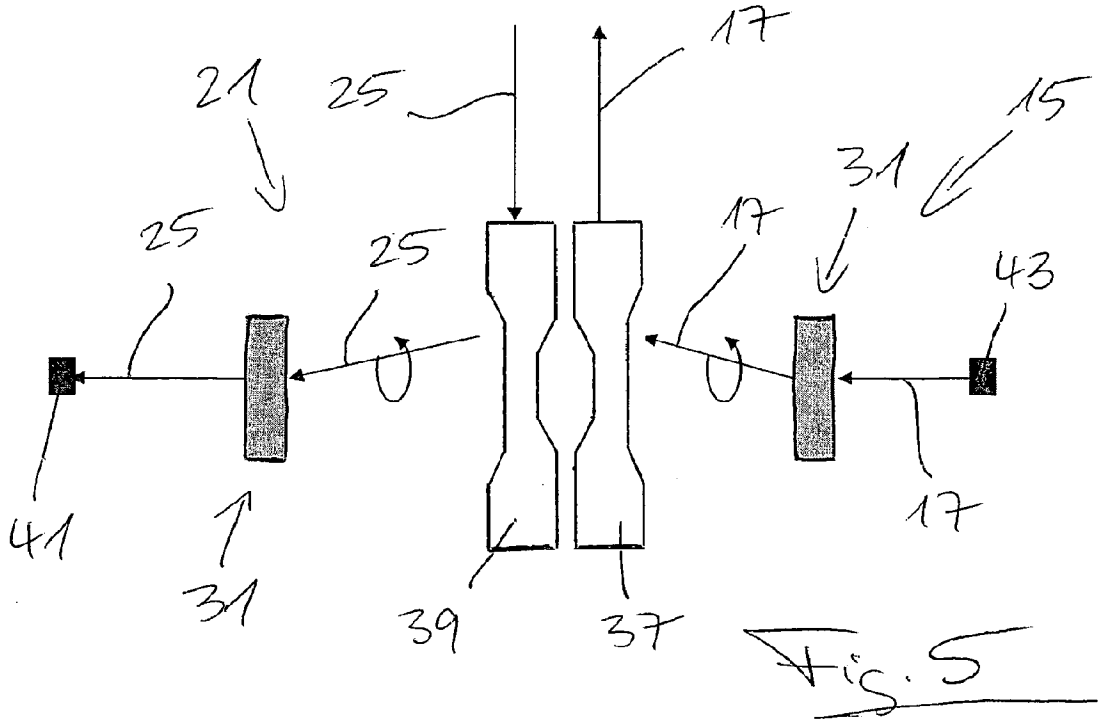


Fig. 5

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Europäisches Patentamt

EUROPÄISCHER RECHERCHENBERICHT

Nummer der Anmeldung
EP 08 00 5342

EINSCHLÄGIGE DOKUMENTE

Kategorie	Kennzeichnung des Dokuments mit Angabe, soweit erforderlich, der maßgeblichen Teile	Betrifft Anspruch	KLASSIFIKATION DER ANMELDUNG (IPC)
X	US 5 018 447 A (MILLER JR WALTER E [US] ET AL) 28. Mai 1991 (1991-05-28)	1-3, 7-10, 12-19, 21,22	INV. G01S7/481 G01S17/42 G02B26/10
Y	* Spalte 1, Zeilen 56-62; Abbildungen 1-3,5,8 * * Spalte 6, Zeilen 6-26 * * Spalte 3, Zeilen 8-12,42-62 * * Spalte 4, Zeilen 11-15,24-43; Abbildung 5 * * Spalte 2, Zeilen 33,34,45-62 *	4-6,11, 20	
Y	SIMPSON M L ET AL: "INTENSITY-MODULATED, STEPPED FREQUENCY CW LIDAR FOR DISTRIBUTED AEROSOL AND HARD TARGET MEASUREMENTS" APPLIED OPTICS, OSA, OPTICAL SOCIETY OF AMERICA, WASHINGTON, DC, Bd. 44, Nr. 33, 20. November 2005 (2005-11-20), Seiten 7210-7217, XP001236472 ISSN: 0003-6935 * Zusammenfassung *	4-6	
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A	US 6 839 127 B1 (ANDERSON NOEL WAYNE [US]) 4. Januar 2005 (2005-01-04) * Abbildung 1 *	1-22	

RECHERCHIERTE SACHGEBIETE (IPC)

G01S
G02B

Der vorliegende Recherchenbericht wurde für alle Patentansprüche erstellt

Recherchenort	Abschlußdatum der Recherche	Prüfer
München	16. Juni 2008	Metz, Carsten

KATEGORIE DER GENANNTEN DOKUMENTE

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1

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ANHANG ZUM EUROPÄISCHEN RECHERCHENBERICHT ÜBER DIE EUROPÄISCHE PATENTANMELDUNG NR.

EP 08 00 5342

In diesem Anhang sind die Mitglieder der Patentfamilien der im obengenannten europäischen Recherchenbericht angeführten Patentdokumente angegeben.
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ABSTRACT EP3002548

The invention relates to an illumination device for generating an illumination field for an optoelectronic sensor, having at least one light source (9) and an adjustable optical beam shaping element (10), wherein the beam shaping element (10) engages a pressure element (16). In an illumination device which is simple to manufacture, the light source (9) and the beam shaping element (10) directly adjoin one another and form a compact unit (8).

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(54) **Beleuchtungseinrichtung und Verfahren zum Erzeugen eines Beleuchtungsfeldes**

Illumination device and method for generating an illumination field

Dispositif d'éclairage et procédé destiné à la production d'une zone d'éclairage

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EP 3 002 548 B1

Beschreibung

[0001] Die Erfindung betrifft eine Beleuchtungseinrichtung zum Erzeugen eines Beleuchtungsfeldes nach dem Oberbegriff von Anspruch 1.

[0002] Für die Inspektion oder Vermessung von Objekten werden häufig Kamerasysteme eingesetzt, welche auch zum Lesen von Barcodes weite Verbreitung gefunden haben. Dabei werden Bilder des Objektes erfasst und entsprechend der Aufgabe durch Bildverarbeitungsverfahren ausgewertet. Eine weitere Anwendung von Kameras ist das Lesen von Codes. Derartige kamerabasierte Codeleser lösen die noch weit verbreiteten Barcode-Scanner zunehmend ab. Mit Hilfe eines Bildsensors werden Objekte mit den darauf befindlichen Codes aufgenommen, in den Bildern die Codebereiche identifiziert und dann decodiert. Kamerabasierte Codeleser kommen problemlos auch mit anderen Codearten als eindimensionalen Strichcodes zurecht, die wie ein Matrixcode auch zweidimensional aufgebaut sind und mehr Informationen zur Verfügung stellen.

[0003] Alle diese Anwendungen haben gemein, dass sie eine Beleuchtung benötigen, um den zu lesenden Barcode bzw. die zu inspizierenden und zu vermessenden Objekte unabhängig vom Umgebungs- oder Fremdlicht zu erfassen. Zu diesem Zweck weisen diese Kamerasysteme Lichtquellen auf, die häufig als LEDs ausgebildet sind. Im Vergleich zu den ebenfalls gelegentlich verwendeten Laserlichtquellen haben LEDs meist eine divergentere Abstrahlungscharakteristik und größere Abstrahlflächen.

[0004] Darüber hinaus ist bekannt, Vergusslinsen zur Strahlfokussierung direkt auf ein LED-Gehäuse aufzubringen.

[0005] In der DE 602 15 093 T2 ist eine steuerbare flüssige Mikrolinse offenbart, welche aus einer Isolierschicht und einem Tröpfchen einer transparenten leitenden Flüssigkeit besteht, die auf einem Trägermaterial angeordnet ist. Die Mikrolinse enthält mehrere Elektroden, wobei sich die Position der Mikrolinse durch die, an den Elektroden jeweilig angelegten Spannungen verändern lässt.

[0006] Aus dem Stand der Technik ist weiterhin eine Beleuchtungsvorrichtung bekannt, bei welcher eine LED ein Strahlführungselement in Form einer festen TIR-Linse (Total Internal Reflection) beleuchtet und welche zur effizienten Projektion des Lichtes in die Szene eingesetzt wird. An das Strahlführungselement schließt sich ein Mikrolinsenarray aus Silikon an, auf welchem eine Deckplatte aus Glas aufliegt. Durch eine Krafteinwirkung wird die Deckplatte an das elastische Mikrolinsenarray gedrückt und somit das Mikrolinsenarray deformiert. Durch die Deformation des Mikrolinsenarrays wird das Beleuchtungsfeld geformt.

[0007] Aus der WO2009/034511 A2 ist eine Beleuchtungseinrichtung nach dem Oberbegriff bekannt.

[0008] Es ist die Aufgabe der Erfindung, eine Beleuchtungseinrichtung zur Erzeugung eines Beleuchtungsfeldes für einen optoelektronischen Sensor anzugeben, der konstruktiv einfach herstellbar ist.

[0009] Diese Aufgabe wird durch eine Beleuchtungseinrichtung nach Anspruch 1 gelöst. Dabei geht die Erfindung von dem Grundgedanken aus, dass das optische Strahlformungselement direkt auf der Lichtquelle aufliegt und durch einen, an dem Strahlformungselement angreifenden Druck dieses Strahlformungselement zur Lichtformung deformiert wird. Das Strahlformungselement bildet dabei mit der Lichtquelle eine einfach zu betätigende kompakte Einheit. Auf ein Strahlführungselement kann dabei verzichtet werden.

[0010] In einem Strahlengang hinter dem Strahlformungselement, der Lichtquelle abgewandt, ist ein Mikrolinsen aufweisendes Mustererzeugungselement angeordnet, welches einen Erfassungsbereich des optoelektronischen Sensors durch ein Beleuchtungsmuster sichtbar macht. Ein solches Mustererzeugungselement erlaubt die Einstellung der Größe bzw. der Art der Zielgeometrie des optoelektronischen Sensors.

[0011] Das Mustererzeugungselement ist als adaptiver, Mikrolinsen aufweisender Punktmustergenerator ausgebildet, welcher bei einer mechanischen Druckbeanspruchung der elastisch ausgebildeten Mikrolinsen durch die aus einem festen Material bestehenden Deckplatte in Abhängigkeit der vertikal angreifenden Druckkraft ein Beleuchtungsmuster mit variierendem Punktdurchmesser erzeugt. Mittels einer solchen adaptiven Punktmusterbeleuchtung ist eine Umschaltung zwischen einem Punktlichtmuster und einer homogenen Beleuchtung, was ein Beleuchtungsmuster ohne Struktur darstellt, einfach möglich. Hierbei wird die homogene Beleuchtung der Szene verwendet, um neben der 3D-Information (mit strukturierter Beleuchtung) Grauwertbilder aufzunehmen. Diese zusätzliche Information kann zur reinen Darstellung oder algorithmischen Auswertung des Erfassungsbereiches des optoelektronischen Sensors verwendet werden.

[0012] Um beispielsweise bei einem Objektivwechsel des Kamerasystems des optoelektronischen Sensors die Zielgeometrie an den Sichtbereich des Objektivs anzupassen, bestehen die Mikrolinsen aus einem elastischen oder festen Material und sind auf einem festen Trägermaterial angeordnet, wobei eine beweglich gelagerte, vorzugsweise lateral verschiebliche, aus einem festen oder elastischen Material bestehende, transparente Abdeckung auf den Mikrolinsen aufliegt. Die Druckbeaufschlagung der Mikrolinsen bewirkt eine Vergrößerung der Krümmungsradien bzw. der Brennweiten der Mikrolinsen. Dies hat eine Verringerung der Strahldivergenz und somit eine Verkleinerung des Lichtmusters im Erfassungsbereich des optoelektronischen Sensors zur Folge. Die optische Strahlformung im deformierten bzw. undeformierten Zustand der Mikrolinsen kann durch eine asphärische oder frei geformte oder sphärische Linsenoberfläche und/oder Oberfläche der Deckplatte verändert werden. Die Mikrolinsen können dabei auch ein Mikrolinsenarray bilden. Anstelle eines elastischen Mikrolin-

senarrays und einer festen transparenten Deckplatte können ein festes Mikrolinsenarray und eine elastische Deckplatte verwendet werden.

[0013] Das Mustererzeugungselement besteht bevorzugt aus zwei gekreuzten, vorzugsweise senkrecht zueinander stehenden, elastischen Mikrolinsenarrays, die durch eine Trennplatte voneinander beabstandet sind, wobei jedes Mikrolinsenarray mit je einer festen Deckplatte abgedeckt ist und die Deckplatten unabhängig voneinander lateral und/oder vertikal beweglich ausgebildet sind. Durch die jeweilige Bewegung einer der Deckplatten in lateraler Richtung entsteht eine Scherung des jeweiligen Mikrolinsenarrays, was zu einer nicht rotationssymmetrischen Deformation der Mikrolinsen führt. Dadurch wird das Beleuchtungsmuster im Erfassungsbereich des optoelektronischen Sensors lateral verschoben. Dies hat den Vorteil, dass die Position des Beleuchtungsmusters an den Sichtbereich der Kamera angepasst werden kann, wenn diese Kamera ein neues Objektiv erhält oder wenn das Beleuchtungsmustermuster an eine bevorzugte Stelle im Kamerasichtbereich positioniert werden soll. Die gekreuzte Ausführung der Mikrolinsenarrays ermöglicht darüber hinaus eine individuelle Einstellung der zwei Dimensionen des Beleuchtungsmusters.

[0014] Besonders einfach ist es möglich, von einem strukturierten auf ein homogenes Lichtmuster umzuschalten, wenn der Punktmustergenerator bei einer lateralen Deformation des Mikrolinsenarrays durch die Deckplatte ein Beleuchtungsmuster erzeugt, welches lateral im Erfassungsbereich verschoben ist. Durch diese laterale Verschiebung der festen Deckplatte entsteht eine Scherung des Mikrolinsenarrays, was zu einer nicht rotationssymmetrischen Deformation der Mikrolinsen führt. Dies hat zur Folge, dass das Punktmuster lateral verschoben wird und auf diese Weise die Position des Punktmusters an die zu betrachtende Szene angepasst wird.

[0015] Für alle beschriebenen Ausführungsbeispiele gilt alternativ, dass anstelle der elastisch ausgebildeten Mikrolinsen auch feste Mikrolinsen verwendet werden können, wobei eine elastische Deckplatte an den Mikrolinsen angreift.

[0016] Die Erfindung wird nachstehend auch hinsichtlich weiterer Merkmale und Vorteile beispielhaft anhand von Ausführungsformen und unter Bezug auf die beigefügte Zeichnung näher erläutert. Die Abbildungen der Zeichnung zeigen in:

Fig. 1 eine schematische Schnittdarstellung einer optoelektronischen Kamera mit einer Beleuchtungseinrichtung,

Fig. 2 ein Ausführungsbeispiel einer erfindungsgemäßen Beleuchtungseinrichtung,

Fig.3 ein erstes Ausführungsbeispiel der Funktionsweise der erfindungsgemäßen Beleuchtungseinrichtung nach Fig. 2,

Fig.4 ein weiteres Ausführungsbeispiel der Funktionsweise der erfindungsgemäßen Beleuchtungseinrichtung nach Fig. 2,

Fig.5 ein weiteres Ausführungsbeispiel der Funktionsweise der erfindungsgemäßen Beleuchtungseinrichtung nach Fig. 2,

Fig. 6 eine simulierte Oberflächengeometrie einer deformierten sphärischen Mikrolinse,

Fig.7 ein erstes Ausführungsbeispiel einer Funktionsweise eines adaptiven Mustererzeugungselementes,

Fig.8 ein zweites Ausführungsbeispiel der Funktionsweise eines adaptiven Mustererzeugungselementes,

Fig.9 ein weiteres Ausführungsbeispiel der Funktionsweise eines adaptiven Mustererzeugungselementes,

Fig. 10 ein Ausführungsbeispiel zur Funktionsweise eines Punktmustergenerators,

Fig. 11 ein weiteres Ausführungsbeispiel zur Funktionsweise eines Punktmustergenerators.

[0017] Fig. 1 zeigt eine schematische Darstellung eines optoelektronischen Sensors 1. Der optoelektronische Sensor 1 ist beispielsweise ein kamerabasierter Codeleser, kann aber ebenso ein anderer optoelektronischer Sensor sein, dessen Erfassungsbereich 2 ausgerichtet werden soll und deshalb von einer Visualisierung mittels einer Zieleinrichtung profitiert.

[0018] Der optoelektronische Sensor 1 empfängt Licht aus dem Erfassungsbereich 2. Im Falle eines Codelesers können sich dort beispielsweise Objekte mit zu lesenden Codes befinden. Das Licht aus dem Erfassungsbereich 2 wird durch ein Aufnahmeobjektiv oder eine Empfangsoptik empfangen, die vereinfacht durch eine Linse 3 dargestellt ist. Ein Lichtempfänger 4 wandelt das Empfangslicht in ein elektrisches Signal um. Bei dem Lichtempfänger 4 handelt es sich beispielsweise um eine Photodiode oder, wie bei einem kamerabasierten Codeleser, um einen CCD- oder CMOS-Chip mit einer Vielzahl von zu einer Zeile oder einer Matrix angeordneten Pixelelementen.

[0019] Das elektrische Signal des Lichtempfängers 4 wird einer Auswerteeinheit 5 zugeführt, die daraus Objektinformationen des Erfassungsbereiches 2 gewinnt. Im Beispiel des Codelesers enthält das elektrische Signal Bilddaten aus einem Lesefeld in dem Erfassungsbereich 2. In diesen Bilddaten werden Codebereiche gesucht und die Codeinformationen innerhalb von Codebereichen

werden decodiert. Das Ergebnis der Auswertung wird an einem Ausgang 6 bereitgestellt.

[0020] Der optoelektronische Sensor 1 umfasst weiterhin eine Beleuchtungseinrichtung 7, welche eine kompakte Einheit 8 umfasst, bestehend aus einer Lichtquelle 9, beispielsweise eine Halbleiterlichtquelle, wie eine LED, eine Laserdiode oder eine VC-SEL, und einem Strahlformungselement 10. Weiterhin ist in der Beleuchtungseinrichtung 7 ein Mustererzeugungselement 11 angeordnet. In dem Erfassungsbereich 2 wird damit ein Beleuchtungsmuster erzeugt, um die Lage des Erfassungsbereiches 2 sichtbar zu machen und somit den optoelektronischen Sensor 1 auf einen gewünschten Erfassungsbereich 2 richten zu können.

[0021] In Fig. 2 ist ein erstes Ausführungsbeispiel der kompakten Einheit 8 der Beleuchtungseinrichtung 7 dargestellt, welche dabei als deformierbares LED-Vergusslinsen-Array 12 ausgebildet ist. Bei einem solchen LED-Vergusslinsen-Array 12 sind auf einer Trägerplatte 13 mehrere LEDs 14 befestigt, wobei jede einzelne LED 14 mit einer sphärisch ausgebildeten Vergusslinse 15 aus einem elastischen Material verspritzt ist, so dass die LED 14 und die Vergusslinse 15 die kompakte Einheit 8 bilden. Dabei wird in einem Spritzgussprozess die Vergusslinse 15 aus einem Polymer hergestellt und mit der LED 14 zu einer Beleuchtung assembliert. Ein solches LED-Vergusslinsenarray 12 wird mit einer transparenten, aus einem festen Material bestehenden Deckplatte 16, welche in vorliegenden Fall eine inhomogene Dicke aufweist, zusammengedrückt, wobei das so betätigte deformierte LED-Vergusslinsen-Array 12 zur adaptiven Strahlformung des von den LEDs 14 ausgestrahlten Lichtes genutzt wird.

[0022] Ein Ausführungsbeispiel einer Funktionsweise einer einzelnen, mit einer LED 14 vergossenen Vergusslinse 15, die eine sphärische Linsenoberfläche aufweist, ist in Fig. 3 ersichtlich. Dabei wird durch die feste Deckplatte 16 eine Kraft F1 auf die elastische Vergusslinse 15 ausgeübt (Fig. 3A). Wird die anliegende homogene Kraft F2 gegenüber der Kraft F1 verstärkt, wird die elastische Vergusslinse 15 zusammengedrückt und deformiert (Fig. 3B). Die Abflachung der sphärischen Linsenform im inneren Bereich führt zu einer optischen Strahlformung. Infolge der Deformation der elastischen Vergusslinse 15 wird das von der LED 14 ausgegebene Licht divergent beeinflusst. Alternativ zu der beschriebenen sphärischen Linsenform ist aber auch eine asphärische oder frei geformte Linsenoberfläche einsetzbar.

[0023] Wie aus Fig. 4 ersichtlich, funktioniert ein solches Strahlformungselement 10 aber auch dann, wenn die Vergusslinse 15 fest ausgebildet ist und die Deckplatte 16 aus einem elastischen Material besteht. Dabei verformt sich, wie aus Fig. 4 ersichtlich, die Deckplatte 16, was ebenfalls zu einer Strahlformung des von der LED 14 abgegebenen Lichtstrahles führt.

[0024] Somit sind unterschiedliche Materialkombinationen für Deckplatte 16 und Vergusslinse 15 möglich. Besteht die Vergusslinse 15 aus einem elastischen Material wie beispielsweise Silikon, so kann die Deckplatte 16 aus einem festen Material wie Glas oder Polymer ausgebildet sein. Alternativ kann die Vergusslinse 15 aber auch aus einem festen Material wie Glas und die Deckplatte 16 aus dem elastischen Material wie Silikon bestehen. In einer weiteren Alternative können sowohl Vergusslinse 15 als auch Deckplatte 16 aus einem voll- oder teilelastischen Material hergestellt sein.

[0025] In Fig. 5 ist auf der Oberfläche der sphärisch ausgebildeten Vergusslinse 15 eine Noppe 17 ausgebildet. Diese Noppe 17 ist insbesondere in dem Bereich der Oberfläche der Vergusslinse 15 ausgebildet, wo die Linsenoberfläche zuerst die Deckplatte 16 berührt. Diese Noppe 17 im Kontaktbereich zwischen elastischer Vergusslinse 15 und fester Deckplatte 16 hat den Vorteil, dass eine Hysterese der Beleuchtungsdivergenz unterbunden wird, indem die Kontaktfläche zwischen elastischer Vergusslinse 15 und fester Deckplatte 16 minimiert wird. Dieser Effekt kann verbessert werden, wenn auf der Oberfläche der Vergusslinse 15 in vorgegebenen Abständen mehrere Noppen 17 ausgebildet sind.

[0026] In Fig. 6 ist eine simulierte Oberflächengeometrie der beschriebenen deformierten sphärischen Vergusslinse 15 dargestellt, woraus hervorgeht, dass bei einem auf die Vergusslinse 15 wirkenden Druck infolge der homogenen Kraft die Abflachung der sphärischen Linsenform im inneren Bereich der Vergusslinse 15 erfolgt.

[0027] Fig. 7 zeigt ein Mustererzeugungselement 11 der Beleuchtungseinrichtung 7, welche ebenfalls als Mikrolinsenarray 18 ausgebildet ist, bei dem eine vorgegebene Anzahl aus elastischen Mikrolinsen 19 auf einem festen Trägermaterial 20 positioniert sind. Ein solches Mustererzeugungselement 11 wird bei einer Neujustierung des optoelektronischen Sensors 1 benötigt. Über den Mikrolinsen 19 ist eine transparente, aus festem Material bestehende Deckplatte 21 angeordnet, die in Fig. 7A ohne eine weitere Krafteinwirkung auf den Mikrolinsen 19 aufliegt. Das Ergebnis ist, dass das, von dem Mikrolinsenarray 18 im Erfassungsbereich 2 des optoelektronischen Sensors 1 erzeugte Beleuchtungsmuster ein Zielkreuz 22 darstellt. Wird auf die Deckplatte 21 mit einer homogenen Kraft F2, welche größer ist als F1, gegen die elastischen Mikrolinsen 19 gedrückt, so bewirkt diese Druckbeaufschlagung der Mikrolinsen 19 eine Vergrößerung der Krümmungsradien und somit der Brennweiten der Mikrolinsen 19. Dies hat eine Verringerung der Strahldivergenz und somit eine Verkleinerung der Dimension des Zielkreuzes 22 zur Folge, wie es in Fig. 7B dargestellt ist. Auch hier können anstelle eines elastischen Mikrolinsenarrays und einer festen transparenten Deckplatte ein festes Mikrolinsenarray und eine elastische Deckplatte verwendet werden.

[0028] Im druckbeaufschlagtem Zustand (F>0) des elastischen Mikrolinsenarrays 18 besteht die Möglichkeit, dieses lateral zu deformieren, wie aus Fig. 8 hervorgeht. Dabei befindet sich das Zielkreuz 22 im unbelasteten Zustand in der Mitte des Erfassungsbereiches 2 (Fig.8A). Durch die laterale Verschiebung der festen

transparenten Deckplatte 21 und der gleichzeitigen Druckbeaufschlagung der Mikrolinsen 19 entsteht eine Scherung des Mikrolinsenarrays 18, was zu einer nicht rotationssymmetrischen Deformation der Mikrolinsen 19 führt, wie in Fig. 8B dargestellt. Dies hat zur Folge, dass das Zielkreuz 22 im Erfassungsbereich 2 lateral verschoben wird. Auf diese Weise kann die Position des Zielkreuzes 22 in dem Erfassungsbereich des optoelektronischen Sensors 1 angepasst oder an einer bestimmten bevorzugten Stelle im Erfassungsbereich 2 positioniert werden.

[0029] Es besteht auch die Möglichkeit, die zwei Dimensionen des Zielkreuzes 28 individuell voneinander einzustellen. Zu diesem Zweck besteht das Mustererzeugungselement 23 aus zwei gekreuzten elastischen Mikrolinsenarrays 24, 25. Die Orientierung von Mikrolinsenarray 24 ist senkrecht zur Orientierung vom Mikrolinsenarray 25, wobei die beiden Mikrolinsenarrays 24, 25 zu beiden Seiten eines Trägerelementes angeordnet sind. Im vorgegebenen Beispiel wird das erste Mikrolinsenarray 24 von einer ersten Deckplatte 26 aus einem festen transparenten Material abgedeckt, während das zweite Mikrolinsenarray 25 von einer zweiten Deckplatte 27 überdeckt wird. Wird keinerlei Kraft auf das erste und das zweite Mikrolinsenarray 24, 25 durch die Deckplatten 26, 27 ausgeübt, so ergibt sich ein Zielkreuz 28 wie es in Fig. 9A gezeigt ist. Durch die individuelle Druckbeaufschlagung des Mikrolinsenelementes 24 über die erste Deckplatte 26 und des zweiten Mikrolinsenarrays 25 durch die zweite Deckplatte 27 verschiebt sich die Dimension des Zielkreuzes 28 in beiden Richtungen unabhängig voneinander. So verkürzt sich der waagerechte Strich 29 des Zielkreuzes 28, wenn nur die Deckplatte 26 mit einer vorgegebenen konstanten Kraft F>0 auf das erste Mikrolinsenarray 24 drückt. Wird dem zweiten Mikrolinsenarray 25 keine Kraft zugeführt, so bleibt der vertikale Strich 30 des Zielkreuzes 28 unverändert (Fig. 9B). In einer Alternative, welche in Fig. 9C dargestellt ist, wird das zweite Mikrolinsenarray 25 durch die zweite Deckplatte 27 mit einer vorgegebenen Kraft F>0 beaufschlagt, wodurch sich der vertikale Strich 30 des Zielkreuzes 28 verkürzt. Da in diesem Fall das erste Mikrolinsenarray 24 druckunbeaufschlagt ist, bleibt der waagerechte Strich 29 des Zielkreuzes 28 unverändert.

[0030] Insbesondere bei der Verwendung eines optoelektronischen Sensors 1, der als 3D-Kamerasensor zur Entfernungsmessung ausgebildet ist, basiert das Detektionsprinzip auf Triangulation unter Zuhilfenahme einer aktiven Musterbeleuchtung. In Stereosystemen wird die Beleuchtung zur Generierung eines künstlichen Kontrastes eingesetzt, um dichte Tiefenkanten zu erzeugen und die Abstandswerte periodischer Objekte in der zu betrachtenden Szene eindeutig zu bestimmen. In diesem Fall ist das Mustererzeugungselement als Punktmustergenerator 31 auf der Basis eines Mikrolinsenarrays 32 ausgebildet. Die auf dem Mikrolinsenarray 32 angeordneten Mikrolinsen 33 bestehen aus einem elastischen Material, beispielsweise aus Silikon. Die elastischen Mikrolinsen 33 sind auf einem festen Trägermaterial 34 angeordnet und, wie im Zusammenhang mit Fig. 1 erläutert, ist dieses so geformte Mustererzeugungselement Bestandteil der Beleuchtungseinrichtung 7.

[0031] Ein Ausführungsbeispiel für die Funktionsweise eines solchen Punktmustergenerators 31 ist in Fig. 10 dargestellt. Das Mikrolinsenarray 32 des Punktmustergenerators 31 wird von dem Lichtstrahl der Lichtquelle 9 durchleuchtet, wobei, wie aus Fig. 10A ersichtlich, der Lichtstrahl konvergiert. Dies ist immer dann der Fall, wenn keine Kraft auf das Mikrolinsenarray 32 ausgeübt wird. Ohne diese mechanische Druckbeanspruchung bilden die Mikrolinsen 33 des Mikrolinsenarrays 32 in der Fokusebene des Projektionsobjektivs kleine Brennpunkte aus, dessen Lichtmuster zu einem Beleuchtungsmuster mit kleinen Punktdurchmessern führt. Wird gemäß Fig. 10B eine Kraft F2>0 durch die transparente Deckplatte 35 auf das Mikrolinsenarray 32 ausgeübt, deformieren sich die Mikrolinsen 33, wie im Zusammenhang mit Fig. 5 erläutert. Die Deformation führt zu einer Abflachung des Linsenkrümmungsradius in der Linsenmitte, was wiederum zur Verschiebung des Brennpunktes führt. Die Verschiebung des Brennpunktes in der Fokusebene des Projektionsobjektivs führt zur Vergrößerung des Punktdurchmessers des in der Fokusebene des Projektionsobjektivs dargestellten Beleuchtungsmusters.

[0032] Wird weiterhin der Druck (F>>0) auf das elastische Mikrolinsenarray 32 erhöht (Fig. 10C), verschwindet die gekrümmte Linsenform vollständig. Übrig bleiben zwei parallele Glasplatten in Form der transparenten Deckplatte 35 und des transparenten Trägermaterials 34 mit einem elastischen Material dazwischen. Bei dieser Position der Mikrolinsen 33 erlischt deren Strahlformungseffekt vollständig. In diesem Zustand wird die Fokusebene des Projektionsobjektivs homogen beleuchtet, was zu einer homogenen Beleuchtung der Szene führt.

[0033] Wird in einem druckbeaufschlagten Zustand des elastischen Mikrolinsenarrays 32 dieses lateral deformiert, wie in Fig. 11 dargestellt, indem eine laterale Verschiebung der Deckplatte 34 vorgenommen wird, entsteht eine Scherung des Mikrolinsenarrays 32, was zu einer nicht rotationssymmetrischen Deformation der Mikrolinsen 33 führt. Dies hat zur Folge, dass das Punktmuster in der Fokusebene des Projektionsobjektivs in Richtung der Verschiebung der Deckplatte 34 verschoben wird (Fig. 11 B). Im Vergleich dazu befindet sich das Punktmuster immer dann, wenn das Mikrolinsenarray 32 frei von einer Druckbeaufschlagung ist, im Zentrum der Fokusebene des Projektionsobjektivs (Fig. 11A). Aufgrund der Verwendung eines solchen Punktmuster-Erzeugungselementes in einer 3D-Stereokamera, lassen sich die Beleuchtungsmuster adaptiv an die Gegebenheiten der zu beleuchtenden Szene anpassen, wobei das Beleuchtungsmuster zwischen strukturiert und homogen adaptiv umgeschaltet werden kann. Dieses Umschalten ermöglicht neben den 3D-Tiefendaten auch die Aufnahme von Grauwertbildern.

[0034] Es besteht ebenfalls die Möglichkeit, die Ver-

änderung bzw. Verschiebung des Punktmusters für sichere Stereokameras einzusetzen. In der Sicherheitstechnik muss sichergestellt werden, dass die Bildaufnahme immer zuverlässig funktioniert. Die Funktionalität der Bildsensoren wird dabei mit einem dynamischen Bildsensortest (Hell- und Dunkelbildern) in den Pausen der Stereobildaufnahme mit einer internen Beleuchtungs-LED überprüft. Der Bildsensortest mit interner Beleuchtungs-LED kann eingespart werden, wenn sich das Beleuchtungsmuster

[0035] (Position und Größe der Punkte) von Zeit zu Zeit ändert, um die dynamische Funktion der Bildsensoren mit den Grauwertbildern der beiden Kameramodule aus der Szene zu verifizieren.

Patentansprüche

1. Beleuchtungseinrichtung zum Erzeugen eines Beleuchtungsfeldes für einen optoelektronischen Sensor, die mindestens eine Lichtquelle (9), ein anpassbares optisches Strahlformungselement (10) und ein Druckelement aufweist, wobei das Druckelement an das Strahlformungselement (10) (16) angreift, und zur Lichtformung deformiert, und wobei die Lichtquelle (9) und das Strahlformungselement (10) direkt aneinander grenzen und eine kompakte Einheit (8) bilden, **dadurch gekennzeichnet, dass** im Strahlengang hinter dem Strahlformungselement (10), der Lichtquelle (9) abgewandt, ein Mikrolinsen (19) aufweisendes Mustererzeugungselement (11) angeordnet ist, welches einen Erfassungsbereich (2) des optoelektronischen Sensors (1) durch ein Beleuchtungsmuster (22, 28) sichtbar macht, dass das Mustererzeugungselement (11) als adaptiver, Mikrolinsen (33) umfassender Punktmustergenerator (31) ausgebildet ist, welcher bei einer mechanischen Druckbeanspruchung der elastisch ausgebildeten Mikrolinsen (33) durch die aus einem festen Material bestehenden Deckplatte (35) in Abhängigkeit der senkrecht an den Mikrolinsen (33) angreifenden Druckkraft das Beleuchtungsmuster mit variierendem Punktdurchmesser erzeugt.

2. Beleuchtungseinrichtung nach Anspruch 1, **dadurch gekennzeichnet, dass** der Punktmustergenerator (31) bei einer lateralen Deformation der Mikrolinsen (33) durch die Deckplatte (35) ein Beleuchtungsmuster erzeugt, welches lateral im Erfassungsbereich (2) verschoben ist.

Claims

1. An illumination device for producing an illumination field for an optoelectronic sensor which has at least one light source (9), an adaptable optical beam shaping element (10) and a pressure element, wherein the pressure element (16) engages at the beam shaping element (10) and deforms it for light shaping; and wherein the light source (9) and the beam shaping element (10) are directly adjacent to one another and form a compact unit (8), **characterized in that** a pattern generating element (11) having microlenses (19) is arranged in the optical path behind the beam shaping element (10) and facing away from the light source (9), said pattern generating element making a detection zone (2) of the optoelectronic sensor (1) visible by an illumination pattern (22, 28); **in that** the pattern generating element (11) is configured as an adaptive point pattern generator (31) which comprises microlenses (33) and which produces the illumination pattern with a varying point diameter on a mechanical pressure exertion on the elastic microlenses (33) by the top plate (35) comprising a solid material in dependence on the perpendicular pressure force engaging at the microlenses (33).

2. An illumination device in accordance with claim 1, **characterized in that** the point pattern generator (31) produces an illumination pattern, which is displaced laterally in the detection zone (2), on a lateral deformation of the microlenses (33) by the top plate (35).

Revendications

1. Dispositif d'éclairage destiné à la production d'une zone d'éclairage pour un capteur optoélectronique, qui comprend au moins une source de lumière (9) et un élément de formage de rayon (10) optique adaptable et un élément de compression, l'élément de compression attaquant l'élément de formage de rayon (10) et le déformant pour le formage de la lumière, et dans lequel la source de lumière (9) et l'élément de formage de rayon (10) sont directement adjacents l'un à l'autre et forment une unité compacte (8), **caractérisé en ce qu'**en arrière de l'élément de formage de rayon (10) dans le chemin optique, un élément de génération de motif (11) comprenant des microlentilles (19) est agencé en étant détourné de la source de lumière (9), qui rend visible une zone de détection (2) du capteur optoélectronique (1) par un motif d'éclairage (22, 28), **en ce que** l'élément de génération de motif (11) est réalisé sous forme de générateur de motif de points (31) adaptatif comprenant des microlentilles (33), qui, lors d'une sollicitation mécanique par pression des microlentilles (33) réalisées élastiques, génère le motif d'éclairage avec variation du diamètre des points par la plaque de couverture (35) constituée en un matériau solide, en fonction de la force de compression attaquant verticalement les microlentilles (33).

2. Dispositif d'éclairage selon la revendication 1, **caractérisé en ce que** lors de la déformation latérale des microlentilles (33) par la plaque de couverture (35), le générateur de motif de points (31) génère un motif d'éclairage qui est décalé latéralement dans la zone de détection (2).

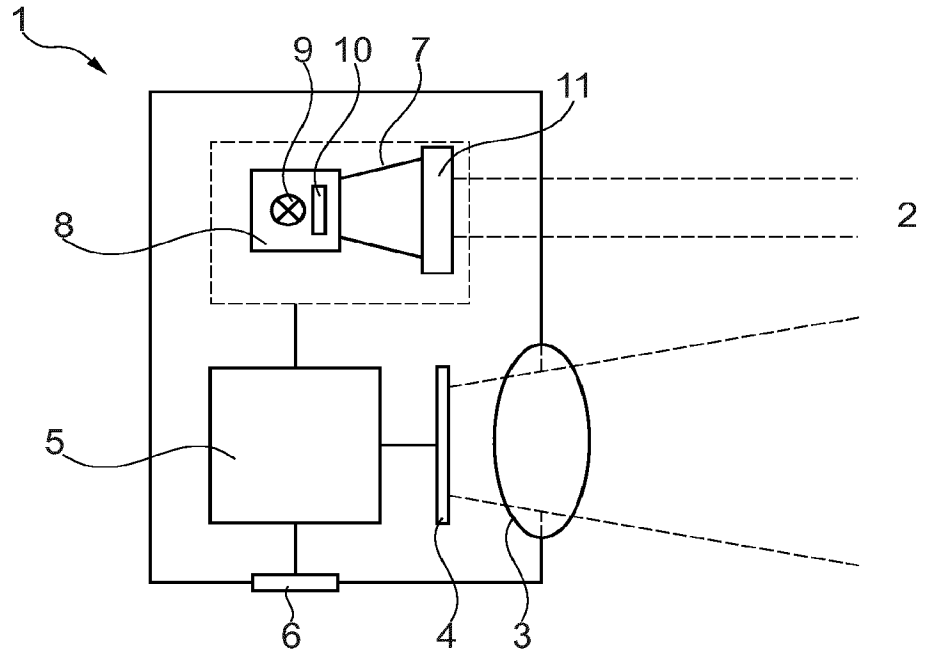


Fig. 1

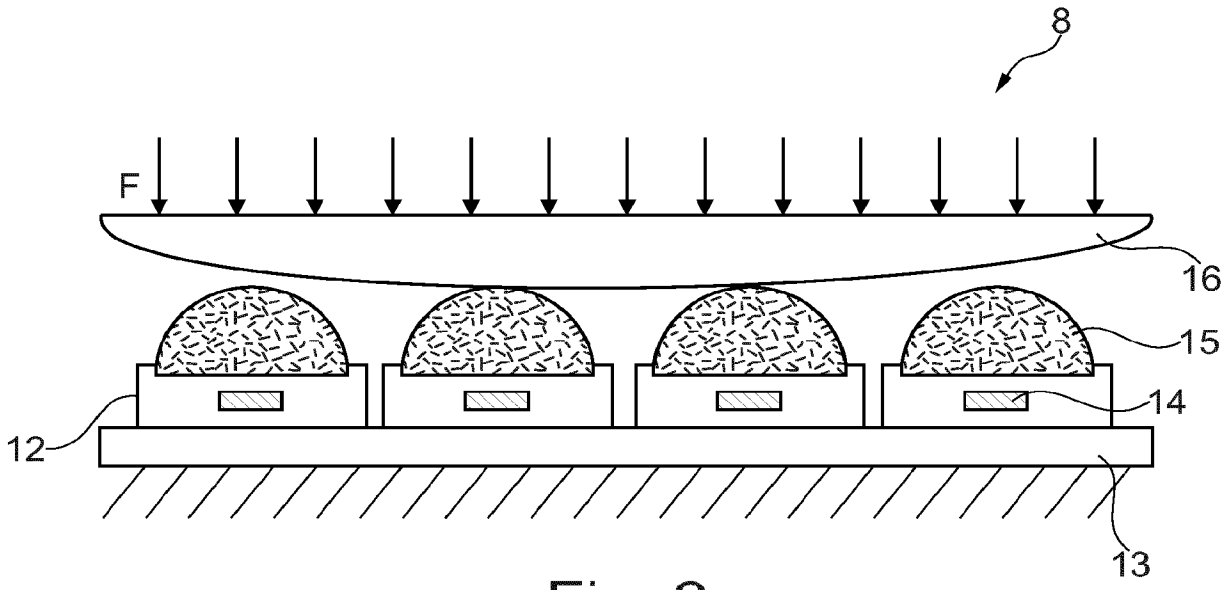


Fig. 2

HESAI EX1002, P.937

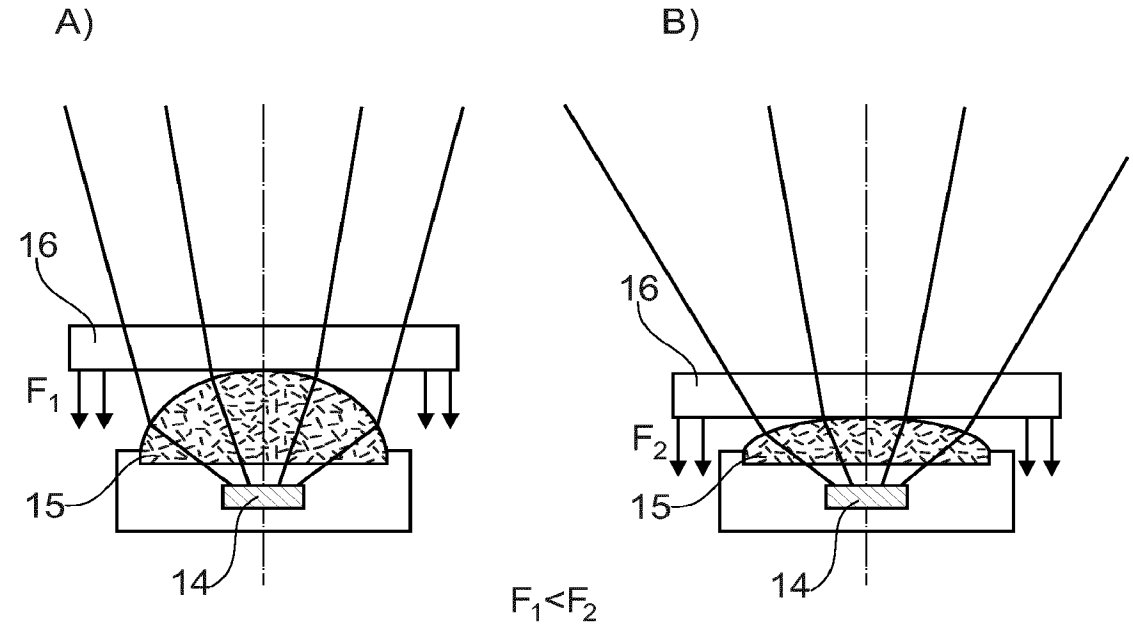


Fig. 3

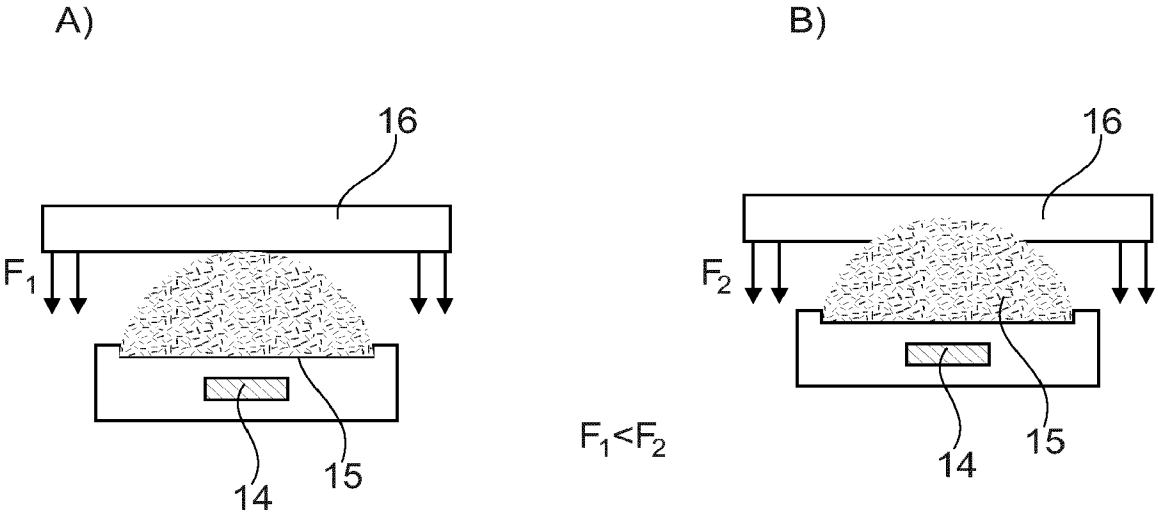


Fig. 4

HESAI EX1002, P.938

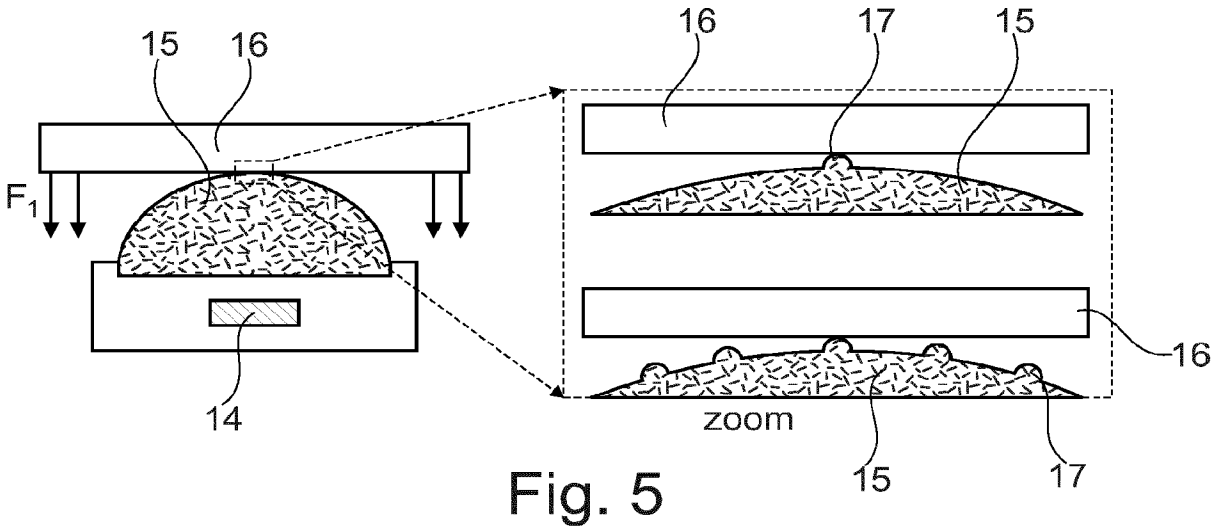

15
16
F1
14
16
17
15
16
zoom
15
17

Fig. 5

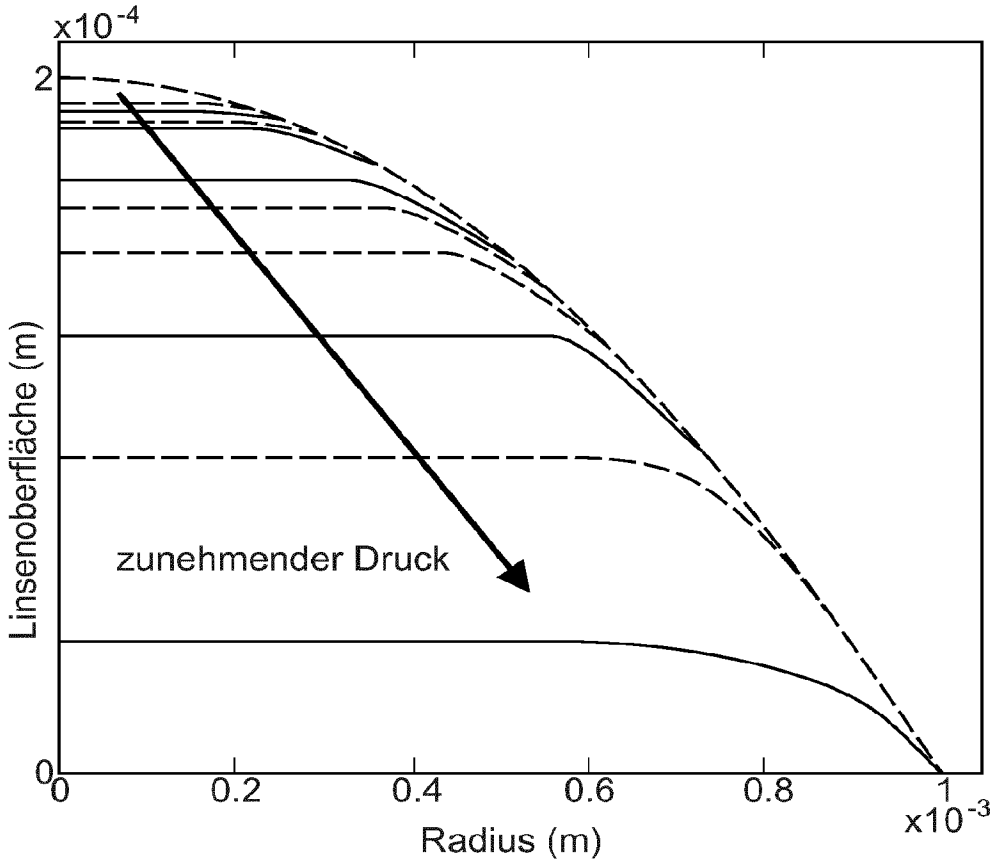

x10-4
2
0
Linsenoberfläche (m)
zunehmender Druck
0
0.2
0.4
0.6
0.8
1
x10-3
Radius (m)

Fig. 6

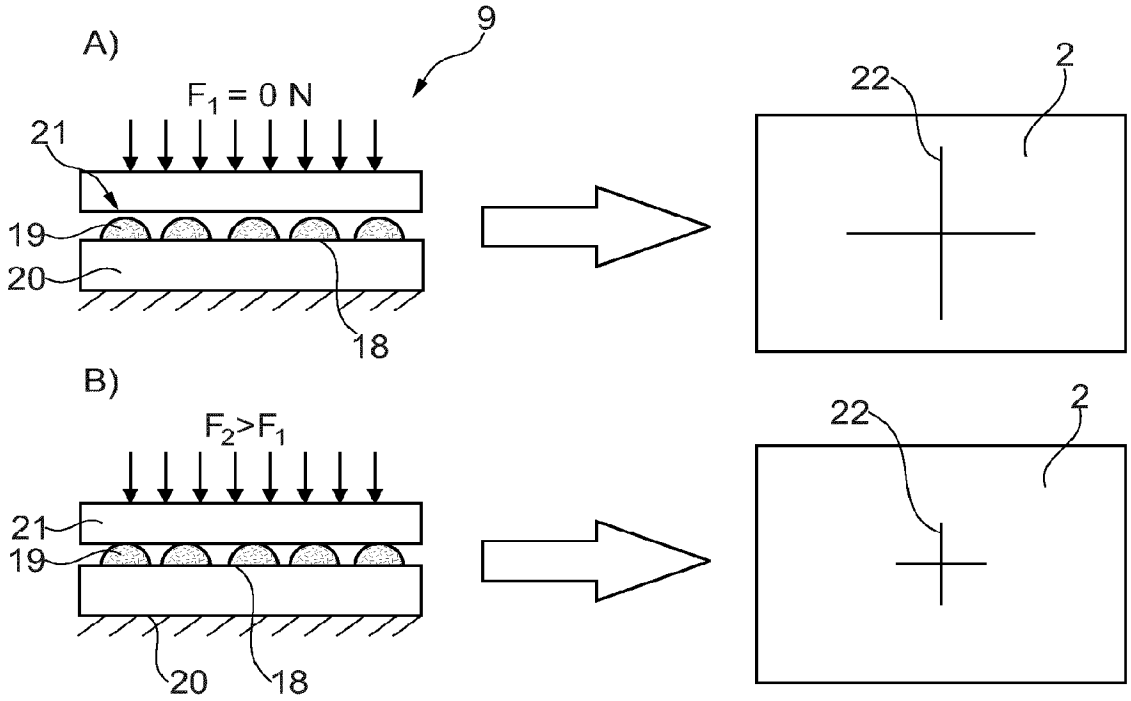


Fig. 7

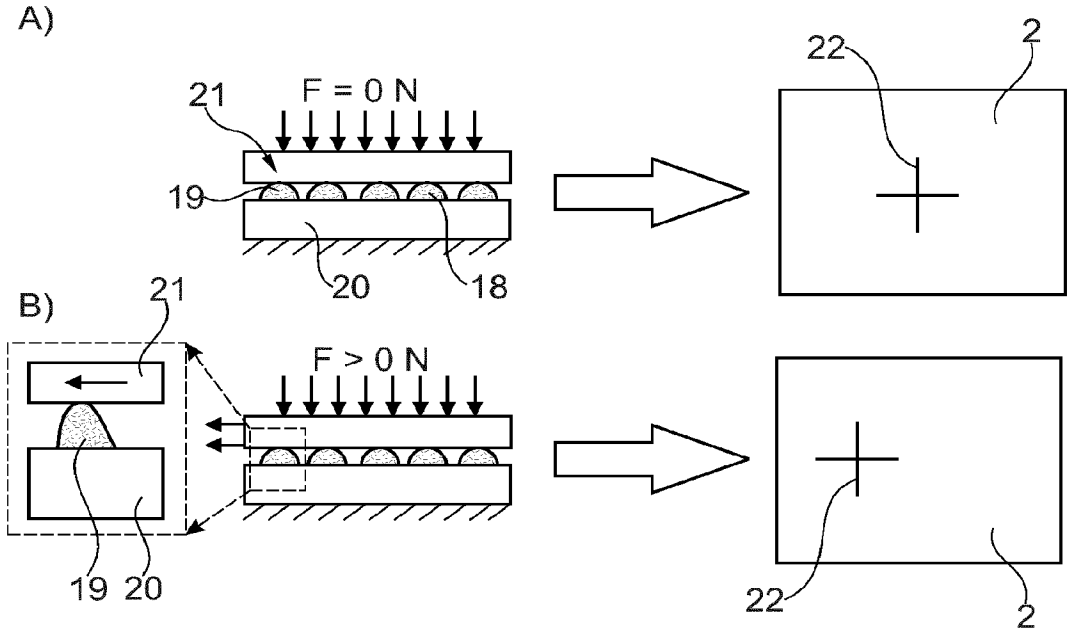


Fig. 8

HESAI EX1002, P.940

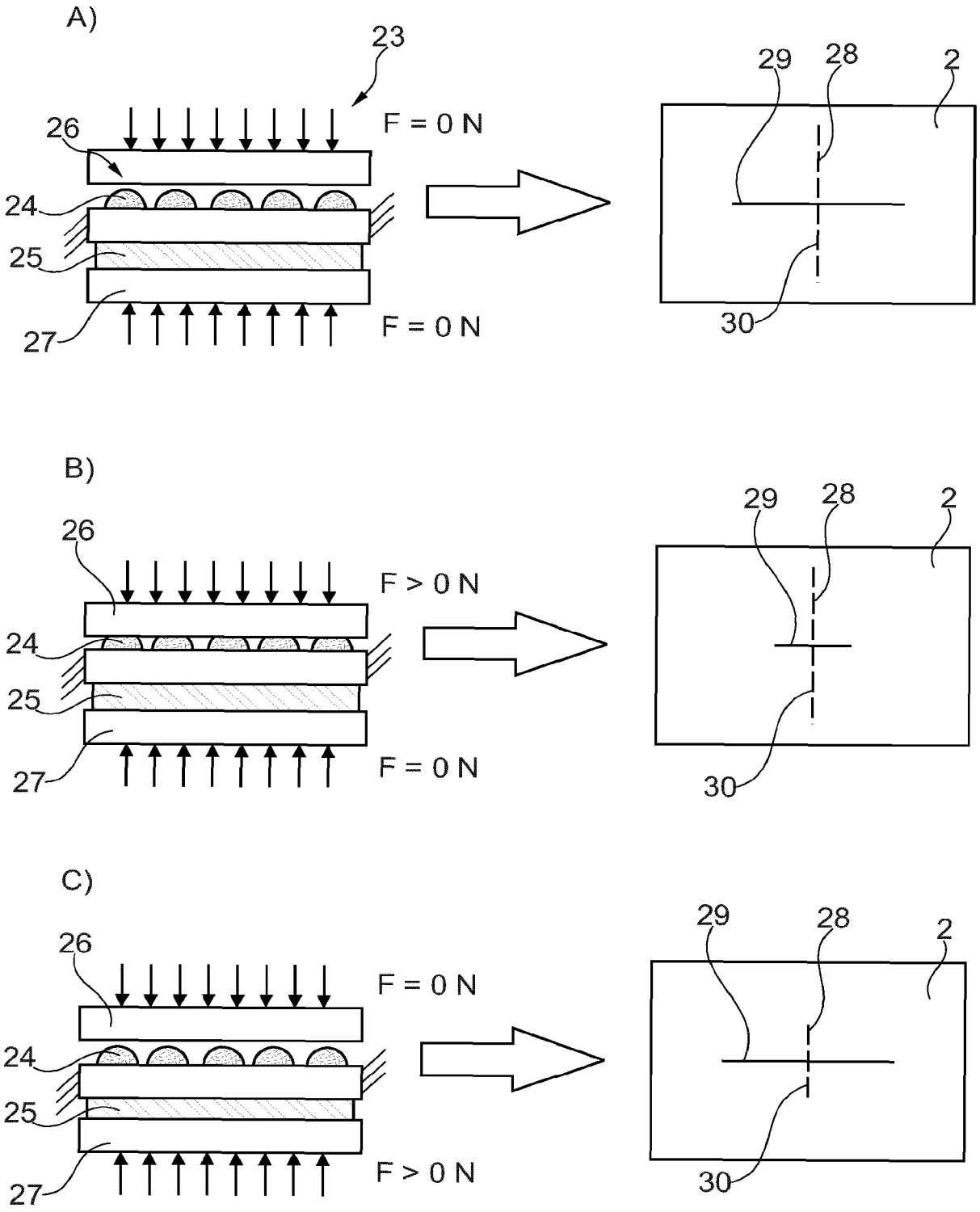


Fig. 9

HESAI EX1002, P.941

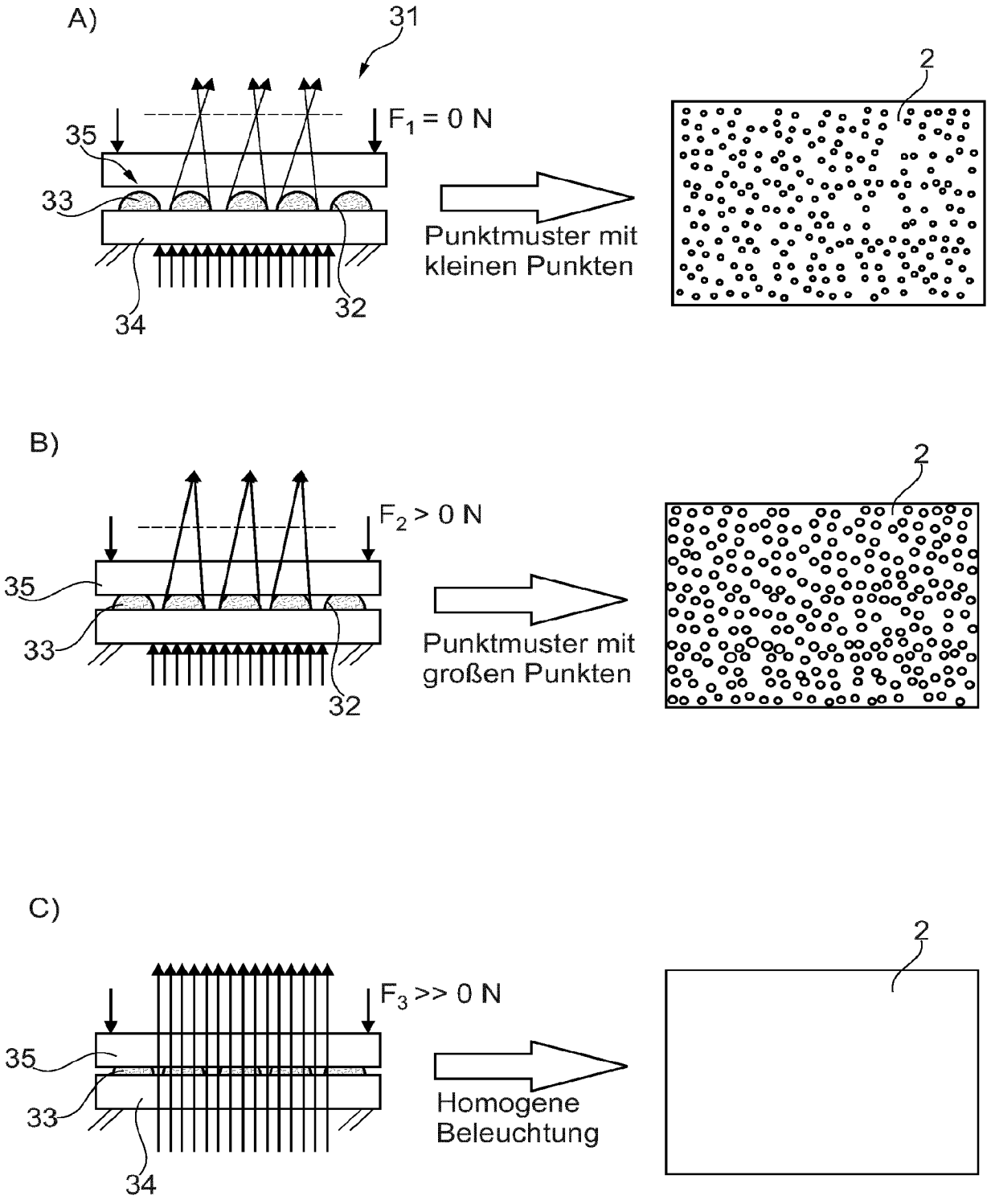


Fig. 10

HESAI EX1002, P.942

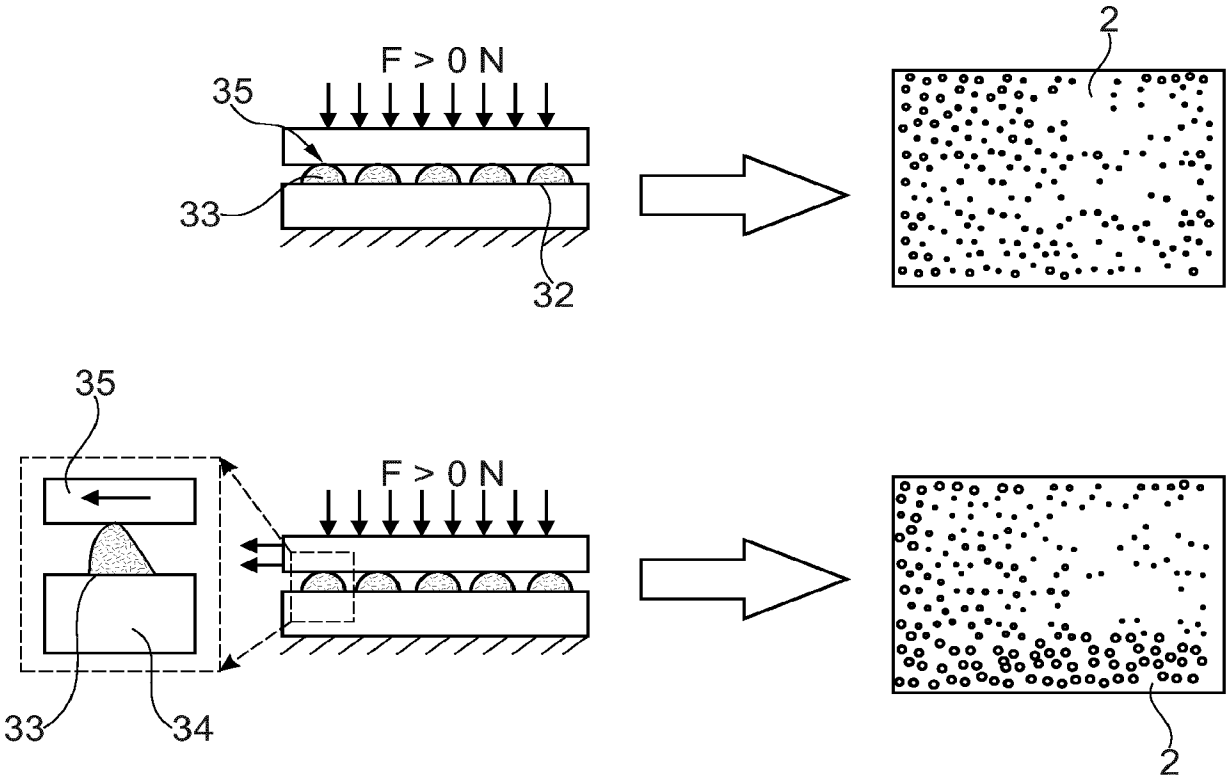


Fig. 11

HESAI EX1002, P.943

IN DER BESCHREIBUNG AUFGEFÜHRTE DOKUMENTE

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In der Beschreibung aufgeführte Patentdokumente

- DE 60215093 T2 **[0005]**
- WO 2009034511 A2 **[0007]**

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Specification

1. Title of the Invention

Peripheral Shape Measurement Device

2. Claims

A peripheral shape measurement device constituting a device that measures the peripheral shape of an object to be measured, the device comprising:

a light-reflection-based distance measurement device that emits a light, receives the reflection of said light, measures the distance up to the point of reflection, and outputs a distance signal that corresponds to said distance;

a rotating member that is provided in a rotatable matter around a center line, and that holds said light-reflection-based distance measurement device in an orientation whereby said light is emitted towards said center line;

a drive means that causes said rotating member to rotate continuously in one direction around said center line;

a moving apparatus that causes said object to be measured and said rotating member to move relative to one another in a direction that is parallel to said center line, with said object to be measured roughly positioned on said center line;

a signal transmission means that is provided between said rotating member and a support member that supports said rotating member, and that transmits the distance signal that is output from said light-reflection-based distance measurement device from said rotating member side to said support member side; and

a signal processing device that---based on the distance signal transmitted via said signal transition means and [proceeding] sequentially along said center line direction—obtains the peripheral shape of said object to be measured around said center line from the distance between the outer peripheral surface of said measured object and said light-reflection-based distance measurement device.

3. Detailed Description of the Invention

- Industrial Field of Applicability

The present invention pertains to a device that measures the peripheral shape of an object to be measured; and in particular, to a device that measures peripheral shapes by using a light-reflection-based distance measurement device.

- Prior Art

As devices for measuring the peripheral shape of an object to be measured, light-scanning measurement devices are known in the prior art. These scan narrow light beams in a direction that intersects the object to be measured, detect light beams using photoreceptors such as image sensors or the like that are disposed on opposite sides sandwiching the object to be measured, and then measure the dimensions of areas where the light is blocked by the object to be measured. With such a configuration, by rotating the measurement device around the object to be measured,

the cross sectional shape of the object to be measured and [aspects] of its peripheral shape such as the diameter size, width dimension, or the like are measured. In addition, by causing the measurement device and object to be measured to move relative to one another in a direction that is parallel to the aforementioned center line of rotation, the peripheral shape of the entire object to be measured can be measured.

- Issues Resolved by the Invention

That said, with such conventional peripheral shape measurement devices, because they measure the shadow of the object to be measured, if, for example, indentations are present on the object to be measured, they will not measured. As a result, it has not necessarily been possible to accurately measure the peripheral shape of the object to be measured.

The present invention was conceived taking the above circumstances into consideration. As such, it is an object of the present invention to provide a peripheral shape measurement device that can accurately measure an object to be measured even if indentations or the like are present thereon.

- Means for Resolving the Issues [Described]

In order to achieve these objectives, the present invention constitutes a peripheral shape measurement device constituting a device that measures the peripheral shape of an object to be measured, the device comprising: (a) a light-reflection-based distance measurement device that emits a light, receives the reflection of said light, measures the distance up to the point of reflection, and outputs a distance signal that corresponds to that distance; (b) a rotating member that is provided in a rotatable matter around a center line, and that holds said light-reflection-based distance measurement device in an orientation whereby said light is emitted towards said center line; (c) a drive means that causes the rotating member to rotate continuously in one direction around said center line; (d) a moving apparatus that causes said object to be measured and said rotating member to move relative to one another in a direction that is parallel to said center line, with said object to be measured roughly positioned on said center line; (e) a signal transmission means that is provided between said rotating member and a support member that supports said rotating member, and that transmits the distance signal that is output from said light-reflection-based distance measurement device from said rotating member side to said support member side; and (f) a signal processing device that—based on the distance signal transmitted via said signal transition means and [proceeding] sequentially along said center line direction---obtains the peripheral shape of said object to be measured around said center line from the distance between the outer peripheral surface of said measured object and said light-reflection-based distance measurement device.

- Operation and Effects of the Invention

In a peripheral shape measurement device such as this, with the object to be measured disposed on a center line [around which] the rotating member is rotationally driven, the rotating member is continuously rotated around that center line by the drive means, and the rotating member and object to be measured are moved, by the moving apparatus, relative to one another in a direction that is parallel to the center line. As a result, the light-reflection-based distance measurement device, which is held on the rotating member in an orientation whereby the light is emitted towards the aforementioned center line, is rotated around the aforementioned center line and made to engage in relative motion vis-à-vis the object to be measured in a direction that is parallel to the center line while receiving the reflected light that was reflected by the peripheral surfaces of the object to be measured that was disposed on the center line and measuring the distance to the peripheral surface [thereof].

Next, a distance signal that corresponds to the distance to the aforementioned peripheral surface and that is output from the light-reflection-based distance measurement device is transmitted from the rotation member side to the support member side via the signal transmission means, and is further provided to the signal processing device. The signal processing device obtains the peripheral shape of the object to be measured in terms of such factors as its size and cross-sectional shape, doing so using the distance between the light-reflection-based distance measurement device and the peripheral surface of the object to be measured expressed by said distance signal---for example, based on the distance between the center line and the light-reflection-based distance measurement device—the rotation speed of the rotating member due to the drive means, and the speed of relative motion due to the moving apparatus.

Here, because the surface shape measurement device of the present invention is designed to measure the distance up to the surface of the object to be measured using a light-reflection-based distance measurement device, such measurements can be taken even in cases where unevenness is present on the surface. For example, it is possible to accurately measure the bottom position or cross-sectional shape of an object to be measured where indentations or flaws are present on the peripheral surface, as well as to measure the peripheral shape of an object to be measured whose cross section is L-shaped or H-shaped.

In addition, because the rotating member is continuously rotated in one direction around the center line by a drive means, then by causing it to rotate at high speed, not only is it possible to measure the peripheral shape of the object to be measured efficiently and at high resolution, but it is possible to measure the peripheral surface shape with high precision even in cases where, for example, the object to be measured is made to move at high speed over the aforementioned center line. In this case, if one provides a plurality of said light-reception-based distance measurement devices at equal angular intervals on said rotating member, then it will be possible to perform measurements at an even greater resolution.

- Embodiments

Below, an embodiment of the present invention shall be described based on the figures.

Figure 1 and Figure 2 are, respectively, a front view and side view of a peripheral shape measurement device constituting an embodiment of the present invention. Their purpose is to inspect the surface flaws or diameter of a copper sample 10 having a cylindrical shape and serving as the object to be measured. In the measurement device in question, a moving table 14 is disposed on a roughly horizontal base 12. The moving table 14 is made to move in a linear reciprocal fashion in the left and right directions of Figure 2 by means of a drive motor 16 [operating] via a feed screw 18 and ball nut 20. A rotary encoder 22 is mounted onto the drive motor 16, and a table position signal ST that expresses the position of the moving table 14, which is moved in accordance with the amount of rotation of the drive motor 16, is output from that rotary encoder 22. The moving device is configured from the above-described moving table 14 and the drive motor 16 and the like.

A frame 24 operating as a support member is fixed on the moving table 14. As is clear from Figure 3, at the top of the frame 24, a cylindrical shape that is parallel to the direction of movement of the moving table 14 is formed, and inside that cylinder, a rotating cylinder 28 is held in a rotatable manner via a pair of bearings 26. At one end of the rotating cylinder 28, a ring-shaped rotating plate 30 is concentrically fixed, while at the other end of the rotating cylinder 28, a pulley 32 is fixed. It is continuously rotated in one direction via a belt 36 by a drive motor 34 provided on the moving table 14. A rotary encoder 38 is mounted onto the drive motor 34, and from that rotary encoder 38, a rotation position signal SR that expresses the rotation position of the rotating plate 30 that is rotated in accordance with the amount of rotation of the drive motor 34 is output. The above-described rotating plate 30 corresponds to a rotating member, and its central line of rotation corresponds to the center line. In addition, the drive motor 34 corresponds to the drive means that continuously rotates that rotating member.

On the above-described rotating plate 30, four laser measurement devices 40 are disposed at 90° intervals around a shared circumference that centers on said center line of rotation. These laser measurement devices 40 constitute light-reflection based distance measurement devices that emit a laser light, receive the reflected light from the laser light using position sensors and image sensors or the like, and based on those light reception positions, measure the distance from the laser measurement device 40 to the reflection point. They are all mounted in such a way as to emit their laser light toward the center line of rotation of the rotating plate 30. Said copper sample 10 is held at a fixed position by a holding apparatus (not shown in the figure) in an orientation whereby its axial center matches the center line of rotation of the rotating plate 30. By emitting laser light toward the center line of rotation of the rotating plate 30, the above-described laser measurement devices 40 measure the distance up to the peripheral surface of the copper sample 10, and they each output distance signals SD that express that distance. Now, the power source of these laser measurement devices 40 can be configured in a variety of manners. One could mount batteries or the like on the rotating plate 30, one could form a generator by providing a coil on a rotating cylinder 28 while fixing magnets on the frame 24, or one could even send power from the frame 24 to the rotating cylinder 28 side via a slip ring.

At the same time, this peripheral shape measurement device is furnished with a measurement circuit shown in Figure 4. After the measurement signals SD that are output from the aforementioned four laser measurement devices 40 are converted to digital signals by means of an A/D converter (not shown in the figure), they are each transmitted to a frame via a rotary transformer 42 that is made up of a pair of coils disposed in mutual opposition between the frame 24 and the rotating cylinder 28. In addition, once they have been transmitted to the frame 24 side in this way, the distance signals SD are each [fed] into a microcomputer 46 in accordance with sample signals SS via an interface 44. The microcomputer 46 is provided with a table position signal ST and a rotation position signal SR from said rotary encoders 22 and 38.

The above-described microcomputer 46 corresponds to the signal processing device; it performs signal processing in accordance with a program that is store in advance in a ROM while also utilizing the temporary storage functions of a RAM.

Based on the distance to the peripheral surface of the copper sample 10 expressed by the distance signal, position of the moving table 14 expressed by the table position signal ST, rotational position of the rotating plate 30 expressed by the rotation position signal SR, and the dimension R [from] the center line of rotation of the rotary plate 30 to the laser measurement device 40 that has been set in advance, it measures the peripheral shape of the copper sample 10 and displays its peripheral shape by outputting a display signal DD to a display unit 48.

The operation of the peripheral shape measurement device configured in the above manner shall now be described.

First, the copper sample 10 is fixed into position at the center line of rotation of the rotating plate 30 by means of a holding device (not shown in the figures), and while the rotating plate 30 is made to rotate continuously in one direction by the drive motor 34, the moving table 14 is moved linearly by the drive motor 16. Because the axis of the copper sample 10 is aligned with the center line of rotation of the rotating plate 30 and the direction of motion of the moving table 14 is made parallel to the center line of rotation of the rotating plate 30, the rotating plate 30 rotates concentrically with the axis of the copper sample 10 and is moved in its axial direction. In addition, because laser measurement devices 40 are mounted onto the rotating plate on the shared circumference centering on its center line of rotation, the laser measurement devices 40 also rotate concentrically with the axis of the copper sample 10 while also moving in its axial direction.

Next, distance signals SD that express the distance to the peripheral surface of the copper sample 10 are output from said laser measurement devices 40. If one defines the distance expressed by these distance signals SD as d, the radius 10 of the copper sample 10 is obtained by the difference (R - d) between the aforementioned dimension R and that distance d. Accordingly, the previously described microcomputer 46 is provided with those distance signals SD and computes that difference (R - d), and in accordance with the rotation position of the rotating plate 30 expressed by the rotation position signal SR, it outputs a display signal DD that expresses that difference (R - d), and causes a graph like that shown, for example, in Figure 6 to be displayed on said display unit 48.

Figure 6 displays the radius over the entire circumference (2 [illegible]) at an arbitrary location in the axial direction of the copper sample 10. Because four laser measurement devices 40 are mounted on the rotating plate 30 at 90° intervals, the peripheral shape at a single location on the copper sample 10 is measured with each quarter rotation of the rotating plate 30. In addition, if the radius, as shown by the solid line, is constant across the entire circumference, then the cross sectional shape of the copper sample 10 in that region will be a perfect circle, indicating that no surface flaws or the like are present. However, in cases where, as shown for example in Figure 5, surface flaws 50 are present, then because the light reflection point of the reflected light will be offset, then the distance signal SD that expresses a distance (d + Δd) that includes the depth of the flaw Δd will be provided from the laser measurement device 40. Consequently, at circumferential positions where surface flaws 50 do exist, then as shown by the dash-dot line in Figure 6, the radius will be smaller, and the location of the flaw in the circumferential direction and the flaw depth Δd will be recognized based on that graph.

Now, as the above-described graph shown in Figure 6 is displayed for each quarter rotation of the rotating plate 30, then based on the position of the moving table 14 expressed by the table position signal ST, the position of the copper sample 10 in the axial direction will be expressed in each graph. Consequently, the peripheral shape of the copper sample 10 will be sequentially measured in the axial direction, and changes in the diameter together with the position and length of surface flaws 50 in the axial direction will be recognized.

In this way, with the peripheral shape measurement device of the present embodiment, because the peripheral shape of the copper sample 10 is measured by obtaining the distances up to the surface of the copper sample 10, it is possible to perform such measurements even in cases where unevenness is present on its surface, and not only is it possible to obtain the diameter of the copper sample 10, but one may also accurately measure the position and depth of said surface flaws 50.

Moreover, in the example above, a copper sample 10 serving as an object to be measured was disposed at a fixed position, and measurements of the peripheral shape in the axial direction of the copper sample 10 were performed by moving laser measurement devices 40 in a direction that was parallel with its center line of rotation. However, it would also be possible to move the object to be measured along the center line of rotation of the laser measurement devices 40. In that case, the rotating plate 30 that holds the above-described laser measurement devices 40 would be continuously rotated in one direction around its center line of rotation, and it could therefore be rotated at high speeds on the order of, for example, 3000 - 5000 rpm. In addition, because four laser measurement devices 40 would be provided on the rotating plate 30

and the outer shape could be measured at each quarter rotation, then even in cases where the object to be measured was moved at a high speed of, for example, several meters per second (m/s), it would still be possible to measure its peripheral shape with high resolution. In addition, in the present embodiment, because a rotary transformer 42 was used as a signal transmission means, then even if the rotating plate 30 is rotated at high speed as described above, noise will not be introduced into said distance signals SD, and this has the benefit of making it possible to measure with high precision.

In addition, the display method of the above-described embodiment was merely an example [of the possibilities], as one could display the cross-sectional shape of the copper sample 10 as is, display it stereoscopically in three dimensions, or record it on a chart or the like. Moreover, rather than performing such display, one could apply a coating material at locations where surface flaws 50 are present, or send a signal that shows the positions and depths of flaws to a separate[ly provided] flaw removal device.

In addition, in the above-described embodiment, because four laser measurement devices 40 were mounted at 90° intervals on the rotating plate 30, the microcomputer 46 serving as the signal processing device may detect misalignment or the like between the axis of the copper sample 10 and the center line of rotation of the laser measurement devices 40 and then correct the peripheral shape [accordingly]. It can also measure the cross sectional shape of the object to be measured by applying differential amplification to the distance signals SD output from the laser measurement devices 40 at oppositely disposed positions. Moreover, so long the object of the present invention is achieved, the number laser measurement devices 40 may be [as low as] 1 or 2, and their number can be appropriately determined in accordance with the measurement requirements.

In addition, in the above-described embodiment, a table position signal ST and rotation position signal SR were provided to the microcomputer 46 from the rotary encoders 22 and 38, but in cases where the drive motors 16 and 34 provide rotational drive at a constant speed, such signals are not necessarily required.

Further still, a description was given of a case where the diameter of a cylindrically shaped copper sample 10 serving as the object to be measured was measured along with the positions and depths of flaws [thereon], but the peripheral shape measurement device of the present invention could be advantageously applied to peripheral shape measurements of objects to be measured having various shapes, such as L-shaped or H-shaped copper samples, resin products, or objects whose cross-sectional shape changes in the axial direction.

Furthermore, in the above-described embodiment, a rotary transformer 42 was employed as the signal transmission means, but it would also be possible to use a slip ring or the like.

Other embodiments shall not be illustrated [herein], but the present invention could be implemented using various embodiments to which modifications or improvements have been applied based on expertise of those skilled in the art.

4. Brief Description of the Figures

Figure 1 is a front view of a peripheral shape measurement device constituting an embodiment of the present invention. Figure 2 is a side view wherein a portion of the device of Figure 1 has been cut out. Figure 3 is a diagram that shows an enlarged cutout of a portion of Figure 2. Figure 4 is a block diagram of the measurement circuit that is provided to the device of Figure 1. Figure 5 is a diagram that describes the measurement principles [employed] when measuring the peripheral shape using the device of Figure 1. Figure 6 is a diagram that shows an example of the measurement results that are displayed on the display unit of the device of Figure 1.

10: copper sample (object to be measured)
14: moving table
16: drive motor (moving device)
24: frame (support member)
30: rotating plate (rotating member)
34: drive motor (drive means)
40: laser measurement device (light-reflection-based distance measurement device)
42: rotary transformer (signal transmission means)
46: microcomputer (signal processing device)
SD: distance signal

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Attorneys Haruyuki Ikeda (and two others)

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Figure 1
Figure 2
Figure 3

Figure 4
28 rotary encoder
38 rotary encoder
40 laser measurement device
40 laser measurement device
40 laser measurement device
40 laser measurement device
44 interface
44 interface
44 interface
44 interface
46 microcomputer

/7

Figure 5

Figure 6

Figure 1

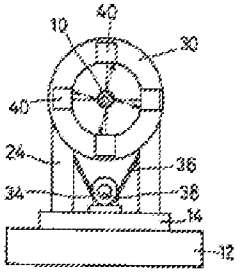


Figure 2

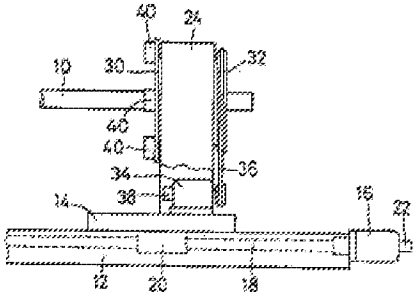


Figure 3

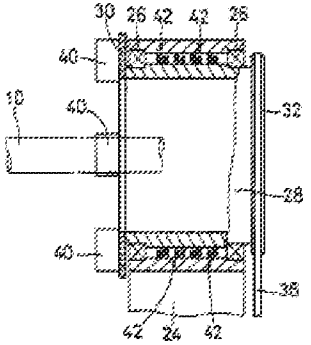
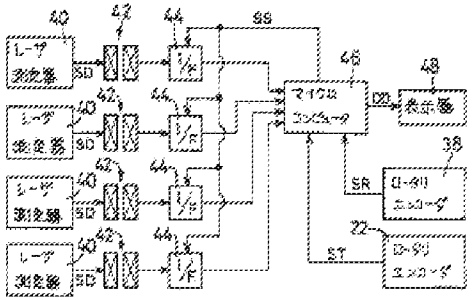


Figure 4
[text in image below illegible]



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Figure 5

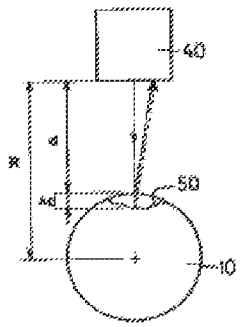
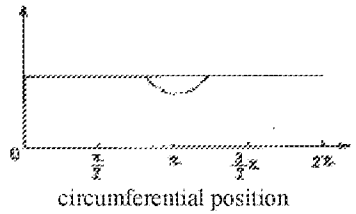


Figure 6

Figure radius
(R - d)



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Chevy Chase, Maryland

I, Daniel Child, hereby certify that I translated document "3_006407_cert" and that this translation is a true and accurate translation from Japanese into English. All statements made herein of my own knowledge are true and all statements made on information and belief are believed to be true. These statements were made with the knowledge that willful false statements and the like are punishable by fine or imprisonment, or both, under 18 U.S.C. § 1001.

Daniel Child

Sworn to before me this...
Thursday, September 28, 2017
27

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My Commission Expires 8/9/2019

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審査請求　未請求　請求項の数 1　（全7頁）

⑭発明の名称　外周形状測定装置

⑳特　願　平1−141899
㉒出　願　平1(1989)6月3日

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明　細　書

1．発明の名称

外周形状測定装置

2．特許請求の範囲

被測定物の外周形状を測定する装置であって、

光を出射するとともに該光の反射光を受光して反射位置までの距離を測定し、該距離に対応する距離信号を出力する光反射型距離測定器と、

一中心線まわりの回転可能に設けられ、前記光が該一中心線に向かって出射される姿勢で前記光反射型距離測定器を保持する回転部材と、

該回転部材を前記一中心線まわりにおける一方向へ連続回転させる駆動手段と、

前記一中心線上に前記被測定物が略位置する状態で、該一中心線と平行な方向へ該被測定物と前記回転部材とを相対移動させる移動装置と、

前記回転部材と該回転部材を支持する支持部材との間に設けられ、前記光反射型距離測定器から出力された距離信号を該回転部材側から該支持部材側に伝達する信号伝達手段と、

該信号伝達手段を介して伝達される距離信号に基づいて、前記光反射型距離測定器と前記被測定物の外周面との間の距離から該被測定物の前記一中心線まわりにおける外周形状を該一中心線方向に沿って順次求める信号処理装置と

を有することを特徴とする外周形状測定装置。

3．発明の詳細な説明

産業上の利用分野

本発明は被測定物の外周形状を測定する装置に係り、特に、光反射型距離測定器を利用して外周形状を測定する装置に関するものである。

従来の技術

被測定物の外周形状を測定するための装置として、従来から光走査式測定装置が知られている。これは、細い光ビームを被測定物と交差する方向へ走査するとともに、被測定物を挟んで反対側に設けられたイメージセンサ等の受光器によりその光ビームを検出し、被測定物によって光が遮断された部分の寸法を測定するものであり、その状態で測定装置を被測定物のまわりに回転させること

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により、被測定物の横断面形状や直径寸法，幅寸法等の外周形状が測定される。また、被測定物と測定装置とを上記回転中心線と平行な方向へ相対移動させることにより、被測定物全体の外周形状を測定できる。

発明が解決しようとする課題

しかしながら、このような従来の外周形状測定装置は被測定物の影を測定するものであるため、例えば被測定物に凹みが存在してもそれを測定し得ず、被測定物の外周形状を必ずしも正確に測定することはできなかったのである。

本発明は以上の事情に鑑みて為されたもので、その目的とするところは、被測定物に凹み等が存在してもそれを正しく測定できる外周形状測定装置を提供することにある。

課題を解決するための手段

かかる目的を達成するために、本発明は、被測定物の外周形状を測定する装置であって、(a)光を出射するとともにその光の反射光を受光して反射位置までの距離を測定し、その距離に対応する距離信号を出力する光反射型距離測定器と、(b)一中心線まわりの回転可能に設けられ、前記光がその一中心線に向かって出射される姿勢で前記光反射型距離測定器を保持する回転部材と、(c)その回転部材を前記一中心線まわりにおける一方向へ連続回転させる駆動手段と、(d)前記一中心線上に前記被測定物が略位置する状態で、その一中心線と平行な方向へその被測定物と前記回転部材とを相対移動させる移動装置と、(e)前記回転部材とその回転部材を支持する支持部材との間に設けられ、前記光反射型距離測定器から出力された距離信号をその回転部材側からその支持部材側に伝達する信号伝達手段と、(f)その信号伝達手段を介して伝達される距離信号に基づいて、前記光反射型距離測定器と前記被測定物の外周面との間の距離からその被測定物の前記一中心線まわりにおける外周形状をその一中心線方向に沿って順次求める信号処理装置とを有することを特徴とする。

作用および発明の効果

このような外周形状測定装置においては、回転部材が回転駆動される一中心線上に被測定物を配置した状態において、駆動手段によりその回転部材をその一中心線まわりに連続回転させるとともに、移動装置によって回転部材と被測定物とを一中心線と平行な方向へ相対移動させる。これにより、上記一中心線に向かって光を出射する姿勢で回転部材に保持された光反射型距離測定器は、その一中心線上に配置された被測定物の外周面で反射される反射光を受光してその外周面との間の距離を測定しつつ、上記一中心線まわりに回転させられ且つその一中心線と平行な方向へ被測定物に対して相対移動させられる。

そして、かかる光反射型距離測定器から出力される上記外周面との間の距離に対応する距離信号は、信号伝達手段を介して回転部材側から支持部材側に伝達され、更に信号処理装置に供給される。信号処理装置では、上記距離信号が表す被測定物の外周面と光反射型距離測定器との間の距離から、例えば光反射型距離測定器と一中心線との間の距離，駆動手段による回転部材の回転速度，移動装置による相対移動速度等に基づいて、被測定物の横断面形状や大きさ等の外周形状が求められる。

ここで、かかる本発明の表面形状測定装置は、光反射型距離測定器を用いて被測定物の表面までの距離を測定するようになっているため、その表面に凹凸等が存在する場合でもその測定が可能で、例えば外周面に凹みや底がある被測定物の横断面形状や底位置等を正確に測定したり、断面がL字形状やH字形状等の被測定物の外周形状を測定したりすることができるのである。

また、回転部材は駆動手段によって一中心線まわりにおける一方向へ連続回転させられるため、これを高速回転させることにより被測定物の外周形状を高分解能で能率良く測定できるとともに、例えば被測定物が上記一中心線上を高速移動させられる場合でも外周面形状を高い精度で測定することが可能なのである。この場合に、前記光反射型距離測定器を上記回転部材に等角度間隔で複数設けておけば、一層高い分解能で測定を行うことができる。

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実施例

以下、本発明の一実施例を図面に基づいて詳細に説明する。

第１図および第２図は、それぞれ本発明の一実施例である外周形状測定装置の正面図および側面図で、被測定物としての円柱形状を成す鋼材１０の径寸法や表面疵等を検査するためのものである。かかる測定装置において、略水平な基台１２上には移動テーブル１４が配設されており、その移動テーブル１４は、駆動モータ１６により送りねじ１８およびボールナット２０を介して第２図における左右方向へ直線往復移動させられる。駆動モータ１６にはロータリエンコーダ２２が取り付けられており、そのロータリエンコーダ２２からは、駆動モータ１６の回転量に対応して移動させられる移動テーブル１４の位置を表すテーブル位置信号ＳＴが出力される。上記移動テーブル１４および駆動モータ１６等により移動装置が構成されている。

移動テーブル１４上には支持部材としてのフレーム２４が固設されている。フレーム２４の上部は、第３図からも明らかなように、移動テーブル１４の移動方向と平行な円筒形状を成しており、その円筒内には一対のベアリング２６を介して回転筒２８が回転可能に保持されている。回転筒２８の一端部にはリング形状の回転板３０が同心に固設されている一方、回転筒２８の他端部にはプーリ３２が固設され、移動テーブル１４上に設けられた駆動モータ３４によりベルト３６を介して一方向へ連続回転させられるようになっている。駆動モータ３４にはロータリエンコーダ３８が取り付けられており、そのロータリエンコーダ３８からは、駆動モータ３４の回転量に対応して回転させられる回転板３０の回転位置を表す回転位置信号ＳＲが出力される。上記回転板３０は回転部材に相当するもので、その回転中心線は一中心線に相当する。また、駆動モータ３４はその回転部材を連続回転させる駆動手段に相当する。

上記回転板３０には、その回転中心線を中心とする共通の一円周上に９０° 間隔で４個のレーザ測定器４０が設けられている。このレーザ測定器４０は、レーザ光を出射するとともにそのレーザ光の反射光をポジションセンサやイメージセンサ等にて受光し、その受光位置に基づいてレーザ測定器４０から反射位置までの距離を測定する光反射型の距離測定器であって、何れもそのレーザ光を回転板３０の回転中心線に向かって出射する姿勢で取り付けられている。前記鋼材１０は、その軸心が回転板３０の回転中心線と一致する姿勢で図示しない保持装置によって位置固定に保持されるようになっており、上記レーザ測定器４０は、回転板３０の回転中心線に向かってレーザ光を出射することによりその鋼材１０の外周面までの距離を測定し、その距離を表す距離信号ＳＤをそれぞれ出力することとなる。なお、このレーザ測定器４０の動力源は、回転板３０に電池等を取り付けたり、フレーム２４に磁石を固定するとともに回転筒２８にコイルを設けて発電機を形成したり、スリップリングを介してフレーム２４側から回転筒２８側へ電力を通電したりするなど、種々の態様で構成され得る。

一方、かかる外周形状測定装置は、第４図に示されている測定回路を備えており、前記４個のレーザ測定器４０から出力された距離信号ＳＤは、図示しないＡ／Ｄ変換器によってディジタル信号に変換された後、回転筒２８とフレーム２４との間に相対抗して設けられた一対のコイルから成る回転トランス４２を介してそれぞれフレーム２４側へ伝達される。この回転トランス４２は信号伝達手段に相当する。また、このようにしてフレーム２４側へ伝達された距離信号ＳＤは、それぞれインタフェース４４を介してサンプル信号ＳＳに従ってマイクロコンピュータ４６に採り込まれる。マイクロコンピュータ４６には、前記ロータリエンコーダ２２および３８からテーブル位置信号ＳＴおよび回転位置信号ＳＲが供給されるようになっている。

上記マイクロコンピュータ４６は信号処理装置に相当するもので、ＲＡＭの一時記憶機能を利用しつつＲＯＭに予め記憶されたプログラムに従っ

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て信号処理を行い、距離信号ＳＤが表す鋼材１０の外周面までの距離，テーブル位置信号ＳＴが表す移動テーブル１４の位置，回転位置信号ＳＲが表す回転板３０の回転位置，および予め設定されたレーザ測定器４０と回転板３０の回転中心線までの寸法Ｒに基づいて、鋼材１０の外周形状を測定するとともに、表示信号ＤＤを表示器４８に出力してその外周形状を表示させる。

次に、以上のように構成された外周形状測定装置の作動を説明する。

先ず、図示しない保持装置により鋼材１０を回転板３０の回転中心線上に位置固定に配置し、駆動モータ３４により回転板３０を一方向へ連続回転させるとともに、駆動モータ１６により移動テーブル１４を直線移動させる。鋼材１０の軸心は回転板３０の回転中心線と一致させられており、且つ移動テーブル１４の移動方向と回転板３０の回転中心線は平行とされているため、回転板３０は鋼材１０の軸心を中心として回転させられるとともにその軸心方向へ移動させられる。また、かかる回転板３０には、その回転中心線を中心として共通の一円周上にレーザ測定器４０が取り付けられているため、このレーザ測定器４０も、鋼材１０の軸心を中心として回転させられるとともにその軸心方向へ移動させられることとなる。

そして、上記レーザ測定器４０からは鋼材１０の外周面までの距離を表す距離信号ＳＤが出力され、その距離信号ＳＤが表す距離をｄとすると、第５図から明らかなように、その距離ｄと前記寸法Ｒとの差（Ｒ－ｄ）により鋼材１０の半径が求められる。したがって、その距離信号ＳＤが供給される前記マイクロコンピュータ４６においては、その差（Ｒ－ｄ）を算出するとともに、回転位置信号ＳＲが表す回転板３０の回転位置に対応させてその差（Ｒ－ｄ）を表す表示信号ＤＤを出力し、前記表示器４８に例えば第６図に示されるようなグラフを表示させる。

第６図は鋼材１０の軸方向の任意の１箇所での全周（２π）における半径を表示したものであるが、回転板３０には９０°間隔で４個のレーザ測

定器４０が取り付けられているため、回転板３０の１／４回転で鋼材１０の１箇所における外周形状が測定される。また、第６図において実線で示されているように半径が全周において一定であれば、その部分での鋼材１０の横断面形状は完全な円で表面疵等は存在しないこととなるが、例えば第５図に示されているように表面疵５０が存在する場合には、反射光の受光位置がずれて疵深さΔｄを含む距離（ｄ＋Δｄ）を表す距離信号ＳＤがレーザ測定器４０から供給されるため、その表面疵５０が存在する周方向位置では第６図において一点鎖線で示されているように半径が小さくなり、このグラフから疵深さΔｄおよび周方向における疵位置が認識される。

一方、上記第６図に示すグラフは回転板３０の１／４回転毎に表示され、各グラフにはテーブル位置信号ＳＴが表す移動テーブル１４の位置に基づいて、鋼材１０の軸方向位置が表示されるようになっている。したがって、鋼材１０の外周形状が軸方向に順次測定されることとなり、軸方向における径寸法の変化や表面疵５０の位置，長さが認識される。

このように、本実施例の外周形状測定装置においては、鋼材１０の表面までの距離を測定してその鋼材１０の外周形状を測定するようになっているため、その表面に凹凸等が存在する場合でもその測定が可能で、鋼材１０の径寸法のみならず前記表面疵５０の疵深さや疵位置をも正確に測定することができるのである。

なお、上例では被測定物としての鋼材１０を位置固定に配置し、レーザ測定器４０をその回転中心線と平行な方向へ移動させて鋼材１０の軸心方向に向かって外周形状の測定を行うようになっているが、被測定物をレーザ測定器４０の回転中心線に沿って移動させることも可能である。その場合に、上記レーザ測定器４０を保持している回転板３０はその回転中心線まわりの一方向へ連続回転させられるため、例えば３０００～５０００ｒｐｍ程度で高速回転させることが可能であり、しかもその回転板３０には４個のレーザ測定器４０

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が設けられて１／４回転で一外周形状を測定できるようになっているため、被測定物が例えば数ｍ／秒程度の高速で移動する場合でも、その外周形状を高分解能で測定することができるのである。また、この実施例では信号伝達手段として回転トランス４２が用いられているため、上記のように回転板３０が高速回転させられても前記距離信号ＳＤにノイズが混入することがなく、高い精度で測定できる利点がある。

また、前記実施例の表示方法はあくまでも一例で、鋼材１０の横断面形状をそのまま表示させるようにしたり、三次元で立体的に表示させるようにしたり、チャート等に記録させたりすることも可能である。更に、そのような表示を行うことなく、表面疵５９の位置に塗料を付けるようにしたり、別の疵取り装置等に疵位置や疵深さを表す信号を送るようにしたりすることもできる。

また、前記実施例では回転板３０に９０°間隔で４個のレーザ測定器４０が取り付けられているため、信号処理装置としてのマイクロコンピュータ４６においては、レーザ測定器４０の回転中心線と鋼材１０の軸心との芯ずれ等を検出して外周形状を補正するようにしたり、相対向する位置のレーザ測定器４０から出力される距離信号ＳＤを差動増幅して被測定物の断面形状を測定したりすることもできる。なお、本発明の目的を達成する上においては、レーザ測定器４０の数は１個或いは２個等であっても差支えなく、測定条件に応じて適宜定めることができる。

また、前記実施例ではロータリエンコーダ２２，３８からテーブル位置信号ＳＴおよび回転位置信号ＳＲがマイクロコンピュータ４６に供給されるようになっているが、駆動モータ１６，３４が予め定められた一定の速度で回転駆動される場合には、それ等の信号は必ずしも必要ない。

また、前記実施例では被測定物として円柱形状の鋼材１０の径寸法や疵位置，疵深さを測定する場合について説明したが、Ｌ字形状やＨ形状の鋼材，樹脂製品，或いは軸方向において横断面形状が変化するものなど、本発明の外周形状測定装置

は種々の形状を成す被測定物の外周形状測定に利用され得る。

また、前記実施例では信号伝達手段として回転トランス４２が用いられているが、スリップリング等を利用することも可能である。

その他一々例示はしないが、本発明は当業者の知識に基づいて種々の変更，改良を加えた態様で実施できる。

４．図面の簡単な説明

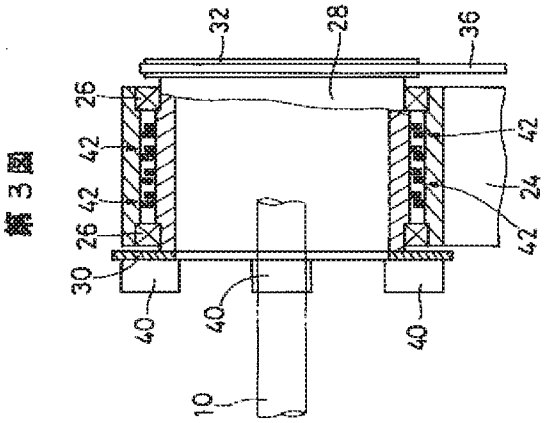
第１図は本発明の一実施例である外周形状測定装置の正面図である。第２図は第１図の装置の一部を切り欠いた側面図である。第３図は第２図の一部を拡大するとともに切り欠いて示した図である。第４図は第１図の装置に備えられている測定回路のブロック図である。第５図は第１図の装置によって外周形状を測定する際の測定原理を説明するための図である。第６図は第１図の装置の表示器に表示される測定結果の一例を示す図である。

１０：鋼材（被測定物）
１４：移動テーブル
１６：駆動モータ　（移動装置）
２４：フレーム（支持部材）
３０：回転板（回転部材）
３４：駆動モータ（駆動手段）
４０：レーザ測定器（光反射型距離測定器）
４２：回転トランス（信号伝達手段）
４６：マイクロコンピュータ（信号処理装置）
ＳＤ：距離信号

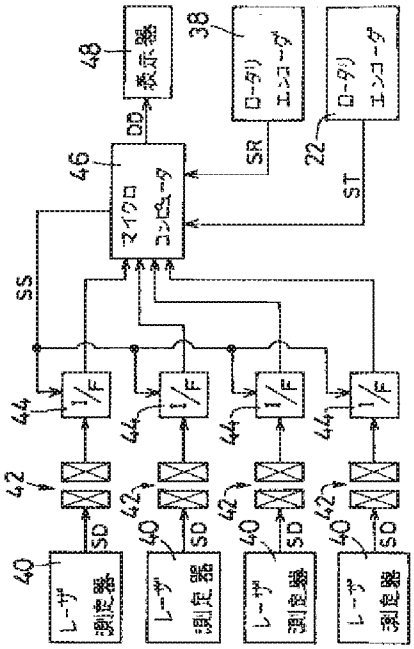
出願人　大同特殊鋼株式会社
代理人　弁理士　池　田　治　幸
（ほか２名）

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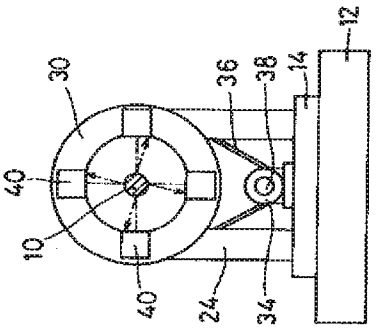
第3図



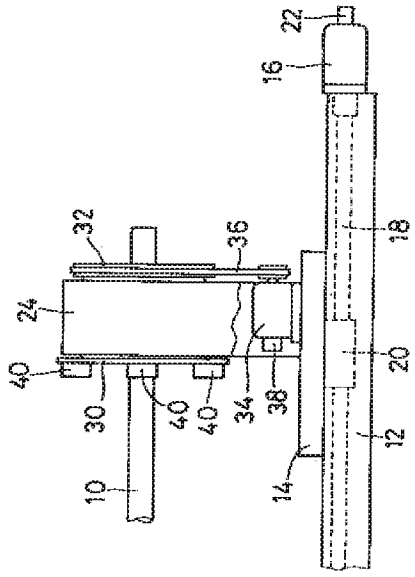
第4図



第1図

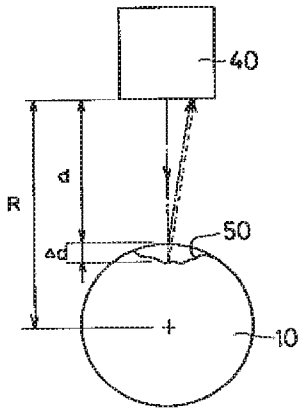


第2図

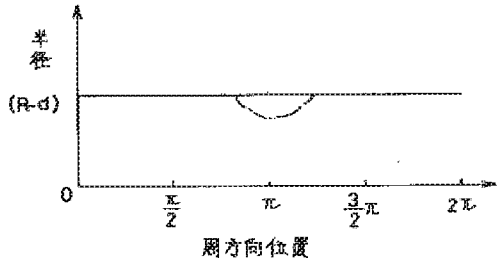


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第 5 図



第 6 図



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[Continued on next page]

(54) Title: LIDAR BASED 3-D IMAGING WITH FAR-FIELD ILLUMINATION OVERLAP

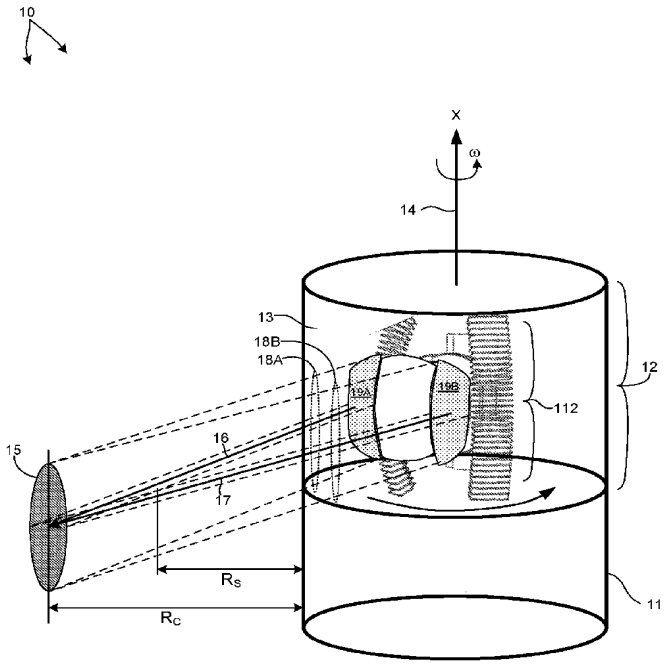


FIG. 3

(57) Abstract: Methods and systems for performing 3-D LIDAR measurements of objects simultaneously illuminated by two or more beams of light in the far field are described herein. A 3-D LIDAR based measurement device simultaneously emits at least two beams of light into a three dimensional environment from different locations. A portion of the three dimensional environment is simultaneously illuminated by the two or more light beams at a distance of at least five meters from the LIDAR device. However, the two or more light beams do not overlap at a distance less than five meters from the LIDAR device. The beams of light are slightly divergent, having highest intensity at the device and steadily lower intensity further away. By overlapping illumination beams in the far field, but not near the LIDAR device, overall intensity is maintained at moderate levels throughout the field of view of the LIDAR device.

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— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

Published:

— *with international search report (Art. 21(3))*

— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

LIDAR BASED 3-D IMAGING WITH FAR-FIELD ILLUMINATION OVERLAP

David S. Hall
Mathew Noel Rekow
Pieter J. Kerstens

CROSS REFERENCE TO RELATED APPLICATION

[0001] The present application for patent claims priority from U.S. patent application serial number 15/420,366, entitled LIDAR Based 3-D Imaging With Far-Field Illumination Overlap," filed January 31, 2017, which, in turn, claims priority under 35 U.S.C. §119 from U.S. provisional patent application serial number 62/289,278, entitled "LIDAR Based 3-D Imaging With Far-Field Illumination Overlap," filed January 31, 2016, the subject matter of which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

[0002] The described embodiments relate to LIDAR based 3-D point cloud measuring systems.

BACKGROUND INFORMATION

[0003] LIDAR systems employ pulses of light to measure distance to an object based on the time of flight (TOF) of each pulse of light. A pulse of light emitted from a light source of a LIDAR system interacts with a distal object. A portion of the light reflects from the object and returns to a detector of the LIDAR system. Based on the time elapsed between emission of the pulse of light and detection of the returned pulse of light, a distance is estimated. In some examples, pulses of light are generated by a laser emitter. The light pulses are

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focused through a lens or lens assembly. The time it takes for a pulse of laser light to return to a detector mounted near the emitter is measured. A distance is derived from the time measurement with high accuracy.

[0004] Some LIDAR systems employ a single laser emitter/detector combination combined with a rotating mirror to effectively scan across a plane. Distance measurements performed by such a system are effectively two dimensional (i.e., planar), and the captured distance points are rendered as a 2-D (i.e. single plane) point cloud. In some examples, rotating mirrors are rotated at very fast speeds (e.g., thousands of revolutions per minute).

[0005] In many operational scenarios, a 3-D point cloud is required. A number of schemes have been employed to interrogate the surrounding environment in three dimensions. In some examples, a 2-D instrument is actuated up and down and/or back and forth, often on a gimbal. This is commonly known within the art as "winking" or "nodding" the sensor. Thus, a single beam LIDAR unit can be employed to capture an entire 3-D array of distance points, albeit one point at a time. In a related example, a prism is employed to "divide" the laser pulse into multiple layers, each having a slightly different vertical angle. This simulates the nodding effect described above, but without actuation of the sensor itself.

[0006] In all the above examples, the light path of a single laser emitter/detector combination is somehow altered to achieve a broader field of view than a single sensor. The number of pixels such devices can generate per unit time is inherently limited due limitations on the pulse repetition rate of a single laser. Any alteration of the beam path, whether it is by mirror, prism, or actuation of the device that achieves a larger

coverage area comes at a cost of decreased point cloud density.

[0007] As noted above, 3-D point cloud systems exist in several configurations. However, in many applications it is necessary to generate image information over a broad field of view. For example, in an autonomous vehicle application, the vertical field of view should extend down as close as possible to see the ground in front of the vehicle. In addition, the vertical field of view should extend above the horizon, in the event the car enters a dip in the road. In addition, it is necessary to have a minimum of delay between the actions happening in the real world and the imaging of those actions. In some examples, it is desirable to provide a complete image update at least five times per second. To address these requirements, a 3-D LIDAR system has been developed that includes an array of multiple laser emitters and detectors. This system is described in U.S. Patent No. 7,969,558 issued on June 28, 2011, the subject matter of which is incorporated herein by reference in its entirety.

[0008] In many applications, a sequence of pulses is emitted. The direction of each pulse is sequentially varied in rapid succession. In these examples, a distance measurement associated with each individual pulse can be considered a pixel, and a collection of pixels emitted and captured in rapid succession (i.e., "point cloud") can be rendered as an image or analyzed for other reasons (e.g., detecting obstacles). In some examples, viewing software is employed to render the resulting point clouds as images that appear three dimensional to a user. Different schemes can be used to depict the distance measurements as 3-D images that appear as if they were captured by a live action camera.

[0009] In some examples, the timing of successive light emission pulses is set such that the return signal associated with a particular pulse emission is detected before the subsequent pulse emission is triggered. This ensures that a detected return signal is properly associated with the particular pulse emission that generated the detected return signal.

[0010] In some other examples, multiple pulses are emitted into the surrounding environment before a return signal from any of the multiple pulses is detected. Traditionally, this approach raises the potential for cross-talk among detected signals. In other words, when multiple pulses are emitted into the surrounding environment before a return signal from any of the multiple pulses is detected, a detected return signal might be incorrectly associated with a different pulse emission than the particular pulse emission that gave rise to detected return signal. This can potentially cause errors in distance measurement.

[0011] Traditionally, to avoid cross-talk among multiple pulses, each of the multiple pulses is projected in a different direction. By projecting each of the multiple pulses in a different direction, each volume of space interrogated by each of the multiple pulses is completely separated from any volume of space interrogated by any of the other multiple pulses. As the separation among simultaneously interrogated spaces is increased, the likelihood of inducing measurement error due to cross-talk is reduced.

[0012] Existing LIDAR systems employ a single beam of light to interrogate a particular volume of the surrounding environment at any given time. The detection of return signals includes significant sources of measurement noise. These problems are exacerbated as

measurement ranges are extended for a LIDAR system without increasing laser pulse intensity.

[0013] These systems are limited in the intensity of light that can be projected onto the volume of the environment subject to measurement by each beam of light. In some examples, human eye safety protocols limit the intensity of light emitted from the LIDAR device.

[0014] Improvements in signal strength and noise rejection are desired to extend the measurement range of a LIDAR system.

SUMMARY

[0015] Methods and systems for performing 3-D LIDAR measurements of objects simultaneously illuminated by two or more beams of light in the far field are described herein. A 3-D LIDAR based measurement device simultaneously emits at least two beams of light into a three dimensional environment. Each beam of light is emitted from the 3-D LIDAR device at a different location. At least two of the emitted beams are projected from the 3-D LIDAR device such that a portion of the three dimensional environment is illuminated by the two or more light beams at a distance of at least five meters from the LIDAR device. In addition, the two or more light beams do not overlap at a distance of less than five meters from the LIDAR device.

[0016] The beams of light emitted from the 3-D LIDAR device are slightly divergent. Thus, the beam intensity is highest at the window of the device, and steadily decreases further away from the device. It follows that the risk of damage to the human eye is greatest in short range of the device and the risk diminishes as the distance from the device increases.

[0017] By emitting multiple beams of light from the 3-D LIDAR device at different locations, the risk of eye

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damage is minimized at short distances because the beams are not overlapping. Hence, at short distances, only a single beam may incidentally interact with a human eye. As the distances increase, the beams begin to overlap, until a critical distance is reached where, ideally, two or more beams fully overlap with each other. In some examples, the critical distance is in a range of 100-200 meters away from the 3-D LIDAR device. At these distances, more than one beam may incidentally interact with a human eye without risk of harm due to beam divergence.

[0018] In a further aspect, the LIDAR system determines the time of flight of the multiple beams of illumination light projected from the LIDAR device to a location in three dimensional environment and back to the LIDAR device. The distance between the LIDAR device and the particular location of the three dimensional environment illuminated by the beams of illumination light is determined based on the time of flight.

[0019] The foregoing is a summary and thus contains, by necessity, simplifications, generalizations and omissions of detail; consequently, those skilled in the art will appreciate that the summary is illustrative only and is not limiting in any way. Other aspects, inventive features, and advantages of the devices and/or processes described herein will become apparent in the non-limiting detailed description set forth herein.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] FIG. 1 is a simplified diagram illustrative of one embodiment of a 3-D LIDAR system 100 in at least one novel aspect.

[0021] FIG. 2 depicts an exploded view of 3-D LIDAR system 100 in one exemplary embodiment.

[0022] FIG. 3 is a simplified diagram illustrative of another embodiment of a 3-D LIDAR system 10 in at least one novel aspect.

[0023] FIG. 4 depicts a view of light emission and collection engine 112 of 3-D LIDAR system 100.

[0024] FIG. 5 depicts a view of collection optics 116 of 3-D LIDAR system 100 in greater detail.

[0025] FIG. 6 depicts a cutaway view of collection optics 116 of 3-D LIDAR system 100 that illustrates the shaping of each beam of collected light 118.

[0026] FIG. 7 depicts elements of a LIDAR system including a pulsed illumination system 130, a light detection system 150, and controller 140.

[0027] FIG. 8 depicts an exemplary diagram 180 illustrating the timing of light emission from each of sixteen different multiple beam illumination systems.

[0028] FIG. 9 depicts an illustration of the timing of emission of a pulse measurement beam and capture of the returning measurement pulse.

[0029] FIG. 10 depicts a flowchart illustrative of a method 200 of performing LIDAR measurements in at least one novel aspect.

DETAILED DESCRIPTION

[0030] Reference will now be made in detail to background examples and some embodiments of the invention, examples of which are illustrated in the accompanying drawings.

[0031] FIG. 1 is a diagram illustrative of an embodiment of a 3-D LIDAR system 100 in one exemplary operational scenario. 3-D LIDAR system 100 includes a lower housing 101 and an upper housing 102 that includes a domed shell element 103 constructed from a material that is transparent to infrared light (e.g., light having a wavelength within the spectral range of 700 to 1,700 nanometers). In one example, domed shell element 103 is

transparent to light having a wavelengths centered at 905 nanometers.

[0032] As depicted in FIG. 1, a plurality of beams of light 105 are emitted from 3-D LIDAR system 100 through domed shell element 103 over an angular range, α, measured from a central axis 104. In the embodiment depicted in FIG. 1, each beam of light is projected onto a plane defined by the x and y axes at a plurality of different locations spaced apart from one another. For example, beam 106 is projected onto the xy plane at location 107.

[0033] In the embodiment depicted in FIG. 1, 3-D LIDAR system 100 is configured to scan each of the plurality of beams of light 105 about central axis 104. Each beam of light projected onto the xy plane traces a circular pattern centered about the intersection point of the central axis 104 and the xy plane. For example, over time, beam 106 projected onto the xy plane traces out a circular trajectory 108 centered about central axis 104.

[0034] FIG. 2 depicts an exploded view of 3-D LIDAR system 100 in one exemplary embodiment. 3-D LIDAR system 100 further includes a light emission/collection engine 112 that rotates about central axis 104. In the depicted embodiment, a central optical axis 117 of light emission/collection engine 112 is tilted at an angle, θ, with respect to central axis 104. As depicted in FIG. 2, 3-D LIDAR system 100 includes a stationary electronics board 110 mounted in a fixed position with respect to lower housing 101. Rotating electronics board 111 is disposed above stationary electronics board 110 and is configured to rotate with respect to stationary electronics board 110 at a predetermined rotational velocity (e.g., more than 200 revolutions per minute). Electrical power signals and electronic signals are communicated between stationary electronics board 110 and

rotating electronics board 111 over one or more transformer, capacitive, or optical elements, resulting in a contactless transmission of these signals. Light emission/collection engine 112 is fixedly positioned with respect to the rotating electronics board 111, and thus rotates about central axis 104 at the predetermined angular velocity, ω.

[0035] As depicted in FIG. 2, light emission/collection engine 112 includes an array of light emitting elements 114 and an array of light detecting elements 113. Light emitted from each of the light emitting elements 114 is directed toward a mirror (not shown). Light reflected from the mirror passes through a series of illumination optics 115 that collimate the emitted light into an array of beams of light 105 that are emitted from 3-D LIDAR system 100 as depicted in FIG. 1. In general, any number of light emitting elements can be arranged to simultaneously emit any number of light beams from 3-D LIDAR system 100. Light reflected from objects in the environment is collected by collection optics 116. Collected light passes through collection optics 116 where it is focused onto each detecting element of the array of detecting elements 113. After passing through collection optics 116, the collected light is reflected from a mirror (not shown) onto each detector element.

[0036] In one aspect, a 3-D LIDAR device emits at least two beams of light into a three dimensional environment. Each beam of light is emitted from the 3-D LIDAR device at a different location. At least two of the emitted beams are projected from the 3-D LIDAR device such that the portion of the three dimensional environment illuminated by a first of the plurality of light beams substantially overlaps a portion of the three dimensional environment illuminated by a second of the plurality of light beams at a distance of at least five meters from

the LIDAR device. In addition, the portion of the three dimensional environment illuminated by a first of the plurality of light beams does not substantially overlap a portion of the three dimensional environment illuminated by a second of the plurality of light beams at a distance of less than five meters from the LIDAR device.

[0037] The beams of light emitted from the 3-D LIDAR device are slightly divergent. In one example, the beam diameter is approximately 15 millimeters at the window of the device, and is approximately 20 centimeters at a distance of 100 meters from the device. Thus, the beam intensity is highest at the window of the device, and steadily decreases further away from the device. It follows that the risk of damage to the human eye is greatest in short range of the device and the risk diminishes as the distance from the device increases.

[0038] By emitting multiple beams of light from the 3-D LIDAR device at different locations, at short distances, the risk of eye damage is minimized because the beams are not overlapping. Hence, at short distances, only a single beam may incidentally interact with a human eye. As the distances increase, the beams begin to overlap, until a critical distance is reached where, ideally, two or more beams fully overlap with each other. In some examples, the critical distance is in a range of 100-200 meters away from the 3-D LIDAR device. In these distance ranges, more than one beam may incidentally interact with a human eye. However, at these distances, the combined beam intensity is below eye damage limits due to beam divergence.

[0039] FIG. 3 is a diagram illustrative of another embodiment of a 3-D LIDAR system 10 in one exemplary operational scenario. 3-D LIDAR system 10 includes a lower housing 11 and an upper housing 12 that includes a cylindrical shell element 13 (e.g., outer lens)

constructed from a material that is transparent to infrared light (e.g., light having a wavelength within the spectral range of 700 to 1,700 nanometers). In one example, cylindrical shell element 13 is transparent to light having a wavelengths centered at 905 nanometers.

[0040] As depicted in FIG. 3, 3-D LIDAR system 10 includes a light emission/collection engine 112 tilted at a ninety degree angle with respect to central axis 14. In one aspect, two beams of light are emitted from 3-D LIDAR system 10 from different, spatially distinct locations of the 3-D LIDAR device. As depicted in FIG. 3, a beam of light characterized by chief ray 16 is emitted from light emission/collection engine 112 at the surface of illumination optic 19A and a beam of light characterized by chief ray 17 is simultaneously emitted from light emission/collection engine 112 at the surface of illumination optic 19B. The surfaces of illumination optics 19A and 19B are spatially distinct. In addition, the beam of light characterized by chief ray 16 is emitted from 3-D LIDAR system 10 at location 18A on the outer lens 13 and the beam of light characterized by chief ray 17 is simultaneously emitted from the 3-D LIDAR system 10 at location 18B on the outer lens 13. Location 18A and 18B are spatially distinct.

[0041] Furthermore, the beams are pointed such that they begin to overlap at a distance, R_s, from the device and maximally overlap at a critical distance, R_c, (e.g., 100-200 meters from 3-D LIDAR device 10). In the embodiment depicted in FIG. 3, the chief ray 16 of one illumination beam of light and the chief ray 17 of another illumination beam of light are illustrated. Each beam of light is projected outward into the surrounding environment along different trajectories. The trajectories intersect at location 15 in the far-field.

Location 15 is located at a critical distance, R_C, from 3-D LIDAR system 10.

[0042] Each beam of light emitted from system 10 diverges slightly as illustrated in FIG. 3. In one example, a beam of light emitted from system 10 illuminates a spot size of 20 centimeters in diameter at a distance of 100 meters from system 10. In this manner, each beam of illumination light is a cone of illumination light emitted from system 10. For a portion of each beam trajectory from 3-D LIDAR system 10 to location 15, the beams do not intersect. At a distance, R_S, the beams begin to overlap. In some examples, the distance, R_s, where the beams begin to overlap is five meters, or more. Hence, at a distance of less than five meters, the beams do not overlap at all. As the distance increases beyond R_s, the percentage of overlap continues to increase until a maximum overlap is reached at the critical distance, R_C. Ideally, the percentage of overlap at the critical distance is 100%. However, in practice, any significant amount of overlap is beneficial as the overlapping illumination provides a stronger return signal to 3-D LIDAR device 10.

[0043] As depicted in FIG. 3, two beams of light are emitted from 3-D LIDAR system 10 from different locations of the 3-D LIDAR device and from two different lens elements. Furthermore, the beams are pointed such that they overlap at a critical distance from the device (e.g., 100-200 meters from 3-D LIDAR device 20). As depicted in FIG. 3, emission lens 19A and 19B are two different lens elements, each having their own optical axis. In some other embodiments, lens elements 19A and 19B may be constructed as a single optical component that includes two different lens elements, each having their own optical axis.

[0044] In the embodiment depicted in FIG. 3, 3-D LIDAR system 10 is configured to scan each of the plurality of beams of light 16 and 17 about central axis 14. As the beams of light rotate about central axis 14, each beam of light projected into the surrounding environment (e.g., each cone of illumination light associated with each beam) illuminates a volume of the environment corresponding the cone shaped illumination beam as it is swept around central axis 14. In general, any number of beams may be emitted from 3-D LIDAR system 10 to provide overlapping illumination in the far-field, or in different locations in the far-field.

[0045] In some embodiments, each beam configured to overlap with another beam in the far-field is generated by a separate illumination source (e.g., laser diode, LED, etc.) In some other embodiments, illumination light generated by a particular illumination source is subdivided and collimated to generate two or more different beams that are each directed such that they overlap in the far field.

[0046] FIG. 4 depicts another view of light emission/collection engine 112. In the depicted embodiment, light emission/collection engine 112 includes intermediate electronics boards 121, 122, and 123 which provide mechanical support and electrical connectivity between rotating electronics board 111 and various elements of light emission/collection engine 112. For example, each of the array of light detecting elements 113 is mounted to intermediate electronics board 121. Intermediate electronics board 121, in turn, is mechanically and electrically coupled to rotating electronics board 111. Similarly, each of the array of light emitting elements 114 is mounted to intermediate electronics board 123. Intermediate electronics board 123, in turn, is mechanically and electrically coupled to

rotating electronics board 111. In another example, illumination optics 115 and collection optics 116 are mechanically mounted to intermediate electronics board 122. In this example, intermediate electronics board 122 spatially and optically separates the illumination optics 115 and the collection optics 116 to avoid contamination of the collected light with illumination light. Intermediate electronics board 122, in turn, is mechanically and electrically coupled to rotating electronics board 111. In this manner, the intermediate electronics boards provide mechanical and electrical connectivity and additional board area for mounting electrical components required for the operation of 3-D LIDAR system 100.

[0047] FIG. 5 depicts a view of collection optics 116 in greater detail. As depicted in FIG. 5, collection optics 116 include four lens elements 116A-D arranged to focus collected light 118 onto each of the array of detecting elements 113. Light passing through collection optics 116 is reflected from mirror 124 and is directed onto each of the array of detecting elements 113. In another aspect, one or more of the optical elements of collection optics 116 is constructed from one or more materials that absorb light outside of a predetermined wavelength range that includes the wavelengths of light emitted by each of the array of light emitting elements 114. In one example, one or more of the lens elements are constructed from a plastic material that includes a colorant additive to absorb light having wavelengths less than infrared light generated by each of the array of light emitting elements 114. In one example, the colorant is Epolight 7276A available from Aako BV (The Netherlands). In general, any number of different colorants can be added to any of the plastic lens elements of collection optics 116 to filter out undesired spectra.

[0048] FIG. 6 depicts a cutaway view of collection optics 116 to illustrate the shaping of each beam of collected light 118.

[0049] As described hereinbefore, one or more of the optical elements of collection optics 116 is constructed from one or more materials that absorb light outside of a predetermined wavelength range that includes the wavelengths of light emitted by each of the array of light emitting elements 114. However, in general, one or more of the optical elements of illumination optics 115 may also be constructed from one or more materials that absorb light outside of a predetermined wavelength range that includes the wavelengths of light emitted by each of the array of light emitting elements 114.

[0050] A LIDAR system, such as 3-D LIDAR system 10 depicted in FIG. 3, and system 100, depicted in FIG. 1, includes multiple, pulsed illumination sources emitting pulsed beams of illumination light from the LIDAR device into the surrounding environment. In some embodiments, the pulsed illumination sources are laser based. In some embodiments, the pulsed illumination sources are based on one or more light emitting diodes. In general, any suitable pulsed illumination source may be contemplated.

[0051] In one embodiment, two or more pulsed beams of illumination light simultaneously illuminate a particular location of the three dimensional environment (e.g., pixel) with pulses of illumination light. Light reflected from the location is detected by a photosensitive detector of the LIDAR system during a measurement window having a duration that is less than or equal to the time of flight of light from the LIDAR system out to the programmed range of the LIDAR system, and back. The photosensitive detector detects a return pulse or pulses of light reflected from a particular location of the three dimensional environment

simultaneously illuminated by two or more illumination beams. In this manner, the reflection from a particular measurement location of each of the multiple illumination beams is captured by the LIDAR system.

[0052] In a further aspect, the LIDAR system determines the time of flight of the beams of illumination light from the LIDAR device to the particular spot of the three dimensional environment illuminated by the beams of illumination light and back to the LIDAR device. This determination is based on the reflected light detected during the measurement window. The distance between the LIDAR device and the particular location of the three dimensional environment illuminated by the beams of illumination light is determined based on the time of flight.

[0053] FIG. 7 depicts elements of a LIDAR system including a pulsed illumination system 130, a light detection system 150, and controller 140.

[0054] Pulsed illumination system 130 includes pulsed light emitting devices 136 and 137. Pulsed light emitting devices 136 and 137 generate simultaneous, pulsed light emission in response to pulsed electrical current signals 134 and 133, respectively. The light generated by pulsed light emitting devices 136 and 137 is focused and projected onto a particular location 138 in the surrounding environment by one or more optical elements of the LIDAR system. The beams of light generated by the pulsed lighting emitting devices 136 and 137 are directed such that they overlap at location 138. In one example, light emitted by pulsed light emitting devices 136 and 137 is focused and projected onto a particular location by illumination optics 115 that collimate the emitted light into pulsed beams of light 16 and 17 emitted from 3-D LIDAR system 10 as depicted in FIG. 3.

[0055] Pulsed illumination system 130 includes drivers 131 and 132 that supply current pulses to light emitting devices 137 and 136, respectively. The current pulses generated by drivers 131 and 132 are controlled by control signal, MPC. In this manner, the timing and shape of pulses generated by light emitting devices 136 and 137 are controlled by controller 140.

[0056] In a further embodiment, a LIDAR system, such as LIDAR system 100 depicted in FIG. 1, includes sixteen, multiple beam, pulsed illumination systems operating in coordination with a common controller (e.g., controller 140). FIG. 8 depicts an exemplary diagram 180 illustrating the timing of light emission from each of the sixteen, multiple beam illumination systems.

[0057] As depicted in FIG. 8, a measurement pulse is emitted from a first multiple beam illumination system. After a delay time, T_{DELAY}, a measurement pulse is emitted from a second multiple beam illumination system of the LIDAR device. In this manner a sequence of sixteen measurement pulses are emitted in different directions from the LIDAR device during a measurement period, $T_{MEASUREMENT}$. The drivers of each of the sixteen multiple beam illumination systems are charged after the measurement period for a charging period, T_{CHARGE}. After, the charging period, another measurement pulse is emitted from each multiple beam illumination system over a subsequent measurement period.

[0058] In some embodiments, the delay time is set to be greater than the time of flight of the measurement pulse to and from an object located at the maximum range of the LIDAR device. In this manner, there is no cross-talk among any of the sixteen multiple beam illumination systems.

[0059] In some other embodiments, a measurement pulse may be emitted from one multiple beam illumination system

before a measurement pulse emitted from another multiple beam illumination system has had time to return to the LIDAR device. In some of these embodiments, care is taken to ensure that there is sufficient spatial separation between the areas of the surrounding environment interrogated by each set of beams to avoid cross-talk.

[0060] As depicted in FIG. 7, light reflected from location 138 simultaneously illuminated by multiple beams is detected by light detector 155. Light detector 155 generates an output signal 151 that is amplified by an analog trans-impedance amplifier 152. In general, the amplification of output signal 151 may include multiple, amplifier stages. In this sense, analog trans-impedance amplifier 152 is provided by way of non-limiting example, as many other analog signal amplification schemes may be contemplated within the scope of this patent document.

[0061] The amplified signal 153 is communicated to controller 140. An analog-to-digital converter (ADC) 144 of controller 140 is employed to convert the analog signal 153 into a digital signal used for further processing. Controller 140 generates an enable/disable signal 145 employed to control the timing of data acquisition by ADC 144 in concert with control signal, MPC.

[0062] FIG. 9 depicts an illustration of the timing associated with the emission of a measurement pulse and capture of the returning measurement pulse sequence. As depicted in FIG. 9, the measurement begins with pulse firing signals 161 (e.g., MPC[1] and MPC[2]) generated by controller 140. Due to internal system delay, a pulse index signal 162 is determined that is shifted from the multiple pulse firing signal 161 by a time delay, T_D. The time delay includes the known delays associated with emitting light from the LIDAR system (e.g., signal

communication delays and latency associated with the switching elements, energy storage elements, and pulsed light emitting device) and known delays associated with collecting light and generating signals indicative of the collected light (e.g., amplifier latency, analog-digital conversion delay, etc.).

[0063] As depicted in FIG. 9, a return signal 163 is detected by the LIDAR system in response to the illumination of a particular location by both light emitting devices 136 and 137. A measurement window (i.e., a period of time over which collected return signal data is associated with a particular measurement pulse) is initiated by enabling data acquisition from light detecting element 150. Controller 140 controls the timing of the measurement window to correspond with the window of time when a return signal is expected in response to the emission of the corresponding measurement pulse. In some examples, the measurement window is enabled at the point in time when the measurement pulse is emitted and is disabled at a time corresponding to the time of flight of light over a distance that is twice the range of the LIDAR system. In this manner, the measurement window is open to collect return light from objects adjacent to the LIDAR system (i.e., negligible time of flight) to objects that are located at the maximum range of the LIDAR system. In this manner, all other light that cannot possibly contribute to useful return signal is rejected.

[0064] As depicted in FIG. 9, return signal 163 includes two return measurement pulses that correspond with different objects in the path of the multiple beams. In general, signal detection is performed on all detected measurement pulses. Further signal analysis may be performed to identify the closest signal (i.e., first instance of the return measurement pulse), the strongest

signal, and the furthest signal (i.e., last instance of the return measurement pulse in the measurement window). Any of these instances may be reported as potentially valid distance measurements by the LIDAR system. For example, a time of flight, TOF_1, may be calculated from the closest (i.e., earliest) return measurement pulse that corresponds with the emitted measurement pulse sequence as depicted in FIG. 9.

[0065] In the embodiment described with reference to FIG. 7, two different light emitting devices (i.e., light emitting devices 136 and 137) are employed to simultaneously generate two different beams directed to overlap in the far field. However, in general, a single light emitting device may be employed along with a beam splitting optic to subdivide the beam of light emitted from the single light emitting device into two or more beams that are directed to overlap in the far field by additional optical elements. In these embodiments, a single light emitting source simultaneously generates multiple beams that overlap in the far field with a single trigger signal, rather than having to coordinate the timing of multiple trigger signals (e.g., MPC[1] and MPC[2]) to achieve simultaneous overlapping illumination in the far field.

[0066] FIG. 10 illustrates a method 200 of performing LIDAR measurements with multiple illumination beams overlapping in the far field in at least one novel aspect. Method 200 is suitable for implementation by any of the embodiments described herein. In one aspect, it is recognized that data processing blocks of method 200 may be carried out via a pre-programmed algorithm executed by one or more processors of controller 140, or any other general purpose computing system. It is recognized herein that the particular structural aspects

of the described embodiments do not represent limitations and should be interpreted as illustrative only.

[0067] In block 201, two or more light beams are emitted from a LIDAR device into a three dimensional environment in a plurality of different directions. Portions of the three dimensional environment illuminated by each of the two or more light beams substantially overlap at a distance of at least five meters from the LIDAR device. None of the two or more light beams overlap any of the other two or more light beams at a distance less than five meters from the LIDAR device.

[0068] In block 202, an amount of light reflected from a location in the three dimensional environment simultaneously illuminated by the two or more light beams is detected.

[0069] In block 203, a time of flight of the two or more light beams emitted from the LIDAR device and detected by one or more photosensitive detectors of the LIDAR device is determined.

[0070] In one or more exemplary embodiments, the functions described may be implemented in hardware, software, firmware, or any combination thereof. If implemented in software, the functions may be stored on or transmitted over as one or more instructions or code on a computer-readable medium. Computer-readable media includes both computer storage media and communication media including any medium that facilitates transfer of a computer program from one place to another. A storage media may be any available media that can be accessed by a general purpose or special purpose computer. By way of example, and not limitation, such computer-readable media can comprise RAM, ROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other medium that can be used to carry or store desired program code means in the form of

instructions or data structures and that can be accessed by a general-purpose or special-purpose computer, or a general-purpose or special-purpose processor. Also, any connection is properly termed a computer-readable medium. For example, if the software is transmitted from a website, server, or other remote source using a coaxial cable, fiber optic cable, twisted pair, digital subscriber line (DSL), or wireless technologies such as infrared, radio, and microwave, then the coaxial cable, fiber optic cable, twisted pair, DSL, or wireless technologies such as infrared, radio, and microwave are included in the definition of medium. Disk and disc, as used herein, includes compact disc (CD), laser disc, optical disc, digital versatile disc (DVD), floppy disk and blu-ray disc where disks usually reproduce data magnetically, while discs reproduce data optically with lasers. Combinations of the above should also be included within the scope of computer-readable media.

[0071] Although certain specific embodiments are described above for instructional purposes, the teachings of this patent document have general applicability and are not limited to the specific embodiments described above. Accordingly, various modifications, adaptations, and combinations of various features of the described embodiments can be practiced without departing from the scope of the invention as set forth in the claims.

CLAIMS

What is claimed is:

1. A light detection and ranging (LIDAR) device, comprising:

one or more illumination sources configured to emit two or more light beams from the LIDAR device into a three dimensional environment in a plurality of different directions such that a portion of the three dimensional environment is illuminated by each of the two or more light beams, wherein a first of the two or more light beams is emitted from the LIDAR device at a first location, and a second of the two or more light beams is emitted from the LIDAR device at a second location that is spatially distinct from the first location;

one or more photosensitive detectors configured to detect an amount of light reflected from a location in the three dimensional environment simultaneously illuminated by the two or more light beams; and

a computing system configured to determine a time of flight of the two or more light beams emitted from the one or more illumination sources and detected by the one or more photosensitive detectors.

2. The LIDAR device of Claim 1, wherein the portion of the three dimensional environment illuminated by each of the two or more light beams is located at least five meters from the LIDAR device and none of the two or more light beams overlap any of the other two or more light beams at a distance less than five meters from the LIDAR device.

3. The LIDAR device of Claim 2, wherein the first and second locations are located on a surface of an optical element.

4. The LIDAR device of Claim 2, wherein the first location is located on a surface of a first optical element and the second location is located on a surface of a second optical element.

5. The LIDAR device of Claim 1, wherein the one or more illumination sources comprises:

a light emitting device configured to emit a first amount of light;

one or more optical elements configured to collimate the first amount of light into a first beam of light; and

a beam splitting element configured to separate the first beam of light into a second beam of light and a third beam of light, wherein the second beam of light is emitted from the LIDAR device at a first location, and wherein the third beam of light is emitted from the LIDAR device at a second location that is spatially distinct from the first location, and wherein portions of the three dimensional environment illuminated by the second beam of light and the third beam of light substantially overlap at a distance of at least five meters from the LIDAR device and no portions of the second beam of light and the third beam of light overlap at any distance less than five meters from the LIDAR device.

6. The LIDAR device of Claim 1, wherein a first of the one or more illumination sources emits a first of the two or more light beams from the LIDAR device at a first location, and a second of the one or more illumination sources emits a second of the two or more light beams from the LIDAR device at a second location, wherein the first and second locations are spatially distinct.

7. The LIDAR device of Claim 1, wherein each of the one or more illumination sources is laser based.

8. The LIDAR device of Claim 1, wherein each of the one or more illumination sources includes a light emitting diode.

9. The LIDAR device of Claim 1, wherein each of the one or more illumination sources emit pulses of illumination light.

10. A light detection and ranging (LIDAR) device, comprising:

one or more light emitting devices configured to emit a first amount of light;

one or more optical elements configured to collimate the first amount of light into a first beam of light;

a beam splitting element configured to separate the first beam of light into a second beam of light and a third beam of light, wherein the second beam of light is emitted from the LIDAR device at a first location, and wherein the third beam of light is emitted from the LIDAR device at a second location that is spatially distinct from the first location, and wherein portions of the three dimensional environment illuminated by the second beam of light and the third beam of light substantially overlap at a distance of at least five meters from the LIDAR device and no portions of the second beam of light and the third beam of light overlap at any distance less than five meters from the LIDAR device.

11. The LIDAR device of Claim 10, further comprising:

one or more photosensitive detectors configured to detect an amount of light reflected from a location in

the three dimensional environment simultaneously illuminated by the second and third beams of light; and

a computing system configured to determine a time of flight of the second and third beams of light emitted from the one or more light emitting devices and detected by the one or more photosensitive detectors.

12. The LIDAR device of Claim 10, wherein the first location is located on a surface of a first optical element and the second location is located on a surface of a second optical element.

13. The LIDAR device of Claim 10, wherein the first location is located on a surface of a first optical element and the second location is located on a surface of a second optical element.

14. The LIDAR device of Claim 10, wherein each of the one or more light emitting devices is laser based.

15. The LIDAR device of Claim 10, wherein each of the one or more light emitting devices is a light emitting diode.

16. A method comprising:

emitting two or more light beams from a LIDAR device into a three dimensional environment in a plurality of different directions such that portions of the three dimensional environment illuminated by each of the two or more light beams substantially overlap at a distance of at least five meters from the LIDAR device and none of the two or more light beams overlap any of the other two or more light beams at a distance less than five meters from the LIDAR device;

detecting an amount of light reflected from a location in the three dimensional environment simultaneously illuminated by the two or more light beams; and

determining a time of flight of the two or more light beams emitted from the LIDAR device and detected by one or more photosensitive detectors of the LIDAR device.

17. The method of Claim 16, wherein a first of the two or more light beams is emitted from the LIDAR device at a first location, and a second of the two or more light beams is emitted from the LIDAR device at a second location that is spatially distinct from the first location.

18. The method of Claim 17, wherein the first location is located on a surface of a first optical element and the second location is located on a surface of a second optical element.

19. The method of Claim 17, wherein the first location is located on a surface of a first optical element and the second location is located on a surface of a second optical element.

20. The method of Claim 17, further comprising:

emitting a first amount of light from one or more light emitting devices;

collimating the first amount of light into a first beam of light; and

splitting the first beam of light into a second beam of light and a third beam of light, wherein the second beam of light is emitted from the LIDAR device at a first location, and wherein the third beam of light is emitted from the LIDAR device at a second location that is

spatially distinct from the first location, and wherein portions of the three dimensional environment illuminated by the second beam of light and the third beam of light substantially overlap at a distance of at least five meters from the LIDAR device and no portions of the second beam of light and the third beam of light overlap at any distance less than five meters from the LIDAR device.

HESAI EX1002, P.989

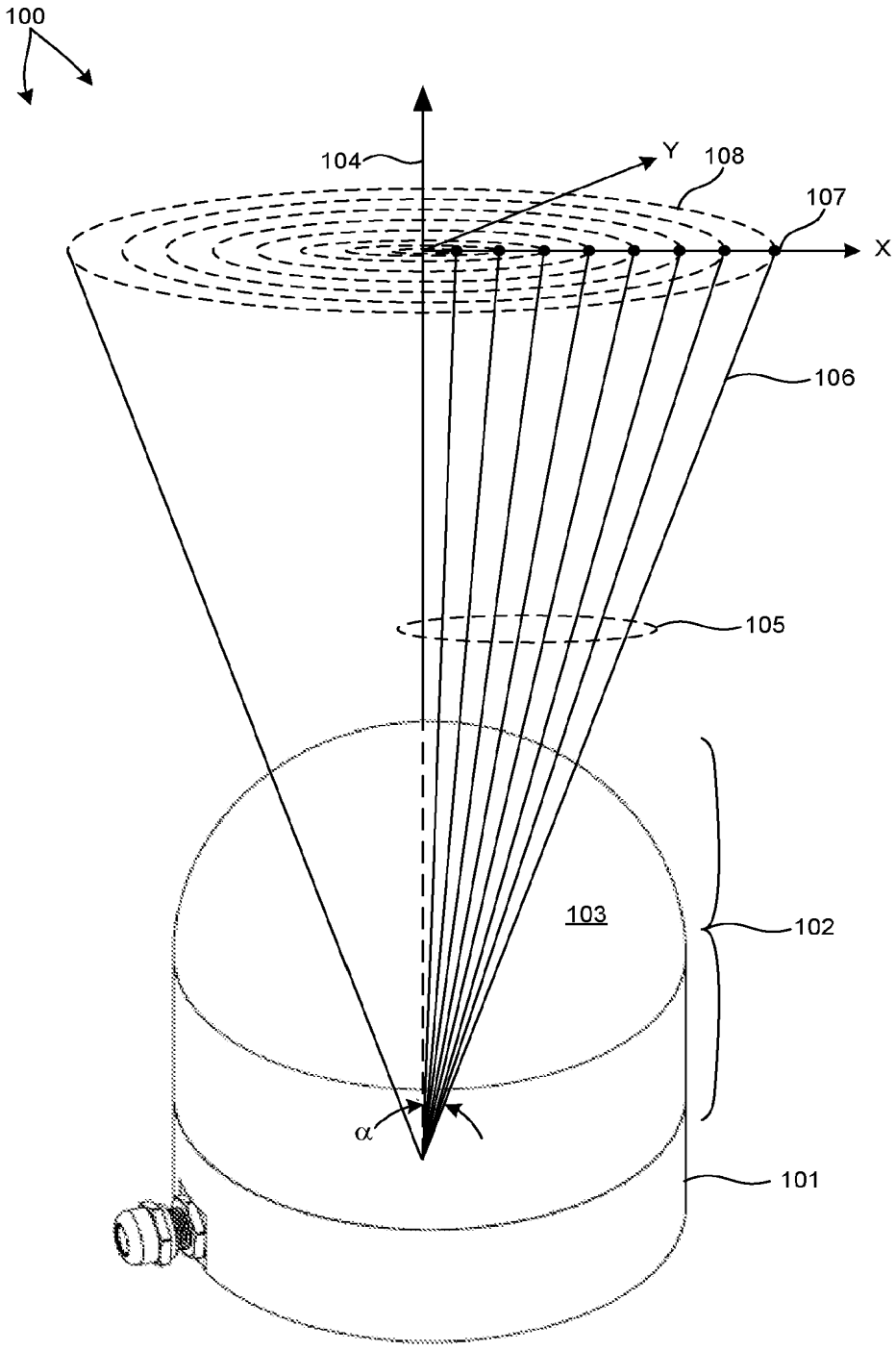


FIG. 1

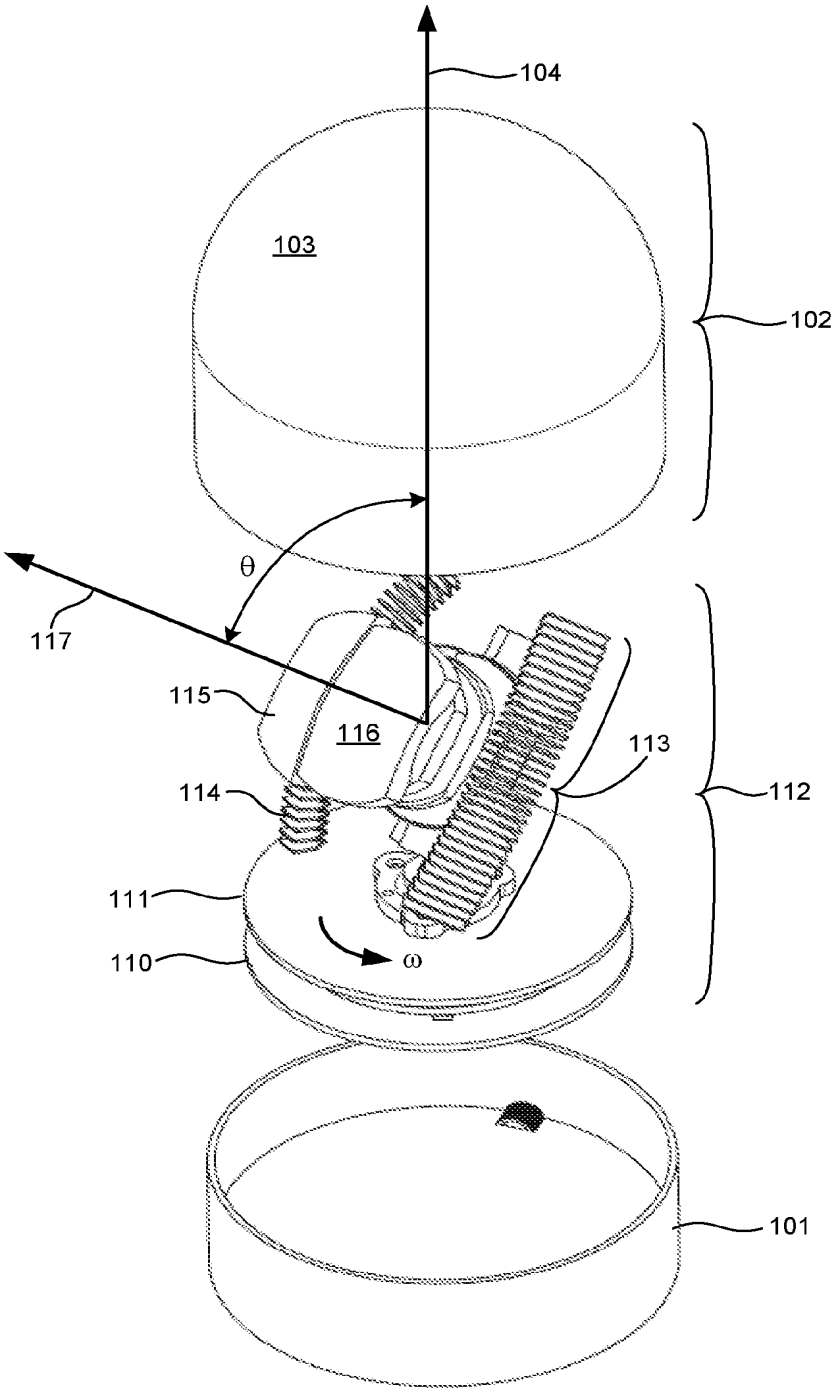


FIG. 2

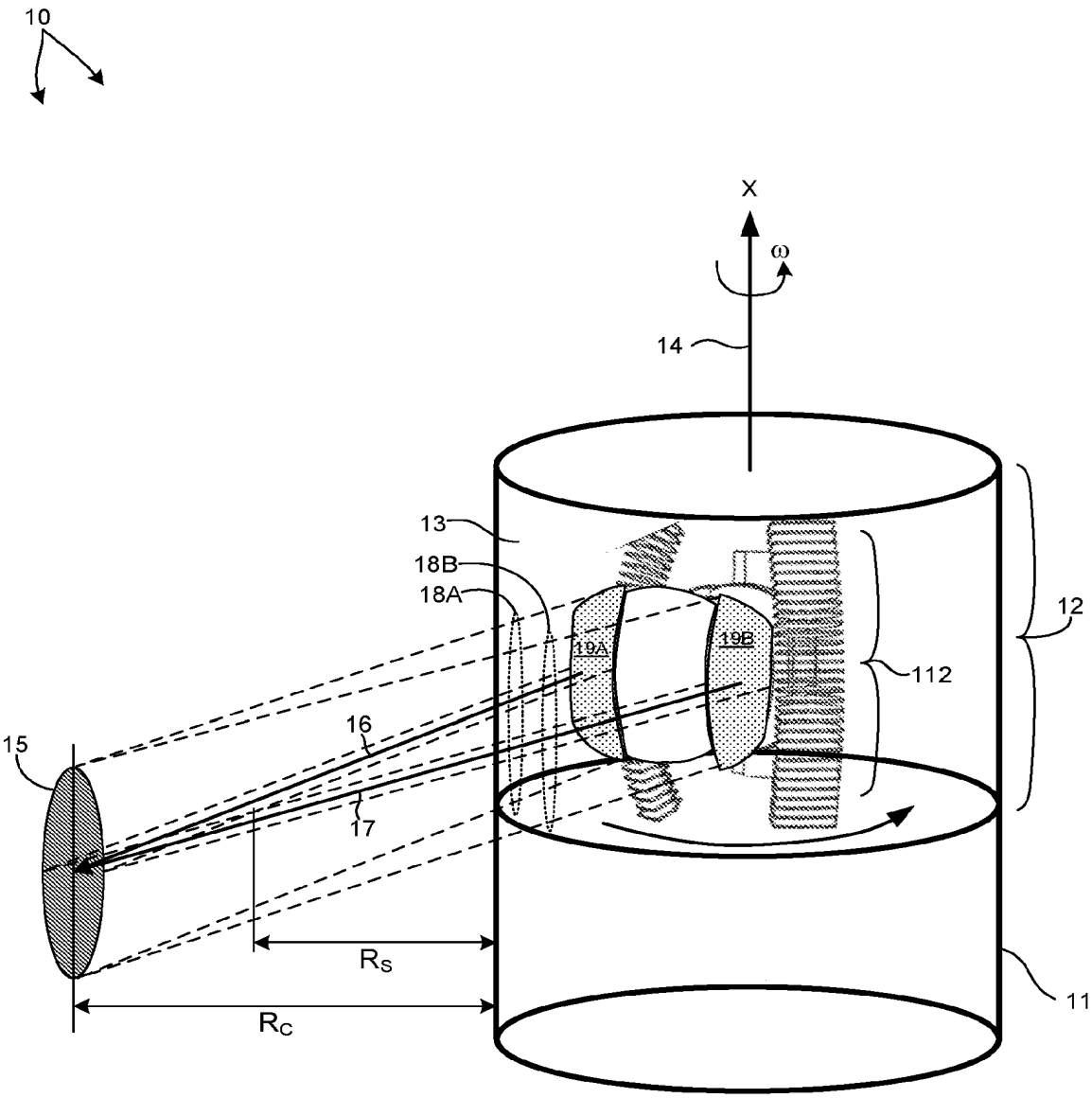


FIG. 3

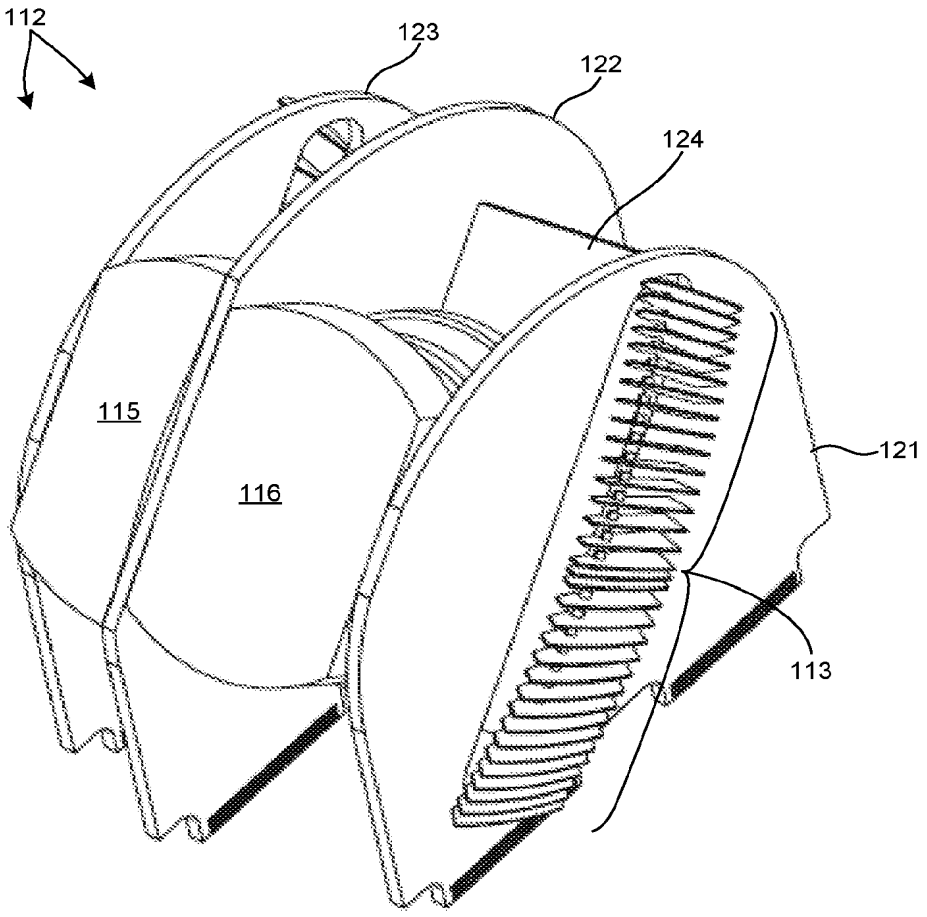


FIG. 4

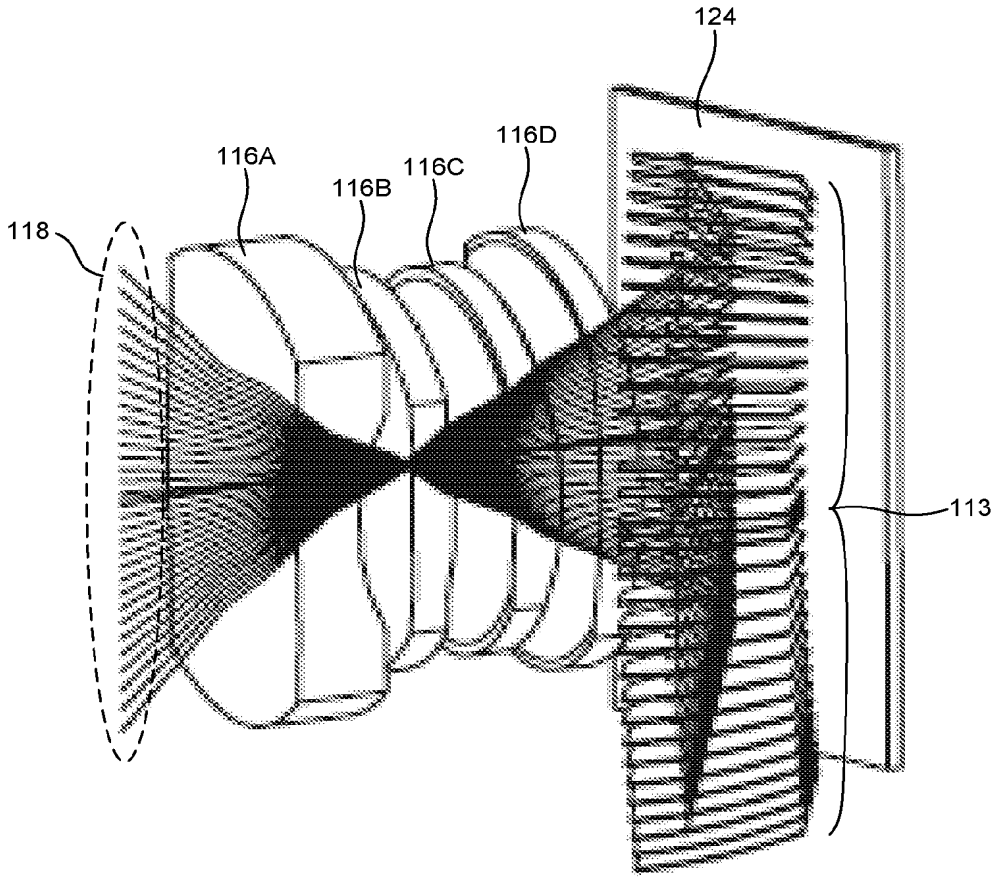


FIG. 5

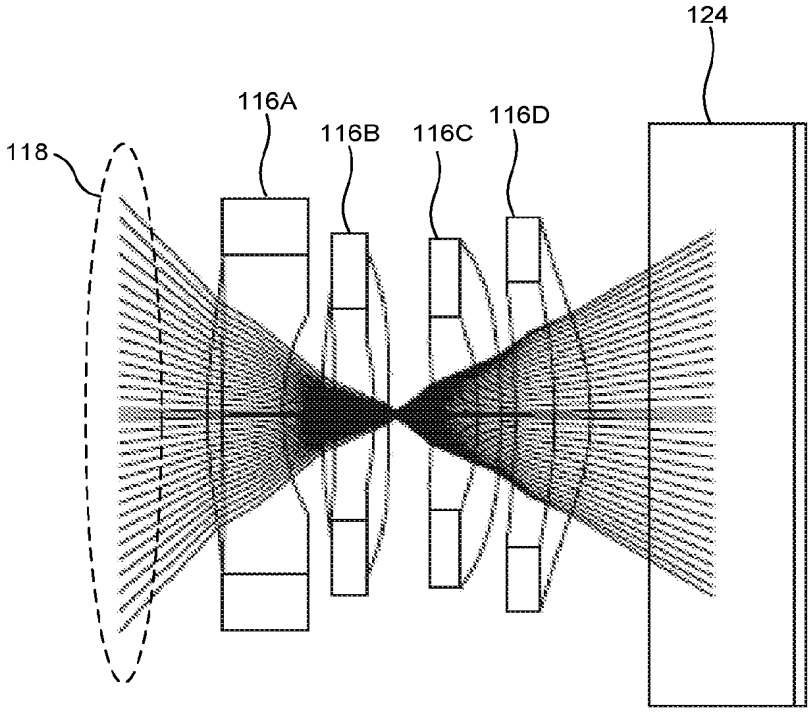


FIG. 6

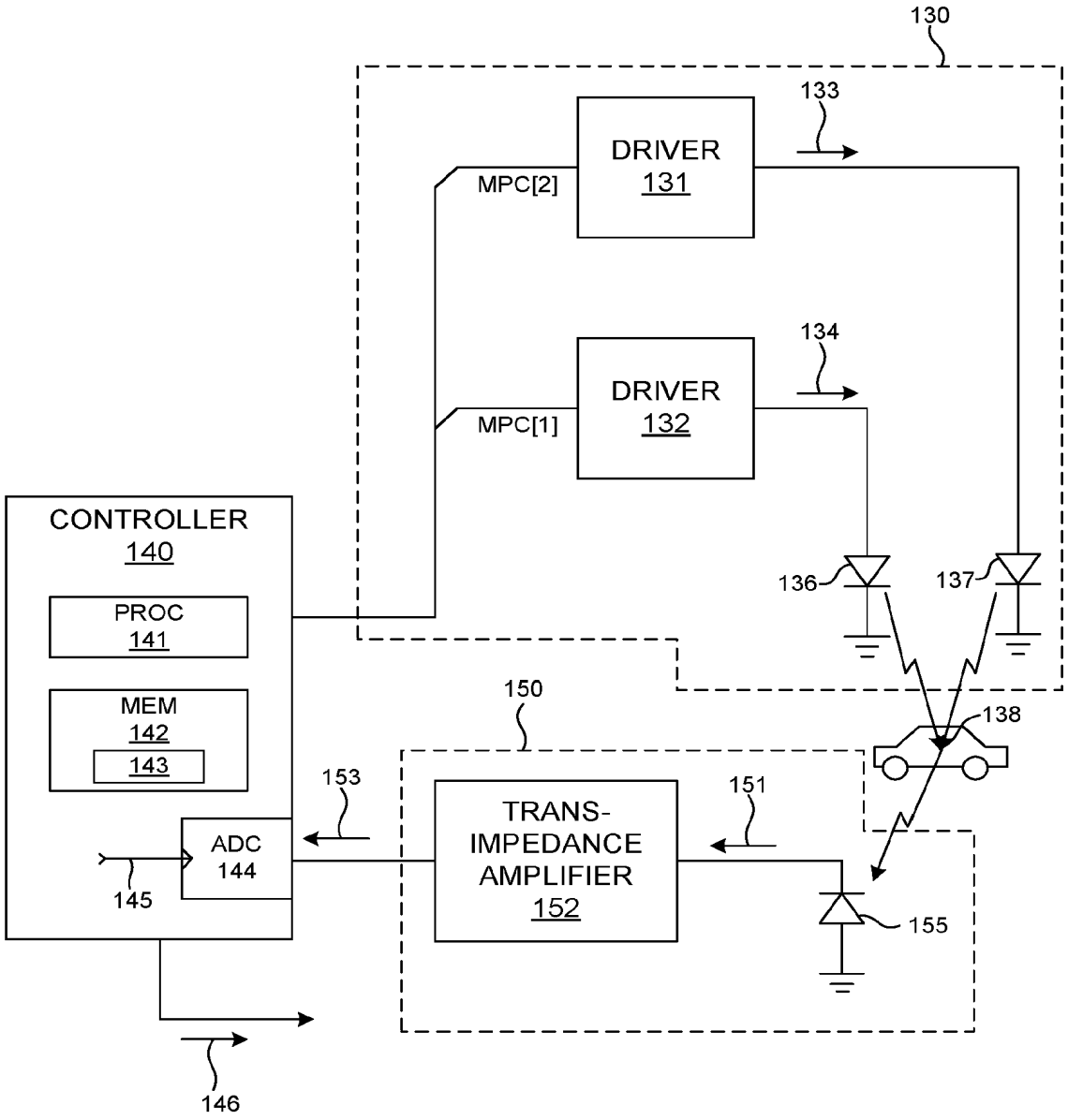

130
133
DRIVER
131
MPC[2]
134
DRIVER
132
MPC[1]
CONTROLLER
140
PROC
141
MEM
142
143
ADC
144
145
146
153
150
TRANS-
IMPEDANCE
AMPLIFIER
152
151
136
137
138
155

FIG. 7

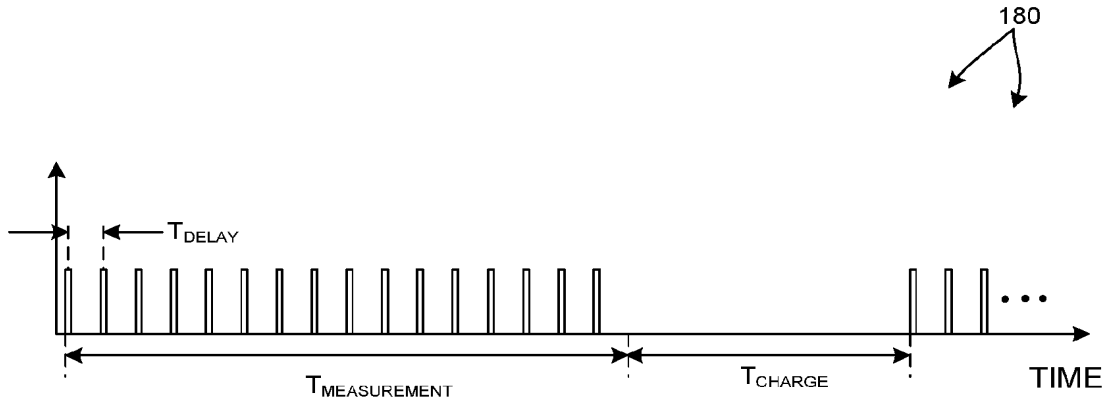


FIG. 8

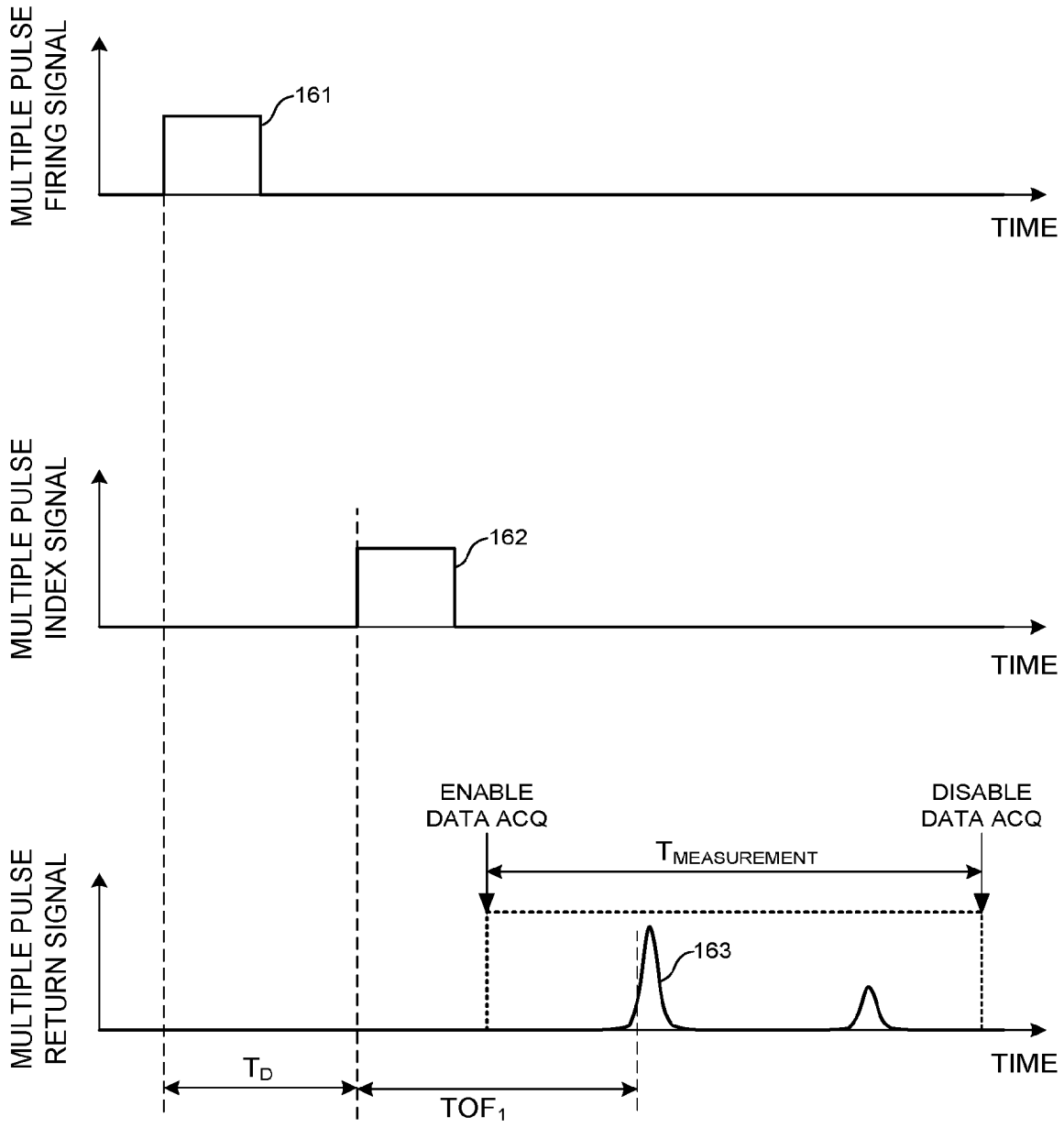

MULTIPLE PULSE FIRING SIGNAL
161
TIME
MULTIPLE PULSE INDEX SIGNAL
162
TIME
ENABLE DATA ACQ
DISABLE DATA ACQ
$T_{MEASUREMENT}$
MULTIPLE PULSE RETURN SIGNAL
163
TIME
T_D
TOF_1

FIG. 9

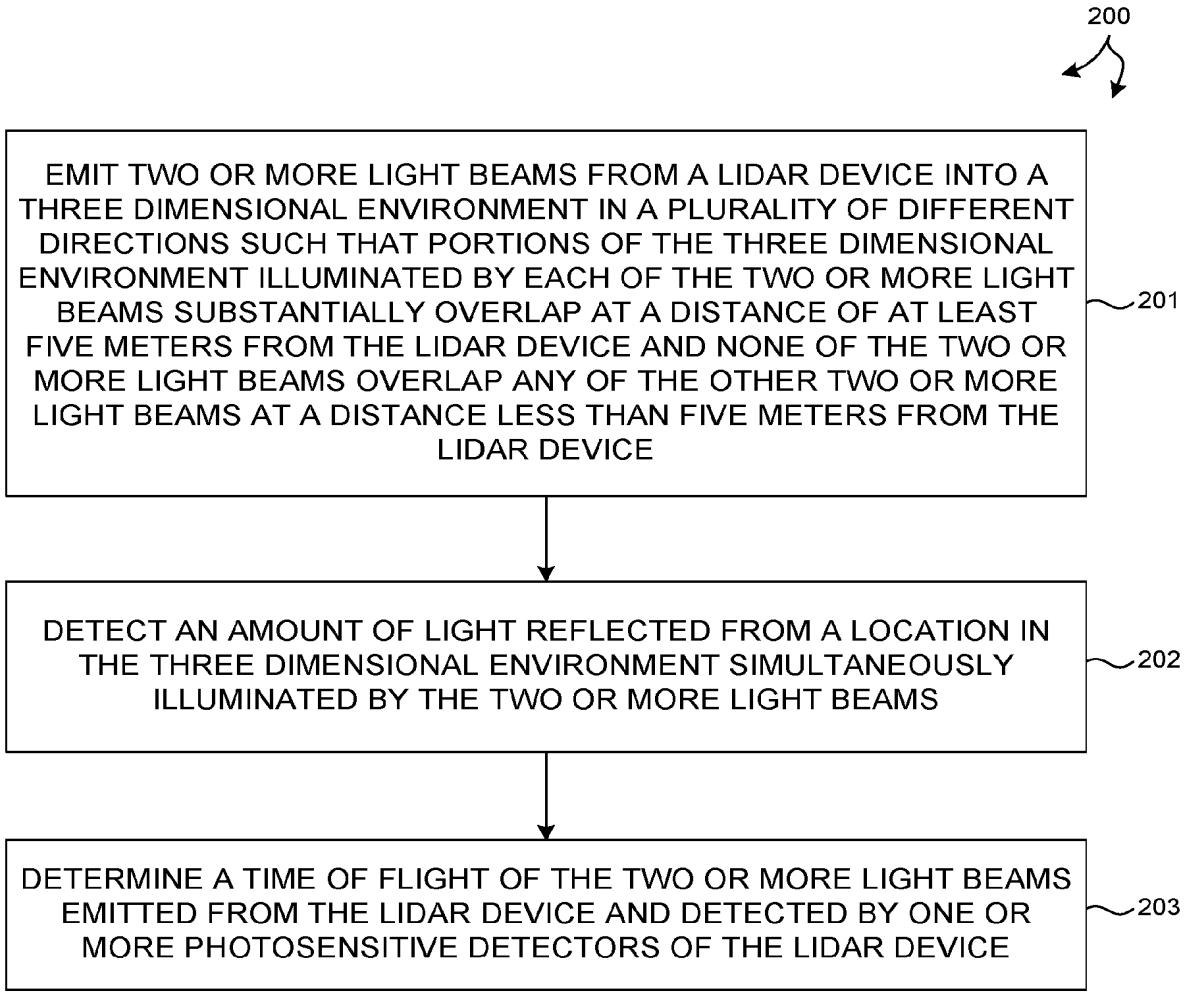

200
EMIT TWO OR MORE LIGHT BEAMS FROM A LIDAR DEVICE INTO A THREE DIMENSIONAL ENVIRONMENT IN A PLURALITY OF DIFFERENT DIRECTIONS SUCH THAT PORTIONS OF THE THREE DIMENSIONAL ENVIRONMENT ILLUMINATED BY EACH OF THE TWO OR MORE LIGHT BEAMS SUBSTANTIALLY OVERLAP AT A DISTANCE OF AT LEAST FIVE METERS FROM THE LIDAR DEVICE AND NONE OF THE TWO OR MORE LIGHT BEAMS OVERLAP ANY OF THE OTHER TWO OR MORE LIGHT BEAMS AT A DISTANCE LESS THAN FIVE METERS FROM THE LIDAR DEVICE
201
DETECT AN AMOUNT OF LIGHT REFLECTED FROM A LOCATION IN THE THREE DIMENSIONAL ENVIRONMENT SIMULTANEOUSLY ILLUMINATED BY THE TWO OR MORE LIGHT BEAMS
202
DETERMINE A TIME OF FLIGHT OF THE TWO OR MORE LIGHT BEAMS EMITTED FROM THE LIDAR DEVICE AND DETECTED BY ONE OR MORE PHOTOSENSITIVE DETECTORS OF THE LIDAR DEVICE
203

FIG. 10

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2017/015874

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - G01S 17/89; G01C 3/08; G01J 3/02; G01J 3/28; G01J 3/44; G01S 7/497; G01S 17/06 (2017.01)

CPC - G01S 17/89; G01C 21/30; G01J 3/0278; G01J 3/2803; G01J 3/4406; G01S 7/4814; G01S 7/4815; G01S 7/4863; G01S 7/4865; G01S 7/497; G01S 17/06; G01S 17/10; G01S 17/93; G06Q 10/047; G06Q 30/02; H04N 13/025; H04N 13/0271 (2017.02)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

See Search History document

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

See Search History document

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

See Search History document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2015/0131080 A1 (FACET TECHNOLOGY CORP.) 14 May 2015 (14.05.2015) entire document	1-9, 16-20
Y	US 2014/0071234 A1 (MILLETT) 13 March 2014 (13.03.2014) entire document	1-9, 16-20
Y	US 2010/0020306 A1 (HALL) 28 January 2010 (28.01.2010) entire document	6, 17-20
Y	US 2015/0015895 A1 (FARO TECHNOLOGIES, INC.) 15 January 2015 (15.01.2015) entire document	8

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
27 April 2017	23 MAY 2017
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, VA 22313-1450 Facsimile No. 571-273-8300	Authorized officer Blaine R. Copenheaver PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

Form PCT/ISA/210 (second sheet) (January 2015)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2017/015874

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:
See Extra Sheet(s)

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:
1-9, 16-20

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

Continued from Box No. III Observations where unity of invention is lacking

This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be examined, the appropriate additional examination fees must be paid.

Group I, claims 1-9,16-20, drawn to a light detection and ranging (LIDAR) device.
Group II, claims 10-20, drawn to a light detection and ranging (LIDAR) device wherein portions of the three dimensional environment illuminated by the second beam of light and the third beam of light substantially overlap at a distance of at least five meters.

The inventions listed as Groups I-II do not relate to a single general inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons: the special technical feature of the Group I invention: one or more photosensitive detectors configured to detect an amount of light reflected from a location in the three dimensional environment simultaneously illuminated by the two or more light beams; and a computing system configured to determine a time of flight of the two or more light beams emitted from the one or more illumination sources and detected by the one or more photosensitive detectors as claimed therein is not present in the invention of Group II. The special technical feature of the Group II invention: wherein portions of the three dimensional environment illuminated by the second beam of light and the third beam of light substantially overlap at a distance of at least five meters from the LIDAR device and no portions of the second beam of light and the third beam of light overlap at any distance less than five meters from the LIDAR device as claimed therein is not present in the invention of Group I.

Groups I and II lack unity of invention because even though the inventions of these groups require the technical feature of one or more illumination sources configured to emit two or more light beams from the LIDAR device into a three dimensional environment in a plurality of different directions such that a portion of the three dimensional environment is illuminated by each of the two or more light beams, wherein a first of the two or more light beams is emitted from the LIDAR device at a first location, and a second of the two or more light beams is emitted from the LIDAR device at a second location that is spatially distinct from the first location, this technical feature is not a special technical feature as it does not make a contribution over the prior art.

Specifically, US 2010/0020306 A1 (HALL) 28 January 2010 (28.01.2010) teaches one or more illumination sources configured to emit two or more light beams from the LIDAR device into a three dimensional environment in a plurality of different directions such that a portion of the three dimensional environment is illuminated by each of the two or more light beams (Paras. 36-38 and Figs. 5-8), wherein a first of the two or more light beams is emitted from the LIDAR device at a first location, and a second of the two or more light beams is emitted from the LIDAR device at a second location that is spatially distinct from the first location (Paras. 45-46 and Figs. 9-10).

Since none of the special technical features of the Group I or II inventions are found in more than one of the inventions, unity of invention is lacking.

PATENT COOPERATION TREATY

From the INTERNATIONAL SEARCHING AUTHORITY

To: Jennifer Hayes
Nixon Peabody LLP
300 South Grand Avenue
Suite 4100
Los Angeles, California 90071-3151
United States of America

PCT

NOTIFICATION OF TRANSMITTAL OF THE INTERNATIONAL SEARCH REPORT AND THE WRITTEN OPINION OF THE INTERNATIONAL SEARCHING AUTHORITY, OR THE DECLARATION

(PCT Rule 44.1)

Applicant's or agent's file reference: 78715-001WO0	Date of mailing (day/month/year): 07 NOV 2017
International application No.: PCT/US17/39306	FOR FURTHER ACTION See paragraphs 1 and 4 below
Applicant: OUSTER, INC.	International filing date (day/month/year): 26 June 2017 (26.06.2017)

1. ☒ The applicant is hereby notified that the international search report and the written opinion of the International Searching Authority have been established and are transmitted herewith.

Filing of amendments and statement under Article 19:
The applicant is entitled, if he so wishes, to amend the claims of the international application (see Rule 46).

When? The time limit for filing such amendments is normally two months from the date of transmittal of the international search report.

How? Directly to the International Bureau of WIPO preferably through ePCT or on paper to, 34 chemin des Colombettes 1211 Geneva 20, Switzerland, Facsimile No.: +41 22 338 82 70

For more detailed instructions, see *PCT Applicant's Guide*, International Phase, paragraphs 9.004 – 9.011.

2. ☐ The applicant is hereby notified that no international search report will be established and that the declaration under Article 17(2)(a) to that effect and the written opinion of the International Searching Authority are transmitted herewith.

3. ☐ **With regard to any protest** against payment of (an) additional fee(s) under Rule 40.2, the applicant is notified that:
☐ the protest together with the decision thereon has been transmitted to the International Bureau together with any request to forward the texts of both the protest and the decision thereon to the designated Offices.
☐ no decision has been made yet on the protest; the applicant will be notified as soon as a decision is made.

4. **Reminders**

The applicant may **submit comments on an informal basis on the written opinion of the International Searching Authority** to the International Bureau. These comments will be made available to the public after international publication. The International Bureau will send a copy of such comments to all designated Offices unless an international preliminary examination report has been or is to be established.

Shortly after the expiration of **18 months from the priority date, the international application will be published** by the International Bureau. If the applicant wishes to avoid or postpone publication, a notice of withdrawal of the international application, or of the priority claim, must reach the International Bureau before the completion of the technical preparations for international publication (Rules 90*bis*.1 and 90*bis*.3).

Within **19 months** from the priority date, but only in respect of some designated Offices, a demand for international preliminary examination must be filed if the applicant wishes to postpone the entry into the national phase **until 30 months** from the priority date (in some Offices even later); otherwise, the applicant must, **within 20 months** from the priority date, perform the prescribed acts for **entry into the national phase** before those designated Offices. In respect of other designated Offices, the time limit of **30 months** (or later) will apply even if no demand is filed within 19 months. For details about the applicable time limits, Office by Office, see www.wipo.int/pct/en/texts/time_limits.html and the *PCT Applicant's Guide*, National Chapters.

Within **22 months from the priority date, the applicant may request that a supplementary international search be carried out** by a different International Searching Authority that offers this service (Rule 45*bis*.1). The procedure for requesting supplementary international search is described in the *PCT Applicant's Guide*, International Phase, paragraphs 8.006-8.032.

Name and mailing address of the ISA/US: Mail Stop PCT, Attn: ISA/US, Commissioner for Patents, P.O. Box 1450, Alexandria, Virginia 22313-1450	Authorized officer: Shane Thomas
Facsimile No. 571-273-8300	Telephone No. PCT Helpdesk: 571-272-4300, PCT OSP: 571-272-7774

Form PCT/ISA/220 (July 2017)

RECEIVED
NOV 16 2017

PATENT COOPERATION TREATY

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference 78715-001WO0	**FOR FURTHER ACTION**	see Form PCT/ISA/220 as well as, where applicable, item 5 below.
International application No. PCT/US17/39306	International filing date *(day/month/year)* 26 June 2017 (26.06.2017)	(Earliest) Priority Date *(day/month/year)* 26 September 2016 (26.09.2016)
Applicant OUSTER, INC.		

This international search report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This international search report consists of a total of 5 sheets.

☐ It is also accompanied by a copy of each prior art document cited in this report.

1. **Basis of the report**

   a. With regard to the **language**, the international search was carried out on the basis of:

   ☒ the international application in the language in which it was filed.

   ☐ a translation of the international application into _____ which is the language of a translation furnished for the purposes of international search (Rules 12.3(a) and 23.1(b)).

   b. ☐ This international search report has been established taking into account the **rectification of an obvious mistake** authorized by or notified to this Authority under Rule 91 (Rule 43.6*bis*(a)).

   c. ☐ With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, see Box No. I.

2. ☐ **Certain claims were found unsearchable** (see Box No. II).

3. ☒ **Unity of invention is lacking** (see Box No. III).

4. With regard to the **title**,

   ☒ the text is approved as submitted by the applicant.

   ☐ the text has been established by this Authority to read as follows:

5. With regard to the **abstract**,

   ☒ the text is approved as submitted by the applicant.

   ☐ the text has been established, according to Rule 38.2, by this Authority as it appears in Box No. IV. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.

6. With regard to the **drawings**,

   a. the figure of the **drawings** to be published with the abstract is Figure No. 1

   ☒ as suggested by the applicant.

   ☐ as selected by this Authority, because the applicant failed to suggest a figure.

   ☐ as selected by this Authority, because this figure better characterizes the invention.

   b. ☐ none of the figures is to be published with the abstract.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US17/39306

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:
SEE EXTRA SHEET

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US17/39306

A. CLASSIFICATION OF SUBJECT MATTER
IPC - G01J1/02, G01J1/08, G02B6/00 (2017.01)
CPC - G01J1/026, G01J1/08, G02B6/002

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
See Search History document

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
See Search History document

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
See Search History document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 7,433,042 B1 (CAVANAUGH, D. et al.) October 7, 2008; figures 1-3; column 2, lines 43-63; column 3, lines 1-5; column 4, lines 6- column 5, line 9; column 5, lines 22-33; column 7, lines 24-30	1-3, 6-9, 14, 17, 20-23, 28, 31, 34-37, 42, 45, 48-51, 56, 59, 62-65, 70, 73, 77, 78, and 80
---		----
Y		4-5, 10-13, 15-16, 18-19, 24-27, 29-30, 32-33, 38-41, 43-44, 46-47, 52-55, 57-58, 60-61, 66-69, 71-72, 74-76, 79, and 81-86
Y	US 6,721,262 B1 (JORDACHE, N. et al.) April 13, 2004; figures 5-6(4); column 3, line 39- column 4, line 3	4, 5, 18, 19, 32, 33, 46-47, 60, 61
Y	US 2016/0150963 A1 (ROUKES, M. et al.) June 2, 2016; figure 13; paragraphs [0027, 0030, 0032, 0070].	10-13, 24-27, 38-41, 52-55, 66-69, 75, 76
Y	US 2015/0292948 A1 (VERIFOOD, LTD.) October 15, 2015; figure 5; paragraphs [0160, 0163].	15, 16, 29, 30, 43, 44, 57, 58, 71, 72, 74
Y	WO 2016/125165 A2 (VERIFOOD, LTD.) August 11, 2016; figures 11-13 and 20; paragraphs [0136, 0170, 0172, 0173, 0181, 0184-0186, 0218].	79, 81-84

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
10 October 2017 (10.10.2017)	07 NOV 2017
Name and mailing address of the ISA/ Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-8300	Authorized officer Shane Thomas PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

Form PCT/ISA/210 (second sheet) (January 2015)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US17/39306

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2010/0008588 A1 (FELDKHUN, D. et al.) Janaury 14, 2010; figures 1 and 12; paragraphs [0031, 0038-0040, 0120].	81-82, and 84-86

HESAI EX1002, P.1007

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US17/39306

-***-Continued from Box III -***-

This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be examined, the appropriate additional examination fee must be paid.

Group I: Claims 1-72 are directed towards a micro-optical receiver channel, an image sensor, and a method.
Group II: Claims 1-16 and 73-86 are directed towards an optical channel for receiving photons and detecting the photons.

The inventions listed as Groups I-II do not relate to a single general inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons:

The special technical features of Group I include at least wherein the aperture accepts an input cone of light containing a wide range of wavelengths, and the optical filter filters out all but a narrow band of the wavelengths centered at an operating wavelength, and wherein the pixel is configured to detect photons within the narrow band of wavelengths, which are not present in Group II.

The special technical features of Group II include at least a bulk imaging optic; an aperture layer located at an imaging plane of the bulk optic; a collimating lens layer behind the aperture layer and separated therefrom by a focal length of the collimating lens layer; an optical filter behind the collimating lens layer; and a pixel offset from the optical filter opposite the collimating lens layer, and responsive to photons incident on the pixel, which are not present in Group I.

The common technical features shared by Groups I-II are an optical channel comprising: an aperture; an optical lens adjacent the aperture; an optical filter adjacent the optical lens; and a pixel adjacent the optical filter.

However, these common features are previously disclosed by US 2012/0320164 A1 (LIPTON). Lipton discloses an optical channel comprising: an aperture (polarizing aperture 306; Fig. 3 and para [0046]); an optical lens adjacent the aperture (lens 302 adjacent to aperture 306; Fig. 3 and para [0046]); an optical filter adjacent the optical lens (a patterned polarizer (optical filter) adjacent lens 302; Fig. 3 and para [0046]); and a pixel adjacent the optical filter (a pixel image sensor 309 adjacent to the polarizer 308; Fig. 3, paras [0032], [0046]).

Since the common technical features are previously disclosed by the Lipton reference, these common features are not special and so Groups I-II lack unity.

PATENT COOPERATION TREATY

From the
INTERNATIONAL SEARCHING AUTHORITY

To: Jennifer Hayes
Nixon Peabody LLP
300 South Grand Avenue
Suite 4100
Los Angeles, California 90071-3151
United States of America

PCT

WRITTEN OPINION OF THE
INTERNATIONAL SEARCHING AUTHORITY

(PCT Rule 43*bis*.1)

Date of mailing *(day/month/year)* 07 NOV 2017

Applicant's or agent's file reference
78715-001WO0

FOR FURTHER ACTION
See paragraph 2 below

International application No.	International filing date *(day/month/year)*	Priority date *(day/month/year)*
PCT/US17/39306	26 June 2017 (26.06.2017)	26 September 2016 (26.09.2016)

International Patent Classification (IPC) or both national classification and IPC
IPC - G01J1/02, G01J1/08, G02B6/00 (2017.01)
CPC - G01J1/026, G01J1/08, G02B6/002

Applicant OUSTER, INC.

1. This opinion contains indications relating to the following items:

- ☒ Box No. I Basis of the opinion
- ☐ Box No. II Priority
- ☐ Box No. III Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
- ☒ Box No. IV Lack of unity of invention
- ☒ Box No. V Reasoned statement under Rule 43*bis*.1(a)(i) with regard to novelty, inventive step and industrial applicability; citations and explanations supporting such statement
- ☐ Box No. VI Certain documents cited
- ☐ Box No. VII Certain defects in the international application
- ☒ Box No. VIII Certain observations on the international application

2. **FURTHER ACTION**

If a demand for international preliminary examination is made, this opinion will be considered to be a written opinion of the International Preliminary Examining Authority ("IPEA") except that this does not apply where the applicant chooses an Authority other than this one to be the IPEA and the chosen IPEA has notified the International Bureau under Rule 66.1*bis*(b) that written opinions of this International Searching Authority will not be so considered.

If this opinion is, as provided above, considered to be a written opinion of the IPEA, the applicant is invited to submit to the IPEA a written reply together, where appropriate, with amendments, before the expiration of 3 months from the date of mailing of Form PCT/ISA/220 or before the expiration of 22 months from the priority date, whichever expires later.

For further options, see Form PCT/ISA/220.

Name and mailing address of the ISA/US	Date of completion of this opinion	Authorized officer
Mail Stop PCT, Attn: ISA/US Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-8300	10 October 2017 (10.10.2017)	Shane Thomas PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

Form PCT/ISA/237 (cover sheet) (January 2015)

WRITTEN OPINION OF THE
INTERNATIONAL SEARCHING AUTHORITY

International application No.
PCT/US17/39306

Box No. I Basis of this opinion

1. With regard to the **language**, this opinion has been established on the basis of:

   ☒ the international application in the language in which it was filed.

   ☐ a translation of the international application into _____ which is the language of a translation furnished for the purposes of international search (Rules 12.3(a) and 23.1(b)).

2. ☐ This opinion has been established taking into account the **rectification of an obvious mistake** authorized by or notified to this Authority under Rule 91 (Rule 43*bis*.1(a)).

3. ☐ With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, this opinion has been established on the basis of a sequence listing:

   a. ☐ forming part of the international application as filed:

      ☐ in the form of an Annex C/ST.25 text file.

      ☐ on paper or in the form of an image file.

   b. ☐ furnished together with the international application under PCT Rule 13*ter*.1(a) for the purposes of international search only in the form of an Annex C/ST.25 text file.

   c. ☐ furnished subsequent to the international filing date for the purposes of international search only:

      ☐ in the form of an Annex C/ST.25 text file (Rule 13*ter*.1(a)).

      ☐ on paper or in the form of an image file (Rule 13*ter*.1(b) and Administrative Instructions, Section 713).

4. ☐ In addition, in the case that more than one version or copy of a sequence listing has been filed or furnished, the required statements that the information in the subsequent or additional copies is identical to that forming part of the application as filed or does not go beyond the application as filed, as appropriate, were furnished.

5. Additional comments:

HESAI EX1002, P.1010

WRITTEN OPINION OF THE
INTERNATIONAL SEARCHING AUTHORITY

International application No.
PCT/US17/39306

Box No. IV Lack of unity of invention

1. ☒ In response to the invitation (Form PCT/ISA/206) to pay additional fees the applicant has, within the applicable time limit:

   ☒ paid additional fees.

   ☐ paid additional fees under protest and, where applicable, the protest fee.

   ☐ paid additional fees under protest but the applicable protest fee was not paid.

   ☐ not paid additional fees.

2. ☐ This Authority found that the requirement of unity of invention is not complied with and chose not to invite the applicant to pay additional fees.

3. This Authority considers that the requirement of unity of invention in accordance with Rule 13.1, 13.2 and 13.3 is

   ☐ complied with.

   ☒ not complied with for the following reasons:

This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be examined, the appropriate additional examination fee must be paid.

Group I: Claims 1-72 are directed towards a micro-optical receiver channel, an image sensor, and a method.
Group II: Claims 1-16 and 73-86 are directed towards an optical channel for receiving photons and detecting the photons.

The inventions listed as Groups I-II do not relate to a single general inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons:

The special technical features of Group I include at least wherein the aperture accepts an input cone of light containing a wide range of wavelengths, and the optical filter filters out all but a narrow band of the wavelengths centered at an operating wavelength, and wherein the pixel is configured to detect photons within the narrow band of wavelengths, which are not present in Group II.

The special technical features of Group II include at least a bulk imaging optic; an aperture layer located at an imaging plane of the bulk optic; a collimating lens layer behind the aperture layer and separated therefrom by a focal length of the collimating lens layer; an optical filter behind the collimating lens layer; and a pixel offset from the optical filter opposite the collimating lens layer, and responsive to photons incident on the pixel, which are not present in Group I.

The common technical features shared by Groups I-II are an optical channel comprising: an aperture; an optical lens adjacent the aperture; an optical filter adjacent the optical lens; and a pixel adjacent the optical filter.

However, these common features are previously disclosed by US 2012/0320164 A1 (LIPTON). Lipton discloses an optical channel comprising: an aperture (polarizing aperture 306; Fig. 3 and para [0046]); an optical lens adjacent the aperture (lens 302 adjacent to aperture 306; Fig. 3 and para [0046]); an optical filter adjacent the optical lens (a patterned polarizer (optical filter) adjacent lens 302; Fig. 3 and para [0046]); and a pixel adjacent the optical filter (a pixel image sensor 309 adjacent to the polarizer 308; Fig. 3, paras [0032], [0046]).

Since the common technical features are previously disclosed by the Lipton reference, these common features are not special and so Groups I-II lack unity.

4. Consequently, this opinion has been established in respect of the following parts of the international application:

   ☒ all parts.

   ☐ the parts relating to claims Nos. _____

WRITTEN OPINION OF THE
INTERNATIONAL SEARCHING AUTHORITY

International application No.
PCT/US17/39306

Box No. V Reasoned statement under Rule 43*bis*.1(a)(i) with regard to novelty, inventive step and industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Claims	SEE BELOW	YES
	Claims	SEE BELOW	NO
Inventive step (IS)	Claims	NONE	YES
	Claims	1-86	NO
Industrial applicability (IA)	Claims	1-86	YES
	Claims	NONE	NO

2. Citations and explanations:

-***-Continued from Box No. V: 1. Statement-***-

NOVELTY

YES 4-5, 10-13, 15-16, 18-19, 24-27, 29-30, 32-33, 38-41, 43-44, 46-47, 52-55, 57-58, 60-61, 66-69, 71-72, 74-76, 79, and 81-86
NO 1-3, 6-9, 14, 17, 20-23, 28, 31, 34-37, 42, 45, 48-51, 56, 59, 62, 63-65, 70, 73, 77, 78, and 80

-***-Continued from Box No. V: 2. Citations and explanations:-***-

Claims 1-3, 6-9, 14, 17, 20-23, 28, 31, 34-37, 42, 45, 48-51, 56, 59, 62-65, 70, 73, 77, 78, and 80 lack novelty under PCT Article 33(2) as being anticipated by US 7,433,042 B1 to Cavanaugh, D. et al. (hereinafter 'Cavanaugh')

As for claim 1, Cavanaugh discloses a micro-optical receiver channel (a channel defined by the aperture masks 135 and 137 for the light to each superpixel of a detector 110; figure 2; column 4, lines 6-19, 52-58) comprising: an input aperture layer (aperture mask 135; figure 2; column 4, lines 52-58); an optical lens layer adjacent the input aperture layer (micro lens array 130 is between aperture mask 135 and aperture mask 137; figure 2; column 4, lines 6-19, 52-58); an optical filter layer adjacent the optical lens layer (color filter array 120 is adjacent the micro lens array 130; figure 2; column 4, lines 6-19); and a pixel layer adjacent the optical filter layer (color filter array 120 is as close as possible to detector array 110 (pixel array); figure 2; column 4, lines 6-19).

As for claim 2, Cavanaugh discloses the micro-optical receiver channel of claim 1, wherein the input aperture layer comprises an aperture (aperture mask 135 has an array of openings restricting light to the shape of the super pixel (an aperture); figure 2; column 4, lines 52-58).

As for claim 3, Cavanaugh discloses the micro-optical receiver channel of claim 1, wherein the input aperture layer comprises an aperture and a stop material surrounding the aperture (aperture mask 135 has an array of openings restricting light to the shape of the super pixel (an aperture) and may for a field stop, such as by being tubular baffles (stop material surrounding the aperture); figure 2; column 4, lines 52-58).

As for claim 6, Cavanaugh discloses the micro-optical receiver channel of claim 1, wherein the optical lens layer comprises a collimating lens (micro lens array 130 is placed at where the objective lens 140 forms an image of the object under observation to help collimate the light; figure 2; column 4, lines 6-19; column 5, lines 22-33).

As for claim 7, Cavanaugh discloses the micro-optical receiver channel of claim 1, wherein the input aperture layer comprises an aperture (aperture mask 135 has an array of openings restricting light to the shape of the super pixel (an aperture); figure 2; column 4, lines 52-58), and wherein the optical lens layer comprises a lens (micro lens array 130 is an array of lenses, one per super-pixel; figure 2; column 4, lines 6-19), the aperture aligned with the lens (micro lens array 130 is an array of lenses to fill each specific super-pixel with the apertures restricting light to the shape of the super pixel; figure 2; column 4, lines 6-19, 52-58).

As for claim 8, Cavanaugh discloses the micro-optical receiver channel of claim 1, further comprising a second aperture layer between the optical lens layer and the optical filter layer (micro lens array 130 is between aperture mask 135 and aperture mask 137 with optical filter 120 on the other side of aperture mask 137 from micro lens array 130; figure 2; column 4, lines 6-19, 52-58).

As for claim 9, Cavanaugh discloses the micro-optical receiver channel of claim 1, wherein the optical filter layer comprises an optical bandpass filter (the color filter array is made of bandpass filters which may be narrow band; figures 2 and 3; column 3, lines 1-5; column 4, line 59- column 5, line 9).

As for claim 14, Cavanaugh discloses the micro-optical receiver channel of claim 1, wherein the pixel comprises a plurality of subpixels (each super pixel includes an array of subpixels such as a 4x4 array; figures 2 and 3; column 4, lines 6-19; 59-67).

-***-Continued Within the Next Supplemental Box-***-

WRITTEN OPINION OF THE
INTERNATIONAL SEARCHING AUTHORITY

International application No.
PCT/US17/39306

Box No. VIII Certain observations on the international application

The following observations on the clarity of the claims, description, and drawings or on the question whether the claims are fully supported by the description, are made:

Claims 23, 37, 51, and 65 are objected to under PCT Rule 66.2(a)(v) as lacking clarity under PCT Article 6 because claims 23, 37, 51, and 65 lack antecedent basis for 'the optical filter layer'. For the purposes of this examination, claims 29, 43, 57, and 71 interpret 'the optical filter layer' as 'the optical filter'.

Claims 29, 43, 57 and 71 are objected to under PCT Rule 66.2(a)(v) as lacking clarity under PCT Article 6 because claims 29, 43, 57 and 71 lack antecedent basis for 'the pixel layer'. For the purposes of this examination, claims 29, 43, 57, and 71 interpret 'the pixel layer' as 'the pixel'.

Claims 32 and 33 are objected to under PCT Rule 66.2(a)(v) as lacking clarity under PCT Article 6 because claims 32 and 33 lack antecedent basis for 'the stop region'. For the purposes of this examination, claims 32 and 33 interpret 'the stop region' as 'a stop region for the aperture'.

Claims 77 is objected to under PCT Rule 66.2(a)(v) as lacking clarity under PCT Article 6 because claim 77 lacks antecedent basis for 'the bulk imaging optic'. For the purposes of this examination, claim 77 is interpreted as depending on claim 73 rather than claim 63.

Supplemental Box

In case the space in any of the preceding boxes is not sufficient.
Continuation of:

-***-Continued from Box V: Citations and Explanations-***-

As for claim 17, Cavanaugh discloses a micro-optical receiver channel (a channel defined by the aperture masks 135 and 137 for the light to each superpixel of a detector 110; figure 2; column 4, lines 6-19, 52-58) comprising: an aperture surrounded by a stop region (aperture mask 135 is a tubular baffle; figure 2; column 4, lines 52-58); an optical lens adjacent the aperture (micro lens array 130 is between aperture mask 135 and aperture mask 137; figure 2; column 4, lines 6-19, 52-58); an optical filter adjacent the optical lens (color filter array 120 is adjacent the micro lens array 130; figure 2; column 4, lines 6-19); and a pixel adjacent the optical filter (color filter array 120 is as close as possible to detector array 110 (pixel array); figure 2; column 4, lines 6-19), wherein the aperture accepts an input cone of light containing a wide range of wavelengths (light is received into the lenses 130 in a limited cone shaped aperture due to the external aperture 150; figures 2 and 3; column 2, lines 43-63; column 4, line 59- column 5, line 9), and the optical filter filters out all but a narrow band of the wavelengths centered at an operating wavelength (the optical filter array 120 may be an array of narrow band filters to filter the light into a series of narrow band wavelengths 10 nm wide (narrow band of wavelengths centered at an operating wavelength); figures 2 and 3; column 2, lines 43-63; column 4, line 59- column 5, line 9), and wherein the pixel is configured to detect photons within the narrow band of wavelengths (the super pixel has each sub-pixel receive light from a specific narrow band filter in the color filter array 120 to detect only the specific array; figures 2 and 3; column 2, lines 43-63; column 4, line 59- column 5, line 9).

As for claim 20, Cavanaugh discloses the micro-optical receiver channel of claim 17, wherein the optical lens comprises a collimating lens (micro lens array 130 is placed at where the objective lens 140 forms an image of the object under observation; figure 2; column 4, lines 6-19; column 5, lines 22-33).

As for claim 21, Cavanaugh discloses the micro-optical receiver channel of claim 17, wherein the aperture is aligned with the lens (micro lens array 130 is an array of lenses to fill each specific super-pixel with the apertures restricting light to the shape of the super pixel; figure 2; column 4, lines 6-19, 52-58).

As for claim 22, Cavanaugh discloses the micro-optical receiver channel of claim 17, further comprising a second aperture between the optical lens and the optical filter (micro lens array 130 is between aperture mask 135 and aperture mask 137 with optical filter 120 on the other side of aperture mask 137 from micro lens array 130; figure 2; column 4, lines 6-19, 52-58).

As for claim 23, Cavanaugh discloses the micro-optical receiver channel of claim 17, wherein the optical filter comprises an optical bandpass filter (the color filter array is made of bandpass filters which may be narrow band; figures 2 and 3; column 3, lines 1-5; column 4, line 59- column 5, line 9).

As for claim 28, Cavanaugh discloses the micro-optical receiver channel of claim 17, wherein the pixel comprises a plurality of subpixels (each super pixel includes an array of subpixels such as a 4x4 array; figures 2 and 3; column 4, lines 6-19; 59-67).

As for claim 31, Cavanaugh discloses an image sensor (a hyperspectral imager; figure 2; column 4, lines 6-19) comprising: a plurality of micro-optical receiver channels (multiple channels defined by the aperture masks 135 and 137 for the light to reach each superpixel of a detector 110; figure 2; column 4, lines 6-19, 52-58), each micro optical receiver channel comprising: an aperture (aperture mask 135; figure 2; column 4, lines 52-58); an optical lens adjacent the aperture (micro lens array 130 is between aperture mask 135 and aperture mask 137; figure 2; column 4, lines 6-19, 52-58); an optical filter adjacent the optical lens (color filter array 120 is adjacent the micro lens array 130; figure 2; column 4, lines 6-19); and a pixel adjacent the optical filter (color filter array 120 is as close as possible to detector array 110 (pixel array); figure 2; column 4, lines 6-19).

As for claim 34, Cavanaugh discloses the micro-optical receiver channel of claim 31, wherein the optical lens comprises a collimating lens (micro lens array 130 is placed at where the objective lens 140 forms an image of the object under observation; figure 2; column 4, lines 6-19; column 5, lines 22-33).

As for claim 35, Cavanaugh discloses the micro-optical receiver channel of claim 31, wherein the aperture is aligned with the lens (micro lens array 130 is an array of lenses to fill each specific super-pixel with the apertures restricting light to the shape of the super pixel; figure 2; column 4, lines 6-19, 52-58).

As for claim 36, Cavanaugh discloses the micro-optical receiver channel of claim 31, further comprising a second aperture between the optical lens and the optical filter (micro lens array 130 is between aperture mask 135 and aperture mask 137 with optical filter 120 on the other side of aperture mask 137 from micro lens array 130; figure 2; column 4, lines 6-19, 52-58).

As for claim 37, Cavanaugh discloses the micro-optical receiver channel of claim 31, wherein the optical filter comprises an optical bandpass filter (the color filter array is made of bandpass filters which may be narrow band; figures 2 and 3; column 3, lines 1-5; column 4, line 59- column 5, line 9).

As for claim 42, Cavanaugh discloses the micro-optical receiver channel of claim 31, wherein the pixel comprises a plurality of subpixels (each super pixel includes an array of subpixels such as a 4x4 array; figures 2 and 3; column 4, lines 6-19; 59-67).

-***-Continued Within the Next Supplemental Box-***-

Supplemental Box

In case the space in any of the preceding boxes is not sufficient.
Continuation of:

-***-Continued from Previous Supplemental Box-***-

As for claim 45, Cavanaugh discloses a method comprising: providing a micro-optical receiver channel (a channel defined by the aperture masks 135 and 137 for the light to each superpixel of a detector 110; figure 2; column 4, lines 6-19, 52-58) comprising: an aperture surrounded by a stop region (aperture mask 135 is a tubular baffle; figure 2; column 4, lines 52-58); an optical lens adjacent the aperture (micro lens array 130 is between aperture mask 135 and aperture mask 137; figure 2; column 4, lines 6-19, 52-58); an optical filter adjacent the optical lens (color filter array 120 is adjacent the micro lens array 130; figure 2; column 4, lines 6-19); and a pixel adjacent the optical filter (color filter array 120 is as close as possible to detector array 110 (pixel array); figure 2; column 4, lines 6-19), wherein the aperture accepts an input cone of light containing a wide range of wavelengths (light is received into the lenses 130 in a limited cone shaped aperture due to the external aperture 150; figures 2 and 3; column 2, lines 43-63; column 4, line 59- column 5, line 9), and the optical filter filters out all but a narrow band of the wavelengths centered at an operating wavelength (the optical filter array 120 may be an array of narrow band filters to filter the light into a series of narrow band wavelengths 10 nm wide (narrow band of wavelengths centered at an operating wavelength); figures 2 and 3; column 2, lines 43-63; column 4, line 59- column 5, line 9), and wherein the pixel is configured to detect photons within the narrow band of wavelengths (the super pixel has each sub-pixel receive light from a specific narrow band filter in the color filter array 120 to detect only the specific array; figures 2 and 3; column 2, lines 43-63; column 4, line 59- column 5, line 9).

As for claim 48, Cavanaugh discloses the method of claim 45, wherein the optical lens comprises a collimating lens (micro lens array 130 is placed at where the objective lens 140 forms an image of the object under observation; figure 2; column 4, lines 6-19; column 5, lines 22-33).

As for claim 49, Cavanaugh discloses the method of claim 45, wherein the aperture is aligned with the lens (micro lens array 130 is an array of lenses to fill each specific super-pixel with the apertures restricting light to the shape of the super pixel; figure 2; column 4, lines 6-19, 52-58).

As for claim 50, Cavanaugh discloses the method of claim 45, further comprising a second aperture between the optical lens and the optical filter (micro lens array 130 is between aperture mask 135 and aperture mask 137 with optical filter 120 on the other side of aperture mask 137 from micro lens array 130; figure 2; column 4, lines 6-19, 52-58).

As for claim 51, Cavanaugh discloses the method of claim 45, wherein the optical filter comprises an optical bandpass filter (the color filter array is made of bandpass filters which may be narrow band; figures 2 and 3; column 3, lines 1-5; column 4, line 59- column 5, line 9).

As for claim 56, Cavanaugh discloses the method of claim 45, wherein the pixel comprises a plurality of subpixels (each super pixel includes an array of subpixels such as a 4x4 array; figures 2 and 3; column 4, lines 6-19; 59-67).

As for claim 59, Cavanaugh discloses a method comprising: using a micro-optical receiver channel (a channel defined by the aperture masks 135 and 137 for the light to each superpixel of a detector 110; figure 2; column 4, lines 6-19, 52-58) comprising: an aperture surrounded by a stop region (aperture mask 135 is a tubular baffle; figure 2; column 4, lines 52-58); an optical lens adjacent the aperture (micro lens array 130 is between aperture mask 135 and aperture mask 137; figure 2; column 4, lines 6-19, 52-58); an optical filter adjacent the optical lens (color filter array 120 is adjacent the micro lens array 130; figure 2; column 4, lines 6-19); and a pixel adjacent the optical filter (color filter array 120 is as close as possible to detector array 110 (pixel array); figure 2; column 4, lines 6-19), wherein the aperture accepts an input cone of light containing a wide range of wavelengths (light is received into the lenses 130 in a limited cone shaped aperture due to the external aperture 150; figures 2 and 3; column 2, lines 43-63; column 4, line 59- column 5, line 9), and the optical filter filters out all but a narrow band of the wavelengths centered at an operating wavelength (the optical filter array 120 may be an array of narrow band filters to filter the light into a series of narrow band wavelengths 10 nm wide (narrow band of wavelengths centered at an operating wavelength); figures 2 and 3; column 2, lines 43-63; column 4, line 59- column 5, line 9), and wherein the pixel is configured to detect photons within the narrow band of wavelengths (the super pixel has each sub-pixel receive light from a specific narrow band filter in the color filter array 120 to detect only the specific array; figures 2 and 3; column 2, lines 43-63; column 4, line 59- column 5, line 9).

As for claim 62, Cavanaugh discloses the method of claim 59, wherein the optical lens comprises a collimating lens (micro lens array 130 is placed at where the objective lens 140 forms an image of the object under observation; figure 2; column 4, lines 6-19; column 5, lines 22-33).

As for claim 63, Cavanaugh discloses the method of claim 59, wherein the aperture is aligned with the lens (micro lens array 130 is an array of lenses to fill each specific super-pixel with the apertures restricting light to the shape of the super pixel; figure 2; column 4, lines 6-19, 52-58).

As for claim 64, Cavanaugh discloses the method of claim 59, further comprising a second aperture between the optical lens and the optical filter (micro lens array 130 is between aperture mask 135 and aperture mask 137 with optical filter 120 on the other side of aperture mask 137 from micro lens array 130; figure 2; column 4, lines 6-19, 52-58).

As for claim 65, Cavanaugh discloses the method of claim 59, wherein the optical filter comprises an optical bandpass filter (the color filter array is made of bandpass filters which may be narrow band; figures 2 and 3; column 3, lines 1-5; column 4, line 59- column 5, line 9).

As for claim 70, Cavanaugh discloses the method of claim 59, wherein the pixel comprises a plurality of subpixels (each super pixel includes an array of subpixels such as a 4x4 array; figures 2 and 3; column 4, lines 6-19; 59-67).

-***-Continued Within the Next Supplemental Box-***-

Supplemental Box

In case the space in any of the preceding boxes is not sufficient.
Continuation of:

-***-Continued from Previous Supplemental Box-***-

As for claim 73, Cavanaugh discloses an optical channel for receiving photons and detecting the photons (a channel defined by the apertures for the light to each superpixel of a detector 110; figure 1; column 4, lines 6-19) comprising: a bulk imaging optic (objective lens 140; figure 1; column 4, lines 6-19); an aperture layer located at an imaging plane of the bulk optic (aperture 152 is the exit pupil of the optical system with objective lens 140; figures 1 and 3; column 4, lines 28-43); a collimating lens layer behind the aperture layer and separated therefrom by a focal length of the collimating lens layer (to help collimate the light, the micro lens array 130 is placed at where the objective lens 140 forms an image of the object under observation so each MLA lens forms an image of the exit pupil of aperture 152, thus the aperture is separated by focal length from the MLA; figure 2; column 4, lines 28-51; column 5, lines 22-33); an optical filter behind the collimating lens layer (color filter array 120 is adjacent the micro lens array 130; figure 1; column 4, lines 6-19); and a pixel offset from the optical filter opposite the collimating lens layer (detector array 110 comprising super-pixels and is behind filter array 120 and the micro lens array 130; figure 1; column 4, lines 6-19), and responsive to photons incident on the pixel (the super pixels form a detector array to create a hyperspectral imager; figures 1 and 3; column 4, lines 6-19 and 59-67).

As for claim 77, Cavanaugh discloses the optical channel of claim 73, wherein the bulk imaging optic is image space telecentric (objective lens 140 is preferably a telecentric lens, and ; figure 1; column 4, lines 6-27).

As for claim 78, Cavanaugh discloses set of optical channels of claim 73 having the set of pixels of the set of optical channels being arranged on a single image sensor (the imager forms a series of channels for each superpixel, to receive an image from the superpixel, which may be part of a single detector array, such as a CMOS sensor; figures 1 and 3; column 4, lines 6-19 and 28-43; column 5, lines 1-8).

As for claim 80, Cavanaugh the discloses set of optical channels of claim 78 further comprising a bulk imaging optic having apertures at a focal plane projected into a field defining fields of view for each optical channel (lens 140 has the apertures 150 and 152 acting as entrance and exit pupils for the light to reach each superpixel of a detector 110, with the apertures forming the field of view for the superpixels; figure 1; column 4, lines 6-19 and 28-43).

Claims 4, 5, 18, 19, 32, 33, 47, 60, and 61 lack an inventive step under PCT Article 33(3) as being obvious over Cavanaugh in view of US 6,721,262 B1 to Jordache, N. et al. (hereinafter 'Jordache').

As for claim 4, Cavanaugh discloses the micro-optical receiver channel of claim 3, but Cavanaugh fails to disclose wherein the stop material comprises a reflective material. However, Jordache discloses wherein the stop material comprises a reflective material (aperture stop 158 is created from chromium and may be either absorb or reflect light, with the thickness of the chromium layer 170 determining whether the stop absorbs or reflects; figures 5-6(4); column 3, line 39- column 4, line 3). It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the micro-optical receiver channel of Cavanaugh to provide wherein the stop material comprises a reflective material, as taught by Jordache, in order to provide an additional reflection which internal optics may capture scattered light in order to improve the signal.

As for claim 5, Cavanaugh discloses the micro-optical receiver channel of claim 3, but Cavanaugh fails to disclose wherein the stop material comprises a light absorbing material. However, Jordache discloses wherein the stop material comprises a light absorbing material (aperture stop 158 is created from chromium and may be either absorb or reflect light, with the thickness of the chromium layer 170 determining whether the stop absorbs or reflects; figures 5-6(4); column 3, line 39- column 4, line 3). It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the micro-optical receiver channel of Cavanaugh to provide wherein the stop material comprises a light absorbing material, as taught by Jordache, in order to minimize internal reflections from the aperture stop and prevent cross-talk between channels.

As for claim 18, Cavanaugh discloses the micro-optical receiver channel of claim 17, but Cavanaugh fails to disclose wherein the stop region comprises a reflective material. However, Jordache discloses wherein the stop material comprises a reflective material (aperture stop 158 is created from chromium and may be either absorb or reflect light, with the thickness of the chromium layer 170 determining whether the stop absorbs or reflects; figures 5-6(4); column 3, line 39- column 4, line 3). It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the micro-optical receiver channel of Cavanaugh to provide wherein the stop material comprises a reflective material, as taught by Jordache, in order to provide an additional reflection which internal optics may capture scattered light in order to improve the signal.

As for claim 19, Cavanaugh discloses the micro-optical receiver channel of claim 17, but Cavanaugh fails to disclose wherein the stop region comprises a light absorbing material. However, Jordache discloses wherein the stop material comprises a light absorbing material (aperture stop 158 is created from chromium and may be either absorb or reflect light, with the thickness of the chromium layer 170 determining whether the stop absorbs or reflects; figures 5-6(4); column 3, line 39- column 4, line 3). It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the micro-optical receiver channel of Cavanaugh to provide wherein the stop material comprises a light absorbing material, as taught by Jordache, in order to minimize internal reflections from the aperture stop and prevent cross-talk between channels.

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As for claim 32, Cavanaugh discloses the micro-optical receiver channel of claim 31, but Cavanaugh fails to disclose wherein a stop region for the aperture comprises a reflective material. However, Jordache discloses wherein a stop region for the aperture comprises a reflective material (aperture stop 158 is created from chromium and may be either absorb or reflect light, with the thickness of the chromium layer 170 determining whether the stop absorbs or reflects; figures 5-6(4); column 3, line 39- column 4, line 3). It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the micro-optical receiver channel of Cavanaugh to provide wherein a stop region for the aperture comprises a reflective material, as taught by Jordache, in order to provide an additional reflection which internal optics may capture scattered light in order to improve the signal.

As for claim 33, Cavanaugh discloses the micro-optical receiver channel of claim 31, but Cavanaugh fails to disclose wherein a stop region for the aperture comprises a light absorbing material. However, Jordache discloses wherein a stop region for the aperture comprises a light absorbing material (aperture stop 158 is created from chromium and may be either absorb or reflect light, with the thickness of the chromium layer 170 determining whether the stop absorbs or reflects; figures 5-6(4); column 3, line 39- column 4, line 3). It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the micro-optical receiver channel of Cavanaugh to provide wherein a stop region for the aperture comprises a light absorbing material, as taught by Jordache, in order to minimize internal reflections from the aperture stop and prevent cross-talk between channels.

As for claim 46, Cavanaugh discloses the method of claim 45, but Cavanaugh fails to disclose wherein the stop region comprises a reflective material. However, Jordache discloses wherein the stop material comprises a reflective material (aperture stop 158 is created from chromium and may be either absorb or reflect light, with the thickness of the chromium layer 170 determining whether the stop absorbs or reflects; figures 5-6(4); column 3, line 39- column 4, line 3). It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the micro-optical receiver channel of Cavanaugh to provide wherein the stop material comprises a reflective material, as taught by Jordache, in order to provide an additional reflection which internal optics may capture scattered light in order to improve the signal.

As for claim 47, Cavanaugh discloses the method of claim 45, but Cavanaugh fails to disclose wherein the stop region comprises a light absorbing material. However, Jordache discloses wherein the stop material comprises a light absorbing material (aperture stop 158 is created from chromium and may be either absorb or reflect light, with the thickness of the chromium layer 170 determining whether the stop absorbs or reflects; figures 5-6(4); column 3, line 39- column 4, line 3). It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the micro-optical receiver channel of Cavanaugh to provide wherein the stop material comprises a light absorbing material, as taught by Jordache, in order to minimize internal reflections from the aperture stop and prevent cross-talk between channels.

As for claim 60, Cavanaugh discloses the method of claim 59, but Cavanaugh fails to disclose wherein the stop region comprises a reflective material. However, Jordache discloses wherein the stop material comprises a reflective material (aperture stop 158 is created from chromium and may be either absorb or reflect light, with the thickness of the chromium layer 170 determining whether the stop absorbs or reflects; figures 5-6(4); column 3, line 39- column 4, line 3). It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the micro-optical receiver channel of Cavanaugh to provide wherein the stop material comprises a reflective material, as taught by Jordache, in order to provide an additional reflection which internal optics may capture scattered light in order to improve the signal.

As for claim 61, Cavanaugh discloses the method of claim 59, but Cavanaugh fails to disclose wherein the stop region comprises a light absorbing material. However, Jordache discloses wherein the stop material comprises a light absorbing material (aperture stop 158 is created from chromium and may be either absorb or reflect light, with the thickness of the chromium layer 170 determining whether the stop absorbs or reflects; figures 5-6(4); column 3, line 39- column 4, line 3). It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the micro-optical receiver channel of Cavanaugh to provide wherein the stop material comprises a light absorbing material, as taught by Jordache, in order to minimize internal reflections from the aperture stop and prevent cross-talk between channels.

Claims 10 13, 24 27, 38 41, 52 55, 66 69, 76, 76 lack an inventive step under PCT Article 33(3) as being obvious over Cavanaugh in view of US 2016/0150963 A1 to Roukes, M. et al. (hereinafter 'Roukes').

As for claim 10, Cavanaugh discloses the micro-optical receiver channel of claim 1, but Cavanaugh fails to disclose wherein the pixel layer comprises at least one single-photon avalanche diode detector. However, Roukes discloses wherein the pixel layer comprises at least one single-photon avalanche diode detector (an array of optical detectors comprises an array of Single-Photo Avalanche Diode Detectors; figure 13; paragraphs [0027, 0030, 0070]) .It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the micro-optical receiver channel of Cavanaugh to provide wherein the pixel layer comprises at least one single-photon avalanche diode detector, as taught by Roukes, in order to provide the ability to detect very low level signals for spectrographic purposes.

As for claim 11, Cavanaugh discloses the micro-optical receiver channel of claim 1, but Cavanaugh fails to disclose wherein the pixel layer comprises a plurality of single-photon avalanche diode detectors. However, Roukes discloses wherein the pixel layer comprises a plurality of single-photon avalanche diode detectors (an array of optical detectors comprises an array of Single-Photo Avalanche Diode Detectors; figure 13; paragraphs [0027, 0030, 0070]) .It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the micro-optical receiver channel of Cavanaugh to provide wherein the pixel layer comprises a plurality of single-photon avalanche diode detectors, as taught by Roukes, in order to provide the ability to detect very low level signals for spectrographic purposes.

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As for claim 12, Cavanaugh discloses the micro-optical receiver channel of claim 1, but Cavanaugh fails to disclose wherein the pixel layer comprises at least one resonant cavity photodiode. However, Roukes discloses wherein the pixel layer comprises at least one resonant cavity photodiode (an array of optical detectors comprises an array of Single-Photo Avalanche Diode Detectors using resonant cavities; figure 13; paragraphs [0027, 0030, 0032, 0070]) .It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the micro-optical receiver channel of Cavanaugh to provide wherein the pixel layer comprises at least one resonant cavity photodiode, as taught by Roukes, in order to provide the ability to detect very low level signals for spectrographic purposes.

As for claim 13, Cavanaugh discloses the micro-optical receiver channel of claim 1, but Cavanaugh fails to disclose wherein the pixel layer comprises a plurality of resonant cavity photodiodes. However, Roukes discloses wherein the pixel layer comprises a plurality of resonant cavity photodiodes (an array of optical detectors comprises an array of Single-Photo Avalanche Diode Detectors using resonant cavities; figure 13; paragraphs [0027, 0030, 0032, 0070]). It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the micro-optical receiver channel of Cavanaugh to provide wherein the pixel layer comprises a plurality of resonant cavity photodiodes, as taught by Roukes, in order to provide the ability to detect very low level signals for spectrographic purposes.

As for claim 24, Cavanaugh discloses the micro-optical receiver channel of claim 17, but Cavanaugh fails to disclose wherein the pixel comprises at least one single-photon avalanche diode detector. However, Roukes discloses wherein the pixel comprises at least one single-photon avalanche diode detector (an array of optical detectors comprises an array of Single-Photo Avalanche Diode Detectors; figure 13; paragraphs [0027, 0030, 0070]) .It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the micro-optical receiver channel of Cavanaugh to provide wherein the pixel comprises at least one single-photon avalanche diode detector, as taught by Roukes, in order to provide the ability to detect very low level signals for spectrographic purposes.

As for claim 25, Cavanaugh discloses the micro-optical receiver channel of claim 17, but Cavanaugh fails to disclose wherein the pixel comprises a plurality of single-photon avalanche diode detectors. However, Roukes discloses wherein the pixel comprises a plurality of single-photon avalanche diode detectors (an array of optical detectors comprises an array of Single-Photo Avalanche Diode Detectors; figure 13; paragraphs [0027, 0030, 0070]) .It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the micro-optical receiver channel of Cavanaugh to provide wherein the pixel comprises a plurality of single-photon avalanche diode detectors, as taught by Roukes, in order to provide the ability to detect very low level signals for spectrographic purposes.

As for claim 26, Cavanaugh discloses the micro-optical receiver channel of claim 17, but Cavanaugh fails to disclose wherein the pixel comprises at least one resonant cavity photodiode. However, Roukes discloses wherein the pixel comprises at least one resonant cavity photodiode (an array of optical detectors comprises an array of Single-Photo Avalanche Diode Detectors using resonant cavities; figure 13; paragraphs [0027, 0030, 0032, 0070]) .It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the micro-optical receiver channel of Cavanaugh to provide wherein the pixel comprises at least one resonant cavity photodiode, as taught by Roukes, in order to provide the ability to detect very low level signals for spectrographic purposes.

As for claim 27, Cavanaugh discloses the micro-optical receiver channel of claim 17, but Cavanaugh fails to disclose wherein the pixel comprises a plurality of resonant cavity photodiodes. However, Roukes discloses wherein the pixel comprises a plurality of resonant cavity photodiodes (an array of optical detectors comprises an array of Single-Photo Avalanche Diode Detectors using resonant cavities; figure 13; paragraphs [0027, 0030, 0032, 0070]). It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the micro-optical receiver channel of Cavanaugh to provide wherein the pixel comprises a plurality of resonant cavity photodiodes, as taught by Roukes, in order to provide the ability to detect very low level signals for spectrographic purposes.

As for claim 38, Cavanaugh discloses the micro-optical receiver channel of claim 31, but Cavanaugh fails to disclose wherein the pixel comprises at least one single-photon avalanche diode detector. However, Roukes discloses wherein the pixel comprises at least one single-photon avalanche diode detector (an array of optical detectors comprises an array of Single-Photo Avalanche Diode Detectors; figure 13; paragraphs [0027, 0030, 0070]) .It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the micro-optical receiver channel of Cavanaugh to provide wherein the pixel comprises at least one single-photon avalanche diode detector, as taught by Roukes, in order to provide the ability to detect very low level signals for spectrographic purposes.

As for claim 39, Cavanaugh discloses the micro-optical receiver channel of claim 31, but Cavanaugh fails to disclose wherein the pixel comprises a plurality of single-photon avalanche diode detectors. However, Roukes discloses wherein the pixel comprises a plurality of single-photon avalanche diode detectors (an array of optical detectors comprises an array of Single-Photo Avalanche Diode Detectors; figure 13; paragraphs [0027, 0030, 0070]) .It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the micro-optical receiver channel of Cavanaugh to provide wherein the pixel comprises a plurality of single-photon avalanche diode detectors, as taught by Roukes, in order to provide the ability to detect very low level signals for spectrographic purposes.

As for claim 40, Cavanaugh discloses the micro-optical receiver channel of claim 31, but Cavanaugh fails to disclose wherein the pixel comprises at least one resonant cavity photodiode. However, Roukes discloses wherein the pixel comprises at least one resonant cavity photodiode (an array of optical detectors comprises an array of Single-Photo Avalanche Diode Detectors using resonant cavities; figure 13; paragraphs [0027, 0030, 0032, 0070]) .It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the micro-optical receiver channel of Cavanaugh to provide wherein the pixel comprises at least one resonant cavity photodiode, as taught by Roukes, in order to provide the ability to detect very low level signals for spectrographic purposes.

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As for claim 41, Cavanaugh discloses the micro-optical receiver channel of claim 31, but Cavanaugh fails to disclose wherein the pixel comprises a plurality of resonant cavity photodiodes. However, Roukes discloses wherein the pixel comprises a plurality of resonant cavity photodiodes (an array of optical detectors comprises an array of Single-Photo Avalanche Diode Detectors using resonant cavities; figure 13; paragraphs [0027, 0030, 0032, 0070]). It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the micro-optical receiver channel of Cavanaugh to provide wherein the pixel comprises a plurality of resonant cavity photodiodes, as taught by Roukes, in order to provide the ability to detect very low level signals for spectrographic purposes.

As for claim 52, Cavanaugh discloses the method of claim 45, but Cavanaugh fails to disclose wherein the pixel comprises at least one single-photon avalanche diode detector. However, Roukes discloses wherein the pixel comprises at least one single-photon avalanche diode detector (an array of optical detectors comprises an array of Single-Photo Avalanche Diode Detectors; figure 13; paragraphs [0027, 0030, 0070]). It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the method of Cavanaugh the pixel comprises at least one single-photon avalanche diode detector, as taught by Roukes, in order to provide the ability to detect very low level signals for spectrographic purposes.

As for claim 53, Cavanaugh discloses the method of claim 45, but Cavanaugh fails to disclose wherein the pixel comprises a plurality of single-photon avalanche diode detectors. However, Roukes discloses wherein the pixel comprises a plurality of single-photon avalanche diode detectors (an array of optical detectors comprises an array of Single-Photo Avalanche Diode Detectors; figure 13; paragraphs [0027, 0030, 0070]). It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the method of Cavanaugh the pixel comprises a plurality of single-photon avalanche diode detectors, as taught by Roukes, in order to provide the ability to detect very low level signals for spectrographic purposes.

As for claim 54, Cavanaugh discloses the method of claim 45, but Cavanaugh fails to disclose wherein the pixel comprises at least one resonant cavity photodiode. However, Roukes discloses wherein the pixel comprises at least one resonant cavity photodiode (an array of optical detectors comprises an array of Single-Photo Avalanche Diode Detectors using resonant cavities; figure 13; paragraphs [0027, 0030, 0032, 0070]). It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the method of Cavanaugh to provide wherein the pixel comprises at least one resonant cavity photodiode, as taught by Roukes, in order to provide the ability to detect very low level signals for spectrographic purposes.

As for claim 55, Cavanaugh discloses the method of claim 45, but Cavanaugh fails to disclose wherein the pixel comprises a plurality of resonant cavity photodiodes. However, Roukes discloses wherein the pixel comprises a plurality of resonant cavity photodiodes (an array of optical detectors comprises an array of Single-Photo Avalanche Diode Detectors using resonant cavities; figure 13; paragraphs [0027, 0030, 0032, 0070]). It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the method of Cavanaugh to provide wherein the pixel comprises a plurality of resonant cavity photodiodes, as taught by Roukes, in order to provide the ability to detect very low level signals for spectrographic purposes.

As for claim 66, Cavanaugh discloses the method of claim 59, but Cavanaugh fails to disclose wherein the pixel comprises at least one single-photon avalanche diode detector. However, Roukes discloses wherein the pixel comprises at least one single-photon avalanche diode detector (an array of optical detectors comprises an array of Single-Photo Avalanche Diode Detectors; figure 13; paragraphs [0027, 0030, 0070]). It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the method of Cavanaugh to provide wherein the pixel comprises at least one single-photon avalanche diode detector, as taught by Roukes, in order to provide the ability to detect very low level signals for spectrographic purposes.

As for claim 67, Cavanaugh discloses the method of claim 59, but Cavanaugh fails to disclose wherein the pixel comprises a plurality of single-photon avalanche diode detectors. However, Roukes discloses wherein the pixel layer comprises a plurality of single-photon avalanche diode detectors (an array of optical detectors comprises an array of Single-Photo Avalanche Diode Detectors; figure 13; paragraphs [0027, 0030, 0070]). It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the method of Cavanaugh to provide wherein the pixel comprises a plurality of single-photon avalanche diode detectors, as taught by Roukes, in order to provide the ability to detect very low level signals for spectrographic purposes.

As for claim 68, Cavanaugh discloses the method of claim 59, but Cavanaugh fails to disclose wherein the pixel comprises at least one resonant cavity photodiode. However, Roukes discloses wherein the pixel comprises at least one resonant cavity photodiode (an array of optical detectors comprises an array of Single-Photo Avalanche Diode Detectors using resonant cavities; figure 13; paragraphs [0027, 0030, 0032, 0070]). It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the method of Cavanaugh to provide wherein the pixel comprises at least one resonant cavity photodiode, as taught by Roukes, in order to provide the ability to detect very low level signals for spectrographic purposes.

As for claim 69, Cavanaugh discloses the method of claim 59, but Cavanaugh fails to disclose wherein the pixel comprises a plurality of resonant cavity photodiodes However, Roukes discloses wherein the pixel comprises a plurality of resonant cavity photodiodes (an array of optical detectors comprises an array of Single-Photo Avalanche Diode Detectors using resonant cavities; figure 13; paragraphs [0027, 0030, 0032, 0070]). It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the method of Cavanaugh to provide wherein the pixel comprises a plurality of resonant cavity photodiodes, as taught by Roukes, in order to provide the ability to detect very low level signals for spectrographic purposes.

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As for claim 75, Cavanaugh discloses the optical channel of claim 73 but Cavanaugh fails to disclose wherein the pixel comprises at least one single-photon avalanche diode detector. However, Roukes discloses wherein the pixel comprises at least one single-photon avalanche diode detector (an array of optical detectors comprises an array of Single-Photo Avalanche Diode Detectors using resonant cavities; figure 13; paragraphs [0027, 0030, 0032, 0070]). It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the optical channel of Cavanaugh to provide wherein the pixel comprises at least one single-photon avalanche diode detector, as taught by Roukes, in order to provide the ability to detect very low level signals for spectrographic purposes.

As for claim 76, Cavanaugh discloses the optical channel of claim 73 but Cavanaugh fails to disclose wherein the pixel comprises at least one resonant cavity photodiodes. However, Roukes discloses wherein the pixel comprises at least one resonant cavity photodiodes (an array of optical detectors comprises an array of Single-Photo Avalanche Diode Detectors using resonant cavities; figure 13; paragraphs [0027, 0030, 0032, 0070]). It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the optical channel of Cavanaugh to provide wherein the pixel comprises at least one resonant cavity photodiodes, as taught by Roukes, in order to provide the ability to detect very low level signals for spectrographic purposes.

Claims 15, 16, 29, 30, 43, 44, 57, 58, 71, 72, 74 lack an inventive step under PCT Article 33(3) as being obvious over Cavanaugh in view of US 2015/0292948 A1 to Verifood, LTD. (hereinafter 'Verifood').

As for claim 15, Cavanaugh discloses the micro-optical receiver channel of claim 1, but Cavanaugh fails to disclose further comprising a diffuser between the optical filter layer and the pixel layer. However, Verifood discloses a diffuser between the optical filter layer and the pixel layer (a stopper mounting 178 comprises a diffusive material and is between the filter array 170 and detector 190 made of a plurality of pixels; figure 5; paragraphs [0160, 0163]). It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the micro-optical receiver channel of Cavanaugh to provide a diffuser between the optical filter layer and the pixel layer, as taught by Verifood, in order to provide the advantage of a removing any specular component and providing uniform light across a subpixel.

As for claim 16, Cavanaugh, in view of Verifood, discloses the micro-optical receiver channel of claim 15, but Cavanaugh fails to disclose further comprising a third aperture layer between the optical filter layer and the diffuser. However, Verifood discloses a third aperture layer between the optical filter layer and the diffuser (a stopper mounting 178 comprises a diffusive material and is between the filter array 170 and a aperture array 172; figure 5; paragraphs [0160, 0163]). It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the micro-optical receiver channel of Cavanaugh to provide a third aperture layer between the optical filter layer and the diffuser, as taught by Verifood, in order to provide the advantage of a removing any specular component and providing uniform light across a subpixel.

As for claim 29, Cavanaugh discloses the micro-optical receiver channel of claim 17, but Cavanaugh fails to disclose further comprising a diffuser between the optical filter and the pixel . However, Verifood discloses a diffuser between the optical filter and the pixel (a stopper mounting 178 comprises a diffusive material and is between the filter array 170 and detector 190 made of a plurality of pixels; figure 5; paragraphs [0160, 0163]). It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the micro-optical receiver channel of Cavanaugh to provide a diffuser between the optical filter and the pixel, as taught by Verifood, in order to provide the advantage of a removing any specular component and providing uniform light across a subpixel.

As for claim 30, Cavanaugh, in view of Verifood, discloses the micro-optical receiver channel of claim 29, but Cavanaugh fails to disclose further comprising a third aperture between the optical filter and the diffuser. However, Verifood discloses a third aperture between the optical filter and the diffuser (a stopper mounting 178 comprises a diffusive material and is between the filter array 170 and a aperture array 172; figure 5; paragraphs [0160, 0163]). It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the micro-optical receiver channel of Cavanaugh to provide a third aperture between the optical filter layer and the diffuser, as taught by Verifood, in order to provide the advantage of a removing any specular component and providing uniform light across a subpixel.

As for claim 43, Cavanaugh discloses the micro-optical receiver channel of claim 31, but Cavanaugh fails to disclose further comprising a diffuser between the optical filter and the pixel . However, Verifood discloses a diffuser between the optical filter and the pixel (a stopper mounting 178 comprises a diffusive material and is between the filter array 170 and detector 190 made of a plurality of pixels; figure 5; paragraphs [0160, 0163]). It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the micro-optical receiver channel of Cavanaugh to provide a diffuser between the optical filter and the pixel, as taught by Verifood, in order to provide the advantage of a removing any specular component and providing uniform light across a subpixel.

As for claim 44, Cavanaugh, in view of Verifood, discloses the micro-optical receiver channel of claim 43, but Cavanaugh fails to disclose further comprising a third aperture between the optical filter and the diffuser. However, Verifood discloses a third aperture between the optical filter and the diffuser (a stopper mounting 178 comprises a diffusive material and is between the filter array 170 and a aperture array 172; figure 5; paragraphs [0160, 0163]). It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the micro-optical receiver channel of Cavanaugh to provide a third aperture between the optical filter layer and the diffuser, as taught by Verifood, in order to provide the advantage of a removing any specular component and providing uniform light across a subpixel.

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As for claim 57, Cavanaugh discloses the method of claim 45, but Cavanaugh fails to disclose further comprising a diffuser between the optical filter and the pixel . However, Verifood discloses a diffuser between the optical filter and the pixel (a stopper mounting 178 comprises a diffusive material and is between the filter array 170 and detector 190 made of a plurality of pixels; figure 5; paragraphs [0160, 0163]). It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the method of Cavanaugh to provide a diffuser between the optical filter and the pixel, as taught by Verifood, in order to provide the advantage of a removing any specular component and providing uniform light across a subpixel.

As for claim 58, Cavanaugh, in view of Verifood, discloses the method of claim 57, but Cavanaugh fails to disclose further comprising a third aperture between the optical filter and the diffuser. However, Verifood discloses a third aperture between the optical filter and the diffuser (a stopper mounting 178 comprises a diffusive material and is between the filter array 170 and a aperture array 172; figure 5; paragraphs [0160, 0163]). It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the method of Cavanaugh to provide a third aperture between the optical filter layer and the diffuser, as taught by Verifood, in order to provide the advantage of a removing any specular component and providing uniform light across a subpixel.

As for claim 71, Cavanaugh discloses the method of claim 59, but Cavanaugh fails to disclose further comprising a diffuser between the optical filter and the pixel . However, Verifood discloses a diffuser between the optical filter and the pixel (a stopper mounting 178 comprises a diffusive material and is between the filter array 170 and detector 190 made of a plurality of pixels; figure 5; paragraphs [0160, 0163]). It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the method of Cavanaugh to provide a diffuser between the optical filter and the pixel, as taught by Verifood, in order to provide the advantage of a removing any specular component and providing uniform light across a subpixel.

As for claim 72, Cavanaugh, in view of Verifood, discloses the method of claim 71, but Cavanaugh fails to disclose further comprising a third aperture between the optical filter and the diffuser. However, Verifood discloses a third aperture between the optical filter and the diffuser (a stopper mounting 178 comprises a diffusive material and is between the filter array 170 and a aperture array 172; figure 5; paragraphs [0160, 0163]). It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the method of Cavanaugh to provide a third aperture between the optical filter layer and the diffuser, as taught by Verifood, in order to provide the advantage of a removing any specular component and providing uniform light across a subpixel.

As for claim 74, Cavanaugh discloses the optical channel of claim 73, and Cavanaugh futher discloses whereby the pixel can detect incident photons across its full width and height to increase the dynamic range of the system (the super pixel receives a full image of the imaged object across the super pixel (across its full width and height) to create a larger color range with 16 wavelengths possible per super pixel; figures 1 and 3; column 4, lines 6-19, 27-51; column 4 line 59-column 5, line 8). But Cavanaugh fails to disclose further comprising a diffuser that spreads light rays passed from the aperture layer through the optical filter across an area of a corresponding pixel, However, Verifood discloses a diffuser that spreads light rays passed from the aperture layer through the optical filter across an area of a corresponding pixel (a stopper mounting 178 comprises a diffusive material and is between the filter array 170 and detector 190 made of a plurality of pixels; figure 5; paragraphs [0160, 0163]). It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the optical channel of Cavanaugh to provide a diffuser that spreads light rays passed from the aperture layer through the optical filter across an area of a corresponding pixel, as taught by Verifood, in order to provide the advantage of a removing any specular component and providing uniform light across a subpixel.

Claims 79, 81-84 lack an inventive step under PCT Article 33(3) as being obvious over Cavanaugh in view of WO 2016/125165 A2 to Vertifood, LTD. (hereinafter 'Vertifood 2').

As for claim 79, Cavanaugh discloses the set of optical channels of claim 78 but Cavanaugh fails to disclose wherein multiple sets of optical channels are fabricated on the same wafer and diced to yield multiple sets of optical channels. However Vertifood 2 discloses multiple sets of optical channels are fabricated on the same wafer and diced to yield multiple sets of optical channels (lens and filters may be assembled on the same substrate and then cut into multiple individual assemblies; figure 20; paragraphs [0218]). It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the optical channels of Cavanaugh to provide multiple sets of optical channels are fabricated on the same wafer and diced to yield multiple sets of optical channels, as taught by Verifood 2, in order to provide the advantage of being able to assemble the resulting device using wafer level packaging techniques, allowing for cheaper and easier mass production of the optical channels, as well as a compact shape suitable for portable use such as a within a phone for mobile applications.

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As for claim 81, Cavanaugh discloses the set of optical channels with the bulk imaging optic of claim 80 but Cavanaugh fails to disclose further comprising a bulk transmitter optic having a set of optical emitters at a focal plane projecting light into a field defining transmitter fields of view that are overlapping with the fields of view defined by the set of optical channels, and operating at a same wavelength as the set of optical channels and a controller to form an active illumination optical sensor. However Verifood 2 discloses a bulk transmitter optic having a set of optical emitters at a focal plane projecting light into a field defining transmitter fields of view that are overlapping with the fields of view defined by the set of optical channels (the illumination module 140 may comprise an array of LEDs 210 (set of optical emitters) while the spectrometer module 160 comprises multiple photodiodes 263 sharing lens 225 (bulk transmitter optic) able to detect the light from the LEDs 210 being reflected off an object (overlapping field of view); figures 11-13; paragraphs [0170, 0172, 0181]), and operating at a same wavelength as the set of optical channels (the photodiodes 263 are responsive to the illumination from the LEDs across a broad set of wavelengths; figures 11 and 12; paragraphs [0173, 0184]) and a controller to form an active illumination optical sensor (control board 105 and processor 106 may control the LEDs and modulate the light to form a spectrometer (active illumination optical sensor); figure 11; paragraphs [0170, 0184-0186]). It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the optical channels of Cavanaugh to provide a bulk transmitter optic having a set of optical emitters at a focal plane projecting light into a field defining transmitter fields of view that are overlapping with the fields of view defined by the set of optical channels, as taught by Verifood 2, in order to provide the advantage of being able to control the light emitted to ensure sufficient illumination across a broad band of wavelengths to properly image targets, and because Vertifood 2 teaches a compact shape suitable for portable use such as a within a phone for mobile applications.

As for claim 82, Cavanaugh, in view of Verifood 2, discloses the active illumination optical sensor of claim 81 and Cavanaugh further discloses wherein the bulk imaging optic is image space telecentric (objective lens 140 is preferably a telecentric lens, and in various embodiments may be telecentric; figures 1 and 10; column 4, lines 6-27; column 7, lines 24-30).

As for claim 83, Cavanaugh, in view of Verifood 2, discloses the active illumination optical sensor of claim 81 but Cavanaugh fails to disclose wherein the set of optical emitters are arranged on a single semiconductor die. However, Verifood 2 discloses wherein the set of optical emitters are arranged on a single semiconductor die (light sources may be a flip chip mounted LED die which may be mounted in an array ; figure 12-13; paragraphs [0136, 0172, 0174]). It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the optical channels of Cavanaugh to provide wherein the set of optical emitters are arranged on a single semiconductor die, as taught by Verifood 2, in order to provide the advantage of being able to assemble the resulting device using wafer level packaging techniques, allowing for cheaper and easier mass production of the optical channels, as well as a compact shape suitable for portable use such as a within a phone for mobile applications.

As for claim 84, Cavanaugh, in view of Verifood 2, discloses the active illumination optical sensor of claim 81 but Cavanaugh fails to disclose wherein the set of optical emitters are lasers. However, Verifood 2 discloses wherein the set of optical emitters are lasers (either in combination or alternatively to the LEDs, the light sources 140 may comprise lasers; figure 12; paragraph [0172]). It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the optical channels of Cavanaugh to provide wherein the set of optical emitters are lasers, as taught by Verifood 2, in order to provide the advantage of being able to assemble the resulting device using wafer level packaging techniques, allowing for cheaper and easier mass production of the optical channels, as well as a compact shape suitable for portable use such as a within a phone for mobile applications.

Claims 81-82, and 84-86 lack an inventive step under PCT Article 33(3) as being obvious over Cavanaugh in view of US 2010/0008588 A1 to Feldkhun, D. et al. (hereinafter 'Feldkhun').

As for claim 81, Cavanaugh discloses the set of optical channels with the bulk imaging optic of claim 80 but Cavanaugh fails to disclose further comprising a bulk transmitter optic having a set of optical emitters at a focal plane projecting light into a field defining transmitter fields of view that are overlapping with the fields of view defined by the set of optical channels, and operating at a same wavelength as the set of optical channels and a controller to form an active illumination optical sensor. However Feldkhun discloses a bulk transmitter optic having a set of optical emitters at a focal plane projecting light into a field defining transmitter fields of view that are overlapping with the fields of view defined by the set of optical channels (system 100 (bulk transmitter optic) includes a pattern projector 101, comprising a set of radiation sources 107 (optical emitters), which illuminates a sample object 103 (projecting light into a field defining transmitter fields of view) which is images via multi-channel imaging system 102 with lenses 103 (overlapping with fields of view defined by a set of optical channels); figure 1; paragraphs [0038-0040]), and operating at a same wavelength as the set of optical channels (the projector 101 emits light that imaging system 102 comprising the channels is able to image; figure 1; paragraphs [0038-0040]) and a controller to form an active illumination optical sensor (a controller 115 may coordinate the emission and imaging of the light such as to detect depth in three dimensions ; figures 1 and 12; paragraphs [0031, 0038-0040, 0120]). It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the optical channel of Cavanaugh to provide a bulk transmitter optic having a set of optical emitters at a focal plane projecting light into a field defining transmitter fields of view that are overlapping with the fields of view defined by the set of optical channels, and operating at a same wavelength as the set of optical channels and a controller to form an active illumination optical sensor, as taught by Feldkhun, in order to provide the advantage of a reference pattern which may be measured to perform 3D depth measurements using off the shelf optics suitable for use in a phone, providing a further advantage of allowing both depth measurements and color discrimination for augmented reality applications.

As for claim 82, Cavanaugh, in view of Feldkhun, discloses the active illumination optical sensor of claim 81 and Cavanaugh further discloses wherein the bulk imaging optic is image space telecentric (objective lens 140 is preferably a telecentric lens, and in various embodiments may be telecentric; figures 1 and 10; column 4, lines 6-27; column 7, lines 24-30).

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Supplemental Box

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As for claim 84, Cavanaugh, in view of Feldkhun, discloses the active illumination optical sensor of claim 81 but Cavanaugh fails to disclose wherein the set of optical emitters are lasers. However Feldkhun discloses wherein the set of optical emitters are lasers (a pattern projector 101, comprising a set of radiation sources 107 may use laser diodes; figure 1; paragraphs [0039]). It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the optical channel of Cavanaugh to provide wherein the set of optical emitters are lasers, as taught by Feldkhun, in order to provide the advantage of a reference pattern which may be measured to perform 3D depth measurements using off the shelf optics suitable for use in a phone, providing a further advantage of allowing both depth measurements and color discrimination for augmented reality applications.

As for claim 85, Cavanaugh, in view of Feldkhun, discloses the active illumination optical sensor of claim 81 but Cavanaugh fails to disclose wherein the active illumination optical sensor is configured to measure the distance to an object in the scene for each transmit receiver pair. However Feldkhun discloses wherein the active illumination optical sensor is configured to measure the distance to an object in the scene for each transmit receiver pair (the system is able to estimate the location and distance by sequentially emitting patterns from the projector with each emitter and detector array working individually to record separate patterns (each pair) and then using that to measure the location (measure the distance to an object); figure 1; paragraphs [0038-0040]). It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the optical channel of Cavanaugh to provide wherein the active illumination optical sensor is configured to measure the distance to an object in the scene for each transmit receiver pair, as taught by Feldkhun, in order to provide the advantage of a reference pattern which may be measured to perform 3D depth measurements using off the shelf optics suitable for use in a phone, providing a further advantage of allowing both depth measurements and color discrimination for augmented reality applications.

As for claim 86, Cavanaugh, in view of Feldkhun, discloses the active illumination optical sensor of claim 85 but Cavanaugh fails to disclose wherein the active illumination optical sensor is a 3D depth sensor. However Feldkhun discloses wherein the active illumination optical sensor is a 3D depth sensor (the system 100 may be used to project and imaging of the light such as to detect depth in three dimensions; figures 1 and 12; paragraphs [0031, 0038-0040, 0120]). It would have been obvious to one of ordinary skill in the art at the time of the invention to modify the optical channel of Cavanaugh to provide wherein the active illumination optical sensor is a 3D depth sensor, as taught by Feldkhun, in order to provide the advantage of a reference pattern which may be measured to perform 3D depth measurements using off the shelf optics suitable for use in a phone, providing a further advantage of allowing both depth measurements and color discrimination for augmented reality applications.

Claims 1-86 have industrial applicability as defined by PCT Article 33(4) because the subject matter can be made or used in industry.

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Declarations under Rule 4.17:

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

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(54) **Title**: MONOLITHIC LED ARRAYS FOR UNIFORM AND HIGH-BRIGHTNESS LIGHT SOURCES

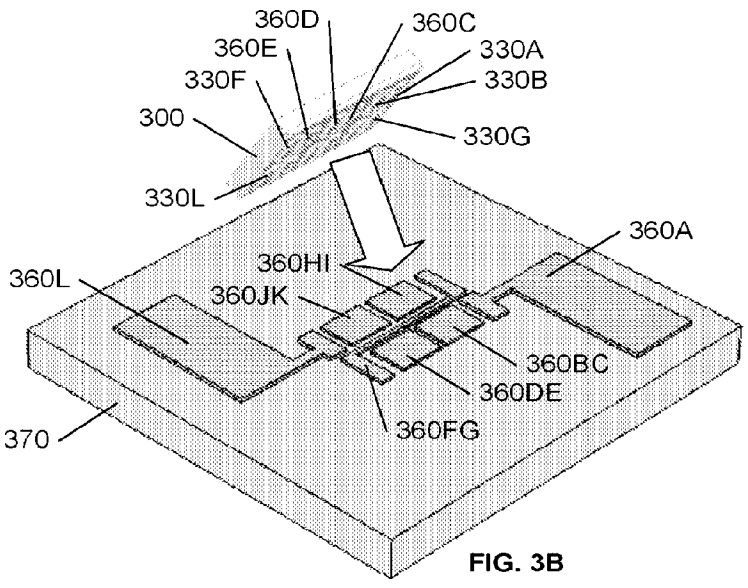


FIG. 3B

(57) **Abstract**: A wafer of light emitting elements is sliced/diced to create monolithic arrays of individual light emitting elements. To increase the light output intensity, more light emitting elements are included within the monolithic array. Accordingly, the light output intensity is determined by the number of light emitting elements that are included in the array. Because each light emitting element is the same, regardless of the number of elements in the array, the differently sized arrays need not be individually characterized. In like manner, because the light emitting elements in each array are fabricated on the same wafer, under the same environmental conditions, all of the light emitting elements in the array will exhibit common light output characteristics.

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MONOLITHIC LED ARRAYS FOR UNIFORM AND HIGH-BRIGHTNESS LIGHT SOURCES

FIELD OF THE INVENTION

This invention relates to the field of light emitting devices, and in particular to a light source comprising a monolithic array of light emitting elements.

BACKGROUND OF THE INVENTION

The ever expanding use of semiconductor light emitting devices has produced a highly competitive market for these devices. In this market, performance and price are often significant for providing product distinction among vendors.

Light emitting elements are typically grown on a wafer ('growth substrate') and include an active light emitting material sandwiched between an N-type semiconductor and a P-type semiconductor. Hundreds or thousands of light emitting elements may be grown simultaneously on the growth substrate, with 'lanes' or 'streets' separating each of the light emitting elements. The light emitting elements are singulated into individual light emitting 'chips' by slicing/dicing along these dividing streets and removing the growth substrate. One or more of these singulated chips may be mounted on a submount that provides structural support to the light emitting chips and provides a means for connecting the chip to an external source of power.

The light output intensity is dependent upon the current that flows through the light emitting element; however, the heat produced within the light emitting element is also dependent upon this current, and thus the maximum current, and therefore light output, is limited by the allowable junction temperature (typically 125°C). In addition, the LED efficacy drops with increased junction temperature and with increased current density due to the "droop" effect.

In order to address these issues one way is to increase the surface area of the LED. This allows to decrease the current density of the LED and improve its efficacy, and at the same time decrease its thermal resistance and lower the junction temperature. This comes at the expense of cost, reliability (larger size LEDs are usually more fragile) footprint, and source size (etendue). Larger LED source size impacts the secondary optics size which are usually needed in LED lamps. This in turn leads to additional cost increases and to larger lamp volume and weight. Additionally, to prevent, for example, localized bright regions and dim regions across larger surface areas, more sophisticated fabrication techniques may be required. Each different fabrication technique will generally require different layout techniques, perhaps different processing techniques, and so on. In addition to the design and testing overhead associated with each differently sized design, the more sophisticated processes required for larger surface area light emitting elements increase the per-unit-area fabrication costs. That is, convention fabrication techniques for light emitting elements are not directly 'scalable' for increasing light output intensity by increasing surface area, per se.

Another technique for improving the performance of a light emitting device is to increase the light output intensity from the device, often by packaging multiple light emitting chips within the device. A plurality of the aforementioned submounted chips may be placed on a larger mount, such as a printed circuit board, suitable for packaging as a single light emitting device. Wavelength conversion material, such as phosphor may be added, to either each individual chip on a submount, or to a plurality of the chips on the larger mount.

The larger mount may include circuit traces that serve to interconnect the chips on the submounts in a desired manner, often as a series connection of light emitting chips of the same color. The circuit traces may also include contact pads or other structures for providing external power to the light emitting device.

The light emitting device may also include an optical element, such as a collimating lens, that serves to provide a desired light output pattern. The optical element may include features that serve to direct the light from each submount chip in a desired orientation relative to the light from the other submounted chips.

Recent advances have allowed for eliminating the submount by providing self-supporting light emitting elements. As disclosed in copending U.S. patent application 61/568,297, "FORMING THICK METAL LAYERS ON A SEMICONDUCTOR LIGHT EMITTING DEVICE", filed 8 December 2011 for Alexander Nickel, Jim Lei, Anneli Munkholm, Grigoriy Basin, Sal Akram, and Stefano Schiaffino (Attorney Docket 2011P00972), and incorporated by reference herein, thick metal layers are added to each of the N-layer and P-layer contacts, separated by an insulating material. These metal layers provide the structural support to the light emitting element, and form contact pads for the light emitting element when used in a 'flip-chip' configuration.

Copending U.S. patent application 61/656,691, "CHIP SCALE LIGHT EMITTING DEVICE WITH METAL PILLARS IN A MOLDING COMPOUND FORMED AT WAFER LEVEL", filed 7 June 2012, for Jipu Lei, Stefano Schiaffino, Alexander Nickel, Mooi Guan Ng, Grigoriy Basin, and Sal Akram, (Attorney docket 2012PF00450) and incorporated by reference herein, discloses providing a multiple pillars upon the N-type and P-type contacts pads and embedding these pillars in a molding compound. The pillars provide the mechanical support and conductivity, while the molding compound prevents distortions in the pillar structure.

In like manner, techniques have been developed that allow the light emitting element to remain on the growth substrate, the growth substrate providing the structural support for the singulated light emitting elements. In such an embodiment, after singulation, the light emitting element emits light into the remaining (transparent) substrate, and the light is emitted from the opposite surface, or the sides, of the substrate. A Patterned Sapphire Substrate (PSS) may be used as the growth substrate, the pattern on the substrate serving to enhance light extraction into the substrate by reducing the likelihood of total internal reflection at the interface between the light emitting element and the sapphire substrate.

By providing a self-supporting light emitting chip, conventional 'pick and place' manufacturing techniques may be used to place these self-supporting chips directly upon the aforementioned larger mount, such as a printed circuit board.

A disadvantage of placing multiple light emitting elements within a light emitting device, however, is that different light emitting elements, and particularly light emitting elements from different fabrication wafers may exhibit different light output characteristics, and this variance may render some of the devices unsuitable for their intended purpose.

SUMMARY OF THE INVENTION

It would be advantageous to provide a technique for increasing light output intensity that is easily scalable. It would also be advantageous to provide a scalable increase in light output intensity that does not necessarily impose a need to re-characterize differently scaled light emitting elements. It would also be advantageous to provide a scalable increase in light output intensity that provides a uniformity in light output characteristics.

To better address one or more of these concerns, in an embodiment of this invention, a wafer of light emitting elements is sliced/diced to create monolithic arrays of individual light emitting elements, with minimal gaps between the light emitting elements. To increase the light output intensity, more light emitting elements are included within the monolithic array. Accordingly, the light output intensity is determined by the number of light emitting elements that are included in the array. Because each light emitting element is the same, regardless of the number of elements in the array, the differently sized arrays need not be individually characterized. In like manner, because the light emitting elements in each array are fabricated on the same wafer, under the same environmental conditions, all of the light emitting elements in the array will exhibit common light output characteristics.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is explained in further detail, and by way of example, with reference to the accompanying drawings wherein:

FIGs. 1A-1C illustrate an example fabrication and singulation of prior art light emitting elements.

FIGs. 2A-2B illustrate an example fabrication and singulation of an array of light emitting elements.

FIGs. 3A-3B illustrate an example mounting of an array of light emitting elements upon a printed circuit board mount.

FIG. 4 illustrates an example printed circuit board that provides a plurality of printed circuit board mounts.

FIGS. 5A-5C illustrate an example fabrication of a light emitting device with an array of light emitting elements on a printed circuit board mount.

Throughout the drawings, the same reference numerals indicate similar or corresponding features or functions. The drawings are included for illustrative purposes and are not intended to limit the scope of the invention.

DETAILED DESCRIPTION

In the following description, for purposes of explanation rather than limitation, specific details are set forth such as the particular architecture, interfaces, techniques, etc., in order to provide a thorough understanding of the concepts of the invention. However, it will be apparent to those skilled in the art that the present invention may be practiced in other embodiments, which depart from these specific details. In like manner, the text of this description is directed to the example embodiments as illustrated in the Figures, and is not intended to limit the claimed invention beyond the limits expressly included in the claims. For purposes of simplicity and clarity, detailed descriptions of well-known devices, circuits, and methods are omitted so as not to obscure the description of the present invention with unnecessary detail.

FIGs. 1A-1C illustrate an example fabrication and singulation of prior art light emitting devices 100, which is a portion of a wafer. FIG. 1A illustrates a side view of the wafer and FIG. 1B illustrates a top view of a wafer including a substrate 110 upon which many semiconductor light emitting elements 120 are formed. FIG. 1C illustrates an individual light emitting device 100 which includes a portion of substrate 110, a single light emitting element 120 and two contacts 130A, 130B. The substrate 110 may be a transparent material, such as sapphire, through which the light from the light emitting elements 120 is transmitted. The light emitting elements 120 typically includes multiple layers in including an active light emitting region sandwiched between an N-type and P-type semiconductors. Contact pads 130 (130A-130B in FIG. 1B) allow for coupling of external power to each of the N-type and P-type semiconductors.

Hundreds, or thousands, of light emitting elements 120 may be formed on the substrate 110. Upon completion of the fabrication of these elements 120 on the substrate 110, the substrate 110 is sliced/diced as illustrated by the cutting lines 150, to 'singulate' each light emitting device 100, as illustrated in FIG. 1C.

FIGs. 2A-2B illustrate an example fabrication and singulation of an array 200 of light emitting elements 120. In this example embodiment, the individual light emitting elements 120 may be formed on the substrate 110 using conventional fabrication techniques. To form an array 200 of light emitting elements 120, the substrate 110 is sliced/diced along cutting lines 250, leaving multiple light emitting elements 120 physically connected to each other.

The individual light emitting elements 120 are delineated in FIG. 2A by the dashed lines, although there may not be a visible delineation between these elements. For example, a layer of the light emitting elements 120 closest to the contact pads 230 may be a dielectric layer that extends into the unused regions ('streets') between the light emitting devices 200.

In this example embodiment, the cutting lines 250 result in four light emitting elements 120 within each array 200. Of particular note, each array 200 is monolithic, in that all of the elements 120 within each array 200 are produced concurrently using the same process and are integrally connected, physically. Electrically, however, each of these light emitting elements 120 is independent of the other light emitting elements, and operates as an individual light emitting element 120. Accordingly, each of the light emitting elements 120 can be expected to exhibit the same performance and reliability characteristics as the light emitting element 120 in the conventional light emitting device 100 of FIG. 1C.

Each array 200 of light emitting elements 120 includes the two contact pads for coupling to each of the N-type and P-type semiconductors of each light emitting element 120, illustrated as contacts 230A through 230H in FIG. 2A. That is, contact pads 230A-230B are coupled to one light emitting element 120; contact pads 230C-230D are coupled to another; and so on. The illumination of the array 200 may be controlled by providing a selective control of each light emitting element 120, or by providing a single source of power to all of the light emitting elements 120 in the array 200. For example, each of the light emitting elements 120 may subsequently be connected in series, allowing for a single pair of contacts for external control of the array 200 of light emitting elements 120.

In the example of FIGs. 2A-2B, all of the light emitting elements 120 are uniformly disposed on the substrate 110, and differently arranged arrays may be formed by slicing along the appropriate streets between the arrays. For example, a 4x2 array of light emitting elements may be provided by eliminating the cuts 250A, 250C. In this manner, the choice of the number and shape of light emitting elements 120 within a particular array can be made as a last step in the process, and the wafer that provides these uniformly disposed light emitting elements can be fabricated without regard to the eventually slicing to provide a particularly sized or shaped array.

One of skill in the art will recognize, however, that if the size and shape of the array is known a priori, the light emitting elements 120 may be laid out on the substrate 110 to optimize the production of the particular array. For example, the width of select streets between the light emitting elements 120 may be reduced if that street is not included in the pattern of cutting lines for the array. That is, in FIG. 2A, the streets identified by dotted lines can be narrower than the streets identified but cutting lines 250 if it is known a priori that the arrays will be 2x2 arrays (or multiples thereof), because the narrower streets do not need to accommodate the width of the kerf of the slicing process at cutting lines 250.

One of skill in the art will also recognize that custom layouts based on an a priori definition of the size and shape of the array may also allow for the use of predefined connections between the light emitting elements. For example, if the wafer of FIG. 2A, which includes many 2x2 arrays 200, is expected to have the light emitting elements 120 within the array 200 connected in a particular fashion (series, parallel, series-parallel, etc.), the layout of this a priori defined array configuration on the substrate 110 may include the appropriate interconnections among the light emitting elements to effect the intended connection pattern.

Alternatively, the interconnection of the light emitting elements within the array may be effected via the submount upon which the array is mounted.

FIGs. 3A-3B illustrate an example mounting of an array 300 of light emitting elements 120 upon a printed circuit board mount 370. In this example embodiment, the array 300 is a 3x2 array of light emitting elements 120, with six pair of contacts, 330A through 330L. As illustrated in FIG. 3B, the array 300 is 'flip-chip' mounted on the mount 370, such that the contacts 330A-330L are on the 'lower' surface of the array 300, and the substrate 110 through which light is emitted is the 'upper' surface of the array 300.

The printed circuit board mount 370 includes a pattern of circuit traces 360A-360L that are arranged to couple the six light emitting elements 120 in series with each other. A first trace 360A provides for an external coupling to contact 330A of a first light emitting element of the array 300. A second trace 360BC provides for an external coupling from contact 330B of the first light emitting element to contact 330C of a second light emitting element in the array 300, placing the second light emitting element in series with the first light emitting element. In like manner, 360DE provides coupling from contact 330D of the second light emitting element to contact 330E of a third light emitting element, and so on. Circuit trace 360L provides for an external coupling to contact 330L of the last light emitting

element. Providing power to circuit traces 360A and 360L will provide a current to each of the six light emitting elements 120 in the array 300 in series.

One of skill in the art will recognize that although a series connection is illustrated, the circuit traces 360 may be arranged to provide alternative interconnections between the contacts 330A-330L as desired.

The mount 370 may also include other components 390, such as ESD protection devices, temperature sensing devices, driving circuits, and the like. Although illustrated as a single component 390 (in FIG. 4) that is coupled in parallel with the series arrangement of the array 300 of light emitting elements 120, one of skill in the art will recognize that additional components may be included on each mount, with circuit traces to provide the desired circuit arrangement.

In like manner, one of skill in the art will recognize that the mount 370 is not limited to a printed circuit board, per se. The circuit traces 360, and optional components 390 may be situated within a lamp structure, on a flexible circuit substrate, and so on, as the situation warrants, each of which may be referred to as a 'mount' for the purposes of this disclosure and claims.

One of skill in the art will also recognize that although the circuit traces 360 that serve to couple the individual light emitting elements 120 are situated on a separate mount 370, the interconnecting circuitry may be applied as a final metal layer upon the light emitting elements 120, interconnecting the contact pads of one light emitting element 120 to another light emitting element 120 in the array 300. Because such interconnections may be provided as a final step in the fabrication process, the basic characteristics of the light emitting elements 120 are unchanged, and only the final mask layers need be customized to form each array 300 of interconnected light emitting elements 120.

In an example embodiment, the printed circuit mount 370 may be a larger printed circuit board that includes a plurality of sets of traces 360, as illustrated in FIG. 4. In this embodiment, a plurality of arrays 300 of light emitting elements 120 are mounted on the larger mount 370, using, for example, a pick and place process, then coupled/soldered to the traces 360 in a single process. In like manner, additional processing of multiple arrays 300 may be performed on the larger mount 370, such as the addition of wavelength conversion material or optical lenses to each array before the larger mount 370 is sliced/diced to provide singulated light emitting devices, each device comprising an array 300 of well matched light emitting elements 120.

FIGS. 5A-5C illustrate an example fabrication of a light emitting device with an array 500 of light emitting elements 120 on a printed circuit board mount 570. In this example embodiment, the array 500 is a 6x6 array of light emitting elements 120 on a substrate 110, as illustrated in FIG. 5A.

FIG. 5B illustrates a printed circuit mount 570 that provides traces 560A, 560Z for external coupling to the array 500, and a pattern of traces 560 that arrange the 6x6 array of light emitting elements 120 in series between these traces 560A, 560Z. The printed circuit mount 570 may include other traces for interconnecting other devices, such as one or more ESD protection devices, temperature sensing devices, driver circuits, and the like.

FIG. 5C illustrates a completed light emitting device that includes an array 500 of light emitting elements 120, a mount 570 with traces 560A, 560Z that provide for external coupling to the array 500, and a lens 550 that protects the array 500. The lens 550 may be shaped to provide a desired light output pattern, and a wavelength conversion material may be included within the lens 550.

A wavelength conversion material (not illustrated), such as one or more phosphors, may also be applied to the array of light emitting elements 120, before the application of the lens 550, or in lieu of this lens 550. The wavelength conversion material may include a wavelength conversion film that is laminated to the array of light emitting elements 120. In one embodiment, a thermally efficient transfer tape is used to laminate the wavelength conversion film to the array of light emitting elements 120 before the mounting of the array on the submount 510. Alternatively, the wavelength conversion material may be applied to the light emitting elements 120 as a silicone, or other coating that is subsequently cured, or as a material that is sprayed or printed upon the array 500 of the light emitting elements 120 before application of the lens 550. The application of this material may include the use of a "dam and fill" process, common in the art.

It is significant to note that each of the example arrays 200, 300, 500 use the same basic light emitting element 120. Accordingly, these arrays 200, 300, 500 can be assumed to have the same basic characteristics of this light emitting element 120, and further characterization tests are not required. However, even though these arrays may have the same basic characteristics, array 200 can be expected to provide four times the light output intensity as the single light emitting device 100 of FIG. 1C; array 300 can be expected to provide six times the light output intensity; and array 500 can be expected to provide thirty-six times the light output intensity.

Additionally, each of these arrays 200, 300, 500 were formed by selectively slicing/dicing the substrate 110 to form the arrays, and the additional design time for these different arrays is merely the layout time for forming the appropriate circuit traces on the circuit board mounts. Some additional design time may be required to provide sufficient heat dissipation, particularly for the larger arrays, but the basic design of the light emitting element 120 is unchanged, regardless of the size of the array.

Although the example embodiments of this disclosure include an array of light emitting elements 120 on a substrate 110, one of skill in the art will recognize that the substrate 110 may be removed from the light emitting element 120. If the light emitting element 120 is self-supporting without the substrate 110, the substrate 110 may be removed before singulating the arrays; otherwise, the substrate 110 may be removed after mounting the array on the circuit board mount.

While the invention has been illustrated and described in detail in the drawings and foregoing description, such illustration and description are to be considered illustrative or exemplary and not restrictive; the invention is not limited to the disclosed embodiments. Other variations to the disclosed embodiments can be understood and effected by those skilled in the art in practicing the claimed invention, from a study of the drawings, the disclosure, and the appended claims. In the claims, the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage. Any reference signs in the claims should not be construed as limiting the scope.

CLAIMS:

1. A light emitting device comprising:

a monolithic array of light emitting elements, each light emitting element being adjacent to at least one other light emitting element that is concurrently and integrally formed on a common substrate.

2. The device of claim 1, wherein each of the light emitting elements in the array is substantially identical to the other light emitting elements.

3. The device of claim 1, including a mount upon which the array is situated, the mount providing circuit traces that facilitate coupling the array to an external power source.

4. The device of claim 3, wherein the mount includes other circuit traces that electrically couple the light emitting elements in the array together.

5. The device of claim 4, wherein the other circuit traces couple the light emitting elements in the array in a series connection.

6. The device of claim 3, including an optical element for transmitting light from the array of light emitting elements.

7. The device of claim 3, wherein the array is situated on the mount in a 'flip-chip' configuration.

8. The device of claim 3, including one or more other, non-light-emitting components situated on the submount and coupled to one or more of the circuit traces.

9. The device of claim 1, wherein the array includes at least four light emitting elements.

10. The device of claim 1, including the common substrate, wherein the common substrate is substantially transparent to the light emitted by the light emitting element.

11. The device of claim 1, including a wavelength conversion material that receives light of a first wavelength from the array of light emitting elements and emits light of a second wavelength.

12. A printed circuit board comprising:

a plurality of sets of circuit traces, each set of circuit traces being situated on the board to receive a monolithic array of light emitting elements and to provide for coupling the array of light emitting elements to a source of external power.

13. The printed circuit board of claim 12, wherein each set of circuit traces include circuit traces that interconnect the light emitting elements of each array when the array is coupled to the set of circuit traces.

14. The printed circuit board of claim 13, including each array of light emitting elements coupled to a corresponding set of circuit traces.

15. The printed circuit board of claim 14, including an optical element that is coupled to a light emitting surface of the array of light emitting elements.

16. The printed circuit board of claim 14, including a wavelength conversion material that receives light of a first wavelength from the array of light emitting elements and emits light of a second wavelength.

17. The printed circuit board of claim 14, including a plurality of sets of one or more other non-light-emitting components that are correspondingly coupled to the each array of light emitting elements.

18. A method comprising:

providing a plurality of light emitting elements upon a common growth substrate, and

slicing the substrate to form monolithic arrays of light emitting elements, each array including adjacent light emitting elements that are formed on the common growth substrate.

19. The method of claim 17, including mounting the formed monolithic arrays of light emitting elements on a corresponding plurality of sets of circuit traces on a mount, and slicing the mount to form a plurality of submounts, each submount including one of the monolithic arrays.

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20. The method of claim 18, including covering a light emitting surface of each of the monolithic arrays with at least one of: an optical element and a wavelength conversion material.

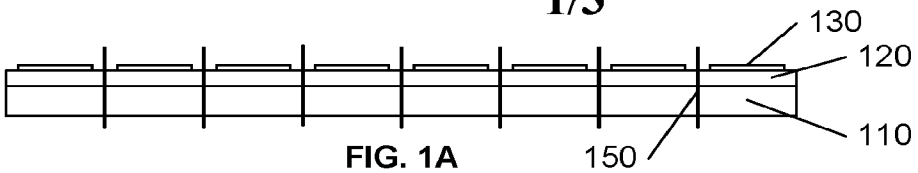


FIG. 1A

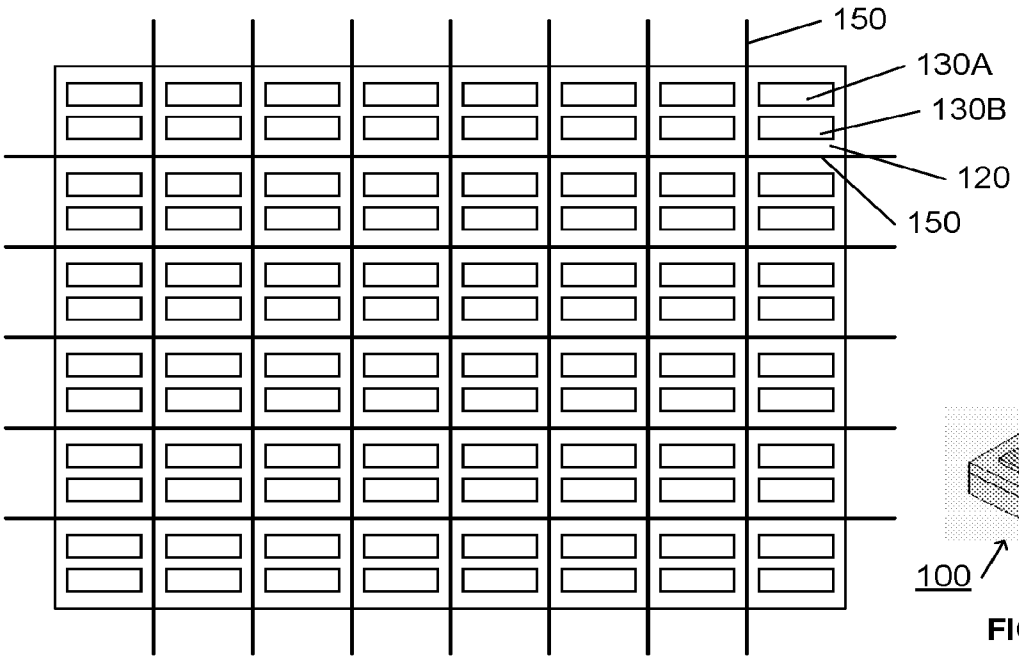


FIG. 1B

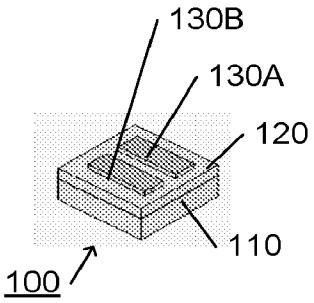


FIG. 1C

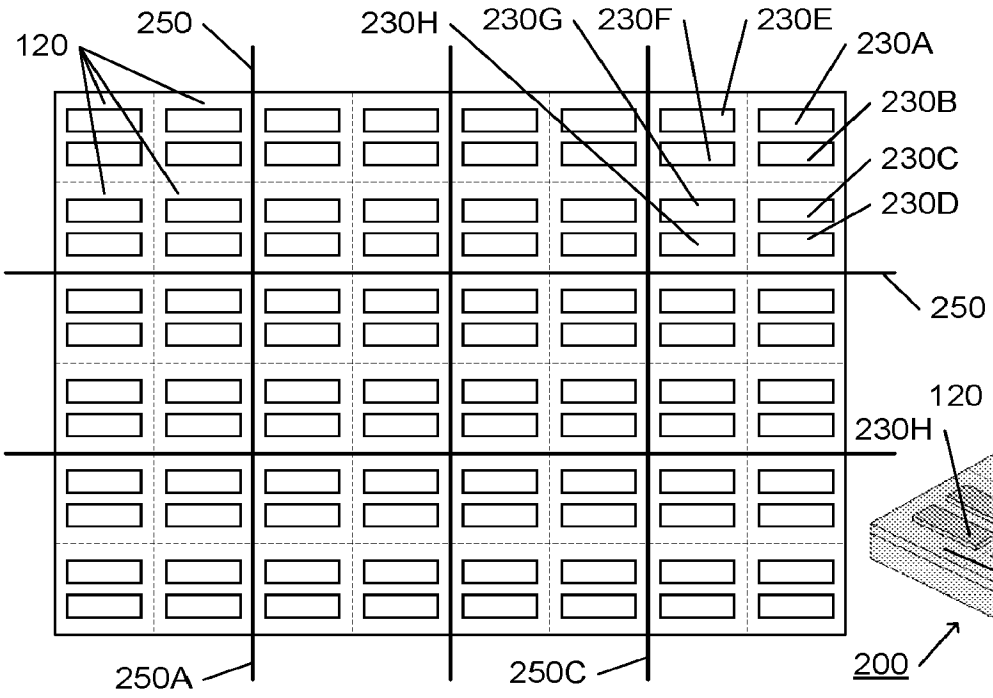


FIG. 2A

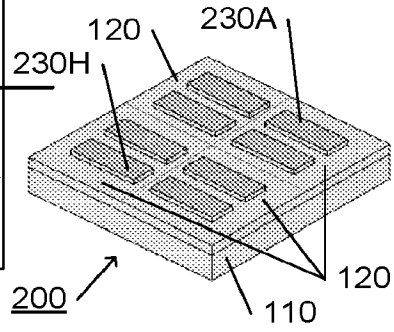


FIG. 2B

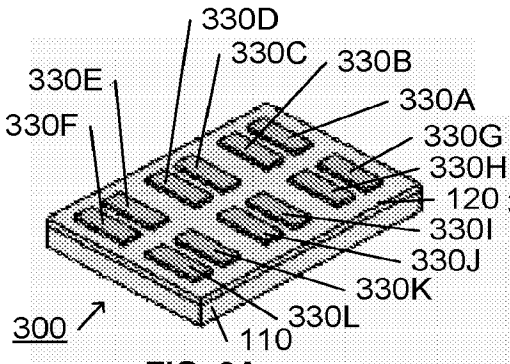


FIG. 3A

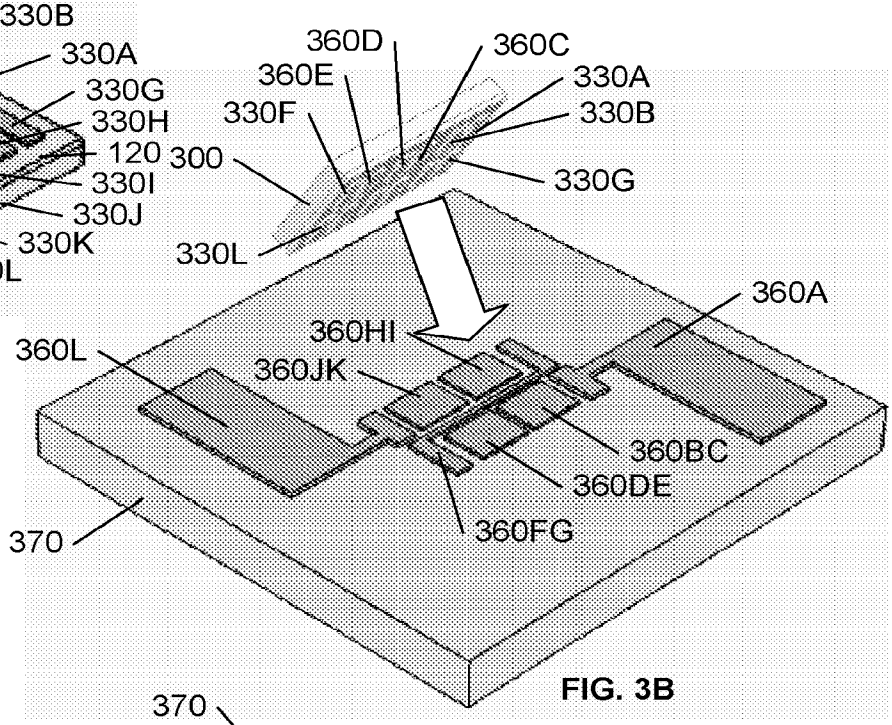


FIG. 3B

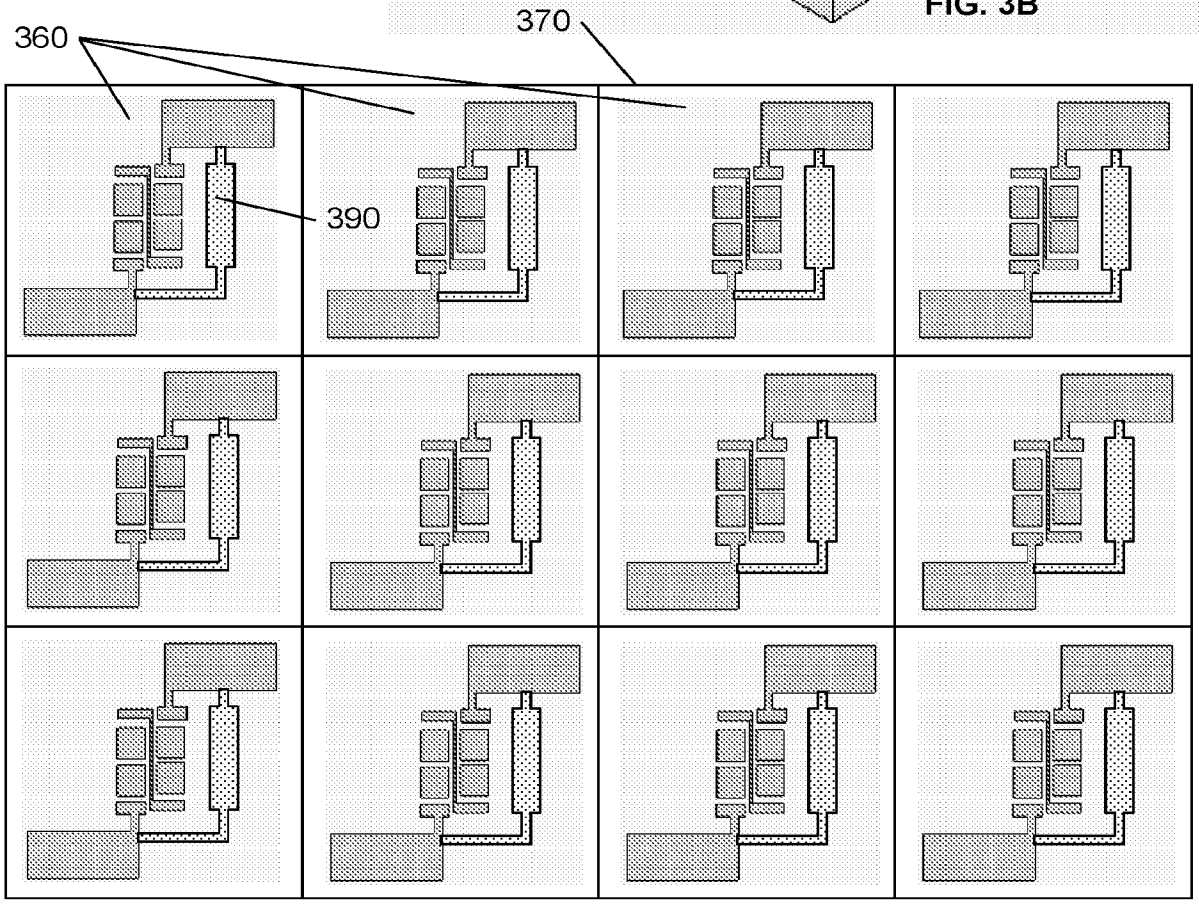


FIG. 4

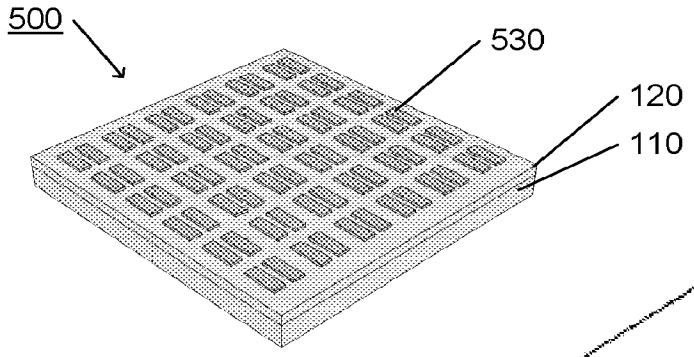


FIG. 5A

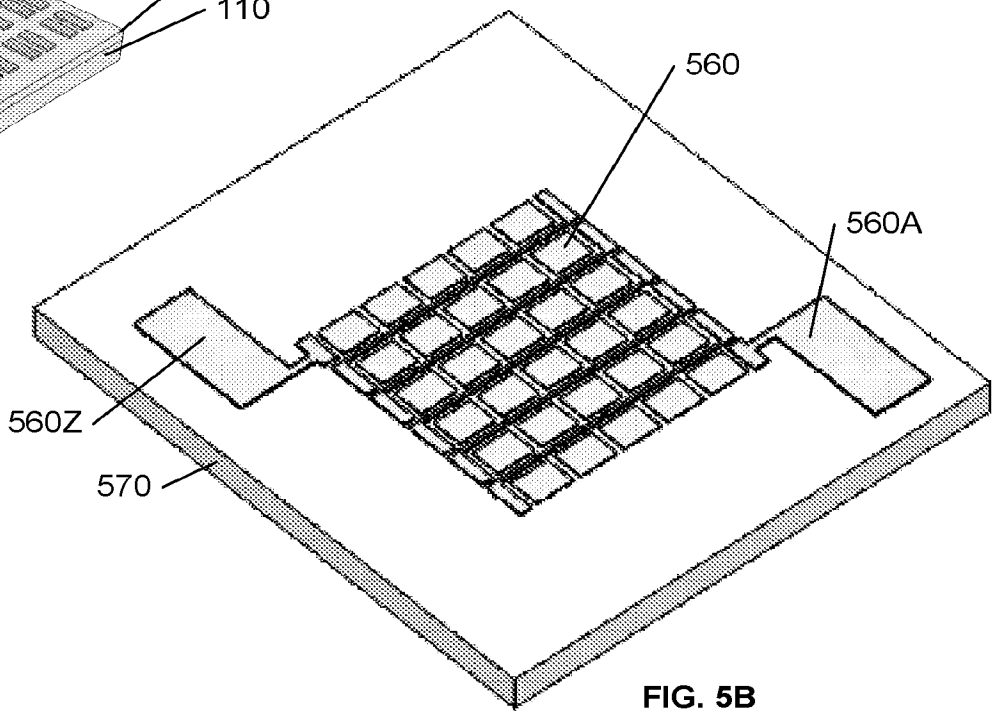


FIG. 5B

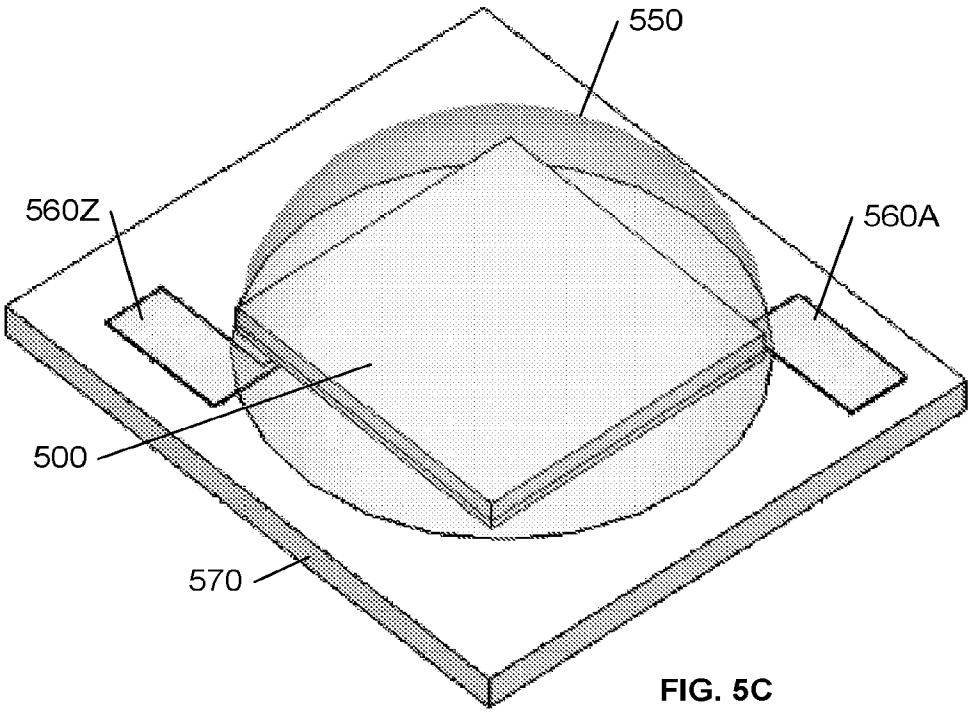


FIG. 5C

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2014/064941

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01L27/15
ADD. H01L25/16 H01L33/54 H01L33/62

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H01L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 2009 111099 A (MITSUBISHI CHEM CORP) 21 May 2009 (2009-05-21) paragraphs [[0882]], [[0883]]; claims; figures	1-20
X	US 2009/108269 A1 (NEGLEY GERALD H [US] ET AL) 30 April 2009 (2009-04-30) figure 9	1,11,12, 16,18,20
X	US 2011/285284 A1 (ZHOU YUGANG [CN] ET AL) 24 November 2011 (2011-11-24) figures 5,6	1,8,12, 17,18
X	US 2010/308347 A1 (YEH WEN-YUNG [TW] ET AL) 9 December 2010 (2010-12-09) figures 10-15	1,8,12, 17,18

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
14 January 2015	22/01/2015

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Ott, André

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Form PCT/ISA/210 (second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IB2014/064941

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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US 2009108269 A1	30-04-2009	CN 101836297 A	15-09-2010
		EP 2203938 A1	07-07-2010
		JP 2011501466 A	06-01-2011
		KR 20100101572 A	17-09-2010
		TW 200919696 A	01-05-2009
		US 2009108269 A1	30-04-2009
		WO 2009055079 A1	30-04-2009
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		EP 2390918 A2	30-11-2011
		JP 5636251 B2	03-12-2014
		JP 2011249755 A	08-12-2011
		US 2011285284 A1	24-11-2011
		WO 2011147063 A1	01-12-2011
US 2010308347 A1	09-12-2010	CN 101908534 A	08-12-2010
		TW 201044557 A	16-12-2010
		US 2010308347 A1	09-12-2010

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G01S 17/42 (2006.01)

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19 January 2016 (19.01.2016)

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(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

(54) **Title**: HOLOGRAPHIC WAVEGUIDE LIDAR

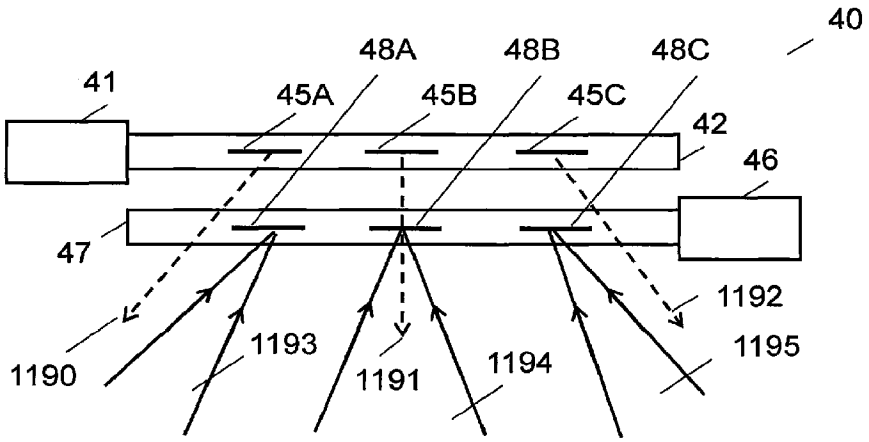


FIG.3

(57) **Abstract**: A holographic waveguide LIDAR comprises a transmitter waveguide coupled to a beam deflector and a receiver waveguide coupled to a detector module. The transmitter waveguide contains an array of grating elements for diffracting a scanned laser beam into a predefined angular ranges. The receiver waveguide contains an array of grating elements for diffracting light reflected from external points within a predefined angular range towards the detector module.

WO 2016/116733 A1

HOLOGRAPHIC WAVEGUIDE LIDAR

PRIORITY CLAIM

This application claims priority from US Provisional Application Serial No.: 62/125,351 entitled HOLOGRAPHIC WAVEGUIDE LIDAR filed on 20 January 2015, which is hereby incorporated by reference in its entirety.

CROSS REFERENCE TO RELATED APPLICATIONS

The following patent applications are incorporated by reference herein in their entireties: US Patent Application No.13/506,389 entitled COMPACT EDGE ILLUMINATED DIFFRACTIVE DISPLAY, , United States Patent No. 8,233,204 entitled OPTICAL DISPLAYS, PCT Application No.: US2006/043938, entitled METHOD AND APPARATUS FOR PROVIDING A TRANSPARENT DISPLAY, PCT Application No.: GB2012/000677 entitled WEARABLE DATA DISPLAY, United States Patent Application No.: 13/317,468 entitled COMPACT EDGE ILLUMINATED EYEGLASS DISPLAY, United States Patent Application No.: 13/869,866 entitled HOLOGRAPHIC WIDE ANGLE DISPLAY, and United States Patent Application No.: 13/844,456 entitled TRANSPARENT WAVEGUIDE DISPLAY, US Patent No. US8,224,133 entitled LASER ILLUMINATION DEVICE, US Patent No. US8, 565,560 entitled LASER ILLUMINATION DEVICE, United States Patent No. 6,115,152 entitled HOLOGRAPHIC ILLUMINATION SYSTEMPCT Application No.: PCT/GB2013/000005 entitled CONTACT IMAGE SENSOR USING SWITCHABLE BRAGG GRATINGS, PCT Application No.: PCT/GB2012/000680, entitled IMPROVEMENTS TO HOLOGRAPHIC POLYMER DISPERSED LIQUID CRYSTAL MATERIALS AND

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DEVICES, PCT Application No.: PCT/GB2014/000197 entitled HOLOGRAPHIC WAVEGUIDE EYE TRACKER, US Provisional Patent Application No. 62/071,534 entitled HOLOGRAPHIC WAVEGUIDE FOR TRACKING AN OBJECT IN 3D SPACE, PCT/GB2013/000210 entitled APPARATUS FOR EYE TRACKING, PCT Application No.:GB2013/000210 entitled APPARATUS FOR EYE TRACKING.

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BACKGROUND OF THE INVENTION

This invention relates to a sensor, and more particularly to a LIDAR using switchable gratings.

LIDAR is a remote-sensing technology that creates a 3D map of an environment by illuminating a target with a pulsed angularly-scanned laser and analyzing the reflected "point cloud". The advantages of LIDAR over cameras are well known. Since LIDAR uses emitted light, it is robust against interference from ambient light and has much higher resolution than radar. Artificial light sources are required for nighttime operation. Current computer vision is inadequate for complex scene representation and is susceptible to illumination variation. Currently, there is growing interest in LIDAR systems for a range of platforms including: cars (for applications such as collision avoidance and cruise control systems), robot vehicle, UAVs and wearable displays for night vision. The increasing use of key-hole procedures in surgery is also stimulating medical applications. An exemplary car LIDAR specification (based on the Velodyne HDL64E) has a FOV of 360° in azimuth; 26.5 ° elevation (+2° to -24.5°); a rerefresh rate of 15Hz; a point cloud rate of 1 million points per second; a maximum range of 120 metres; a horizontal resolution of 0.05 degree; a distance error of less than 1 inch; a laser pulse duration of 5 nanoseconds and a power output of typically 60 watts. However, LIDAR equipment meeting this specification is extremely bulk and expensive. LIDAR operating at around 1.55 microns has the advantage of being eye safe with longer range capability but is even more expensive. Most current LIDAR equipment relies on bulky rotating optics technology. LIDAR systems based on imaging array technology have been developed but are currently very expensive. The inventors believe that the key to overcoming the problems of bulk and cost is waveguide optics based on switchable grating technology.

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One important class of switchable gratings is based on Switchable Bragg Gratings (SBGs). SBGs are fabricated by first placing a thin film of a mixture of photopolymerizable monomers and liquid crystal material between parallel glass plates. One or both glass plates support electrodes, typically transparent indium tin oxide films, for applying an electric field across the film. A volume phase grating is then recorded by illuminating the liquid material (often referred to as the syrup) with two mutually coherent laser beams, which interfere to form a slanted fringe grating structure. During the recording process, the monomers polymerize and the mixture undergoes a phase separation, creating regions densely populated by liquid crystal micro-droplets, interspersed with regions of clear polymer. The alternating liquid crystal-rich and liquid crystal-depleted regions form the fringe planes of the grating. The resulting volume phase grating can exhibit very high diffraction efficiency, which may be controlled by the magnitude of the electric field applied across the film. When an electric field is applied to the grating via transparent electrodes, the natural orientation of the LC droplets is changed causing the refractive index modulation of the fringes to reduce and the hologram diffraction efficiency to drop to very low levels. Typically, SBG Elements are switched clear in 30 μs. With a longer relaxation time to switch ON. Note that the diffraction efficiency of the device can be adjusted, by means of the applied voltage, over a continuous range. The device exhibits near 100% efficiency with no voltage applied and essentially zero efficiency with a sufficiently high voltage applied. In certain types of HPDLC devices magnetic fields may be used to control the LC orientation. In certain types of HPDLC phase separation of the LC material from the polymer may be accomplished to such a degree that no discernible droplet structure results.

SBGs may be used to provide transmission or reflection gratings for free space applications. SBGs may be implemented as waveguide devices in which the HPDLC forms

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either the waveguide core or an evanescently coupled layer in proximity to the waveguide. The parallel glass plates used to form the HPDLC cell provide a total internal reflection (TIR) light guiding structure. Light is "coupled" out of the SBG when the switchable grating diffracts the light at an angle beyond the TIR condition. Waveguides are currently of interest in a range of display and sensor applications. Although much of the earlier work on HPDLC has been directed at reflection holograms transmission devices are proving to be much more versatile as optical system building blocks. Typically, the HPDLC used in SBGs comprise liquid crystal (LC), monomers, photoinitiator dyes, and coinitiators. The mixture frequently includes a surfactant. The patent and scientific literature contains many examples of material systems and processes that may be used to fabricate SBGs. Two fundamental patents are: United States Patent No.5,942,157 by Sutherland, and U. S Patent No. 5,751,452 by Tanaka et al. Both filings describe monomer and liquid crystal material combinations suitable for fabricating SBG devices. One of the known attributes of transmission SBGs is that the LC molecules tend to align normal to the grating fringe planes. The effect of the LC molecule alignment is that transmission SBGs efficiently diffract P polarized light (ie light with the polarization vector in the plane of incidence) but have nearly zero diffraction efficiency for S polarized light (ie light with the polarization vector normal to the plane of incidence. Transmission SBGs may not be used at near-grazing incidence as the diffraction efficiency of any grating for P polarization falls to zero when the included angle between the incident and reflected light is small.

There is a requirement for a compact, lightweight, low cost LIDAR capable of providing wide angle, high-resolution, long-range operation.

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SUMMARY OF THE INVENTION

It is a first object of the invention to provide a compact, lightweight, low cost LIDAR capable of providing wide angle, high-resolution, long-range operation.

The objects of the invention are achieved in one embodiment of the invention in which there is provided a waveguide sensor, comprising: a source of first wavelength light; at least one beam deflector for scanning the light; a transmitter waveguide; a receiver waveguide; and a detector optically coupled to the receiver waveguide. The beam deflector is optically coupled to the transmitter waveguide and configured such that scanned light coupled into the transmitter waveguide executes angular sweeps about the principal diffraction directions of the grating elements. The transmitter waveguide contains a multiplicity of grating elements disposed in at least one grating layer. Each grating element is operative to diffract light into a predefined range of output directions. The receiver waveguide contains a multiplicity of grating elements disposed in at least one grating layer. Each grating element diffracts light reflected from external points and incident within a predefined angular range into a TIR path to the detector.

In some embodiments the grating elements in at least one of the transmitter waveguide or the receiver waveguide are elements of a two dimensional array.

In some embodiments the grating elements in at least one of the transmitter waveguide or the receiver waveguide are elements of a one dimensional array.

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In some embodiments the grating elements in at least one of the transmitter waveguide or the receiver waveguide are elongate elements with longer dimensions aligned orthogonally to the propagation direction of the waveguides.

In some embodiments the grating elements in at least one of the transmitter waveguide or the receiver waveguide are electrically switchable.

In some embodiments the grating elements in at least one of the transmitter waveguide or the receiver waveguide have at least one of aspect ratio or surface area varying across the waveguide.

In some embodiments the receiver waveguide and the transmitter waveguide substantially overlap.

In some embodiments the transmitter waveguide and the receiver waveguide each contain grating elements having at least two different grating vectors.

In some embodiments at least one of the transmitter waveguide or the receiver waveguide contains grating layers operating over different angular ranges.

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In some embodiments at least one of the transmitter waveguide or the receiver waveguide includes at least one grating layer containing a fold grating.

In some embodiments the transmitter waveguide and the receiver waveguide are combined into a single waveguide containing a multiplicity of grating elements disposed in at least one grating layer. Each grating element is operative to diffract the light into a predefined range of output directions. Each grating element diffracts light reflected from external points and incident within a predefined angular range into a TIR path to the detector.

In some embodiments the apparatus is configured to detect a 3D point cloud.

In some embodiments coupling between the scanner and the transmitter waveguide is performed by one of a prism, a grating, a switchable grating, or via edge coupling.

In some embodiments the beam deflector is a micro-electro-mechanical system.

In some embodiments the source is an infrared light emitting diode or an infrared laser. In some embodiments the first wavelength is approximately 1550 nm.

In some embodiments the grating is one of a Bragg grating, a surface relief grating or a switchable Bragg grating recorded in a HPDLC material, a uniform modulation HPDLC material or a reverse mode HPDLC material.

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In some embodiments a waveguide LIDAR according to the principles of the invention forms a layer in a stack further comprising at least one of a waveguide HMD or a waveguide eye tracker.

In some embodiments the apparatus further comprises a beamsplitter for providing optical paths between the source and the transmitter waveguide and the detector and the receiver waveguide.

In some embodiments the detector is a heterodyne detection device.

A more complete understanding of the invention can be obtained by considering the following detailed description in conjunction with the accompanying drawings, wherein like index numerals indicate like parts. For purposes of clarity, details relating to technical material that is known in the technical fields related to the invention have not been described in detail.

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BRIEF DESCRIPTION OF THE DRAWINGS

FIG.1 is a schematic side view of a LIDAR receiver waveguide in one embodiment.

FIG.2 is a schematic side view of a LIDAR transmitter waveguide in one embodiment.

FIG.3 is a schematic side view of a LIDAR comprising a transmitter waveguide and a receiver waveguide in one embodiment.

FIG.4 is a schematic view of a LIDAR comprising multiple receiver-transmitter waveguide layers in one embodiment.

FIG.5A is a schematic plan view of a LIDAR transmitter waveguide and laser scanner module in one embodiment.

FIG.5B is a schematic plan view of a LIDAR receiver waveguide and detector module in one embodiment.

FIG.5C is a schematic plan view of a detail of a LIDAR receiver waveguide in one embodiment.

FIG.6 is an illustration of the scanning geometry of a LIDAR in one embodiment.

FIG.7is a block diagram of a LIDAR signal processor in one embodiment.

FIG.8A is a schematic plan view of a LIDAR transmitter/receiver waveguide and beams scanner and detector modules in one embodiment.

FIG.8B is a schematic plan view a beam steering module used in the embodiment of FIG.8A.

FIG.9 is plan view showing the geometry of a SBG array used in a LIDAR receiver waveguide in one embodiment.

FIG.10 is a schematic view of a LIDAR in which the transmitter and receiver waveguides are fiber-coupled to a beam scanner module and detector module in one embodiment.

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FIG.11 is a schematic side view of a LIDAR transmitter waveguide using passive grating in one embodiment.

FIG.12 is a schematic side view of a LIDAR waveguide in which transmitter and receiver waveguides are disposed adjacent each other.

FIG.13 is a schematic view of an eye tracked wearable waveguide display including a LIDAR waveguide layer.

FIG.14 is a schematic view of a LIDAR receiver waveguide stack comprising two waveguides operating over different fields of view.

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DETAILED DESCRIPTION OF THE INVENTION

The invention will now be further described by way of example only with reference to the accompanying drawings. It will apparent to those skilled in the art that the present invention may be practiced with some or all of the present invention as disclosed in the following description. For the purposes of explaining the invention well-known features of optical technology known to those skilled in the art of optical design and visual displays have been omitted or simplified in order not to obscure the basic principles of the invention. Unless otherwise stated the term "on-axis" in relation to a ray or a beam direction refers to propagation parallel to an axis normal to the surfaces of the optical components described in relation to the invention. In the following description the terms light, ray, beam and direction may be used interchangeably and in association with each other to indicate the direction of propagation of light energy along rectilinear trajectories. Parts of the following description will be presented using terminology commonly employed by those skilled in the art of optical design. It should also be noted that in the following description of the invention repeated usage of the phrase "in one embodiment" does not necessarily refer to the same embodiment.

LIDAR works by sending out short infrared laser pulses. The return signal can be used to build up a 3D map of an environment by timing the pulse return time. The basic optical components of a LIDAR system are a pulsed laser, a means for scanning the laser beam over a wide angle, a receiver means comprising optics and a detector for recording the return signal. The present invention addresses the problem of providing a passive, wide angle transmitter/receiver that eliminates the need to rotate the optical assembly. Instead, we use

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waveguides containing arrays of switchable gratings each optimized to collect signal over a predefined field of view range. It is not necessary to rotate the waveguides. The laser is scanned across each field of view range to provide the required angular resolution. By optimizing the laser scanning cycle to coincide with the duration of the diffracting state of each grating it is possible to build up a large field of view with a high (angular) resolution. The waveguide approach also brings the benefits of transparency, light weight and a very thin form factor. Furthermore, a waveguide LIDAR can be integrated with other waveguide devices such as displays and eye trackers in a thin stack. Advantageously, the LIDAR operates at 1550 which has the advantages of being eye safety and invisible to current night vision technology. However, the invention may be applied at any wavelength in the spectrum from UV to infrared. We will now discuss a series of exemplary embodiments of the invention.

In one embodiment shown in FIG.1 a LIDAR receiver waveguide 20 comprises the light detection module 21 a waveguide 22 with electrodes applied to opposing surfaces the electrodes comprising a common electrode 23 and an array of electrodes 24A-24D the two electrode layers sandwiching grating regions 25A-24C to form a switchable grating array. In one embodiment the grating array is two dimensional. In one embodiment the array comprises a one-dimensional array of column shaped elements. The detector module will typically comprise a lens and an infrared (IR) detector. Advantageously, the IR detector is a fast, high sensitivity device such as an avalanche photodiode. In many applications the preferred wavelength is 1550 nm which is eye safe and is invisible to current night vision devices. Each grating region has a unique k-vector (that is a vector normal to the Bragg fringes) as indicated by 1170-1172. The gratings in their diffracting state couple signal light into a TIR path inside the waveguide. The guided beam

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is coupled into the detector module, typically by a grating or prism. In one embodiment the IR detector is coupled to the end of the waveguide. Each grating has an angular detection field determined by the diffraction efficiency bandwidth of the grating. The principal rays of the fields of view of the grating elements 25A-25C are represented by 1175-1177. Typically, the field of view of a single element is in the region of 10-15 degrees. By switching the gratings to their active state sequentially the entire field of view is covered. For example, if we consider grating region 25A with k-vector 1170 sandwiched by the electrode 24A and the common electrode, when the grating is in its active state light 1175 is coupled into the TIR path indicated by the rays 1173-1174 which are coupled into the detector module. Note that although in FIG.1 (and in the embodiments to be described below) more than one grating is shown in a diffracting state, in practice only one grating region will be diffracting at any time.

In some embodiments the gratings are recorded in uniform modulation liquid crystal-polymer material system such as the ones disclosed in United State Patent Application Publication No.: US2007/0019152 by Caputo et al and PCT Application No.: PCT/EP2005/006950 by Stumpe et al. both of which are incorporated herein by reference in their entireties. Uniform modulation gratings are characterized by high refractive index modulation (and hence high diffraction efficiency) and low scatter. In some embodiments the gratings are recorded in a reverse mode HPDLC material. Reverse mode HPDLC differs from conventional HPDLC in that the grating is passive when no electric field is applied and becomes diffractive in the presence of an electric field. The reverse mode HPDLC may be based on any of the recipes and processes disclosed in PCT Application No.: PCT/GB2012/000680, entitled IMPROVEMENTS TO HOLOGRAPHIC POLYMER DISPERSED LIQUID CRYSTAL

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MATERIALS AND DEVICES.

In one embodiment shown in FIG.2 a LIDAR transmitter waveguide 30 comprises a scanning module (beam deflector) 31 a waveguide 32 with electrodes applied to opposing surfaces, the electrodes comprising a common electrode 33 and an array of electrodes 34A-34D. The electrode layers sandwich the grating regions 35A-34C. The invention does not assume any particular beam scanning technology. At the time of writing this application the preferred technology is based on a micro electro mechanical system (MEMs). Exemplary MEMs scanners are manufactured by Lemoptix Inc. These devices can provide a resolution of 720p (1280×720 pixels) at 60Hz with scanning angles in excess of 60 degrees. Referring again to FIG.2 the scanning beam is coupled into the waveguide by a grating or prism coupler. In one embodiment the beam may be coupled through the end of the waveguide. Each grating region has a unique k-vector (that is a vector normal to the Bragg fringes) as indicated by 1170-1172. The gratings in their diffracting state couple signal light into a TIR path inside the waveguide. Each grating has an angular detection field determined by the diffraction efficiency bandwidth. The principal rays of the fields of view of grating elements 35A-35C are represented by 1185-1187. Typically, the field of view of a single element is in the region 10-15 degrees. By switching the gratings to their active state sequentially the entire field of view is covered. For example, switching grating region 35A with k-vector 1180 is sandwiched by the electrode 34A and the common electrode which switches the grating region 35A between diffracting and non-diffracting states such that light 1185 is coupled out of the TIR path indicated by the rays 1183-1184.

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In one embodiment illustrated in the schematic side view of FIG.3 a complete LIDAR 40 comprises receiver and transmitter waveguides based on the embodiments of FIGS.1-2. The transmitter component comprises the scanner module 41 and the waveguide 42 containing switchable grating elements 45A-45C which deflect light out of the TIR path into scanned beam ranges having the principal rays 1190-92 when in their diffracting states. The receiver component comprises the detector module 46 and the waveguide 47 containing the switchable grating elements48A-48C which couple in signal light in the FOVs 1190-1195 into TIR paths to the detector module when in their diffracting states. The switching electors in the receiver and transmitter waveguides are not shown.

In one embodiment shown in FIG.4 there is provided a LIDAR system 50 comprising a stack of waveguides 51-53 each containing SBG columns such as 54-56. The number of columns in a waveguide will depend on the grating angular bandwidth and the size of the overall field of view of the LIDAR. A scanned laser beam is coupled into each waveguide layer in turn via a coupling means such as a grating or prism. Alternatively, the laser beam may be edge coupled into the waveguide. Each waveguide layer may have a separate coupler designed to accept input beams in a predefined angular range. The coupler may employ at least one switching grating. A single coupler may be used to address multiple layers. In one embodiment the LIDAR may comprise a single waveguide layer. The SBG columns 54-56 have unique k-vectors for deflecting scanned laser beams into unique angular ranges with principal ray directions such 1202-1204. A scanned laser beam 1200 is coupled into the waveguides via a prism 57 into the TIR path 1201 in waveguide 51 and is deflected out of the waveguide 51 into a unique direction 1204 by an active (that is, diffracting) SBG column 56 according to the

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principles of the above described embodiments. The scanned laser beam irradiates a region 1205 of a remote reflective surface. The return signal 1206 reflected from the reflective surface is coupled into the waveguide 51 by the same active SBG column and relayed to the beam scanner and detector module 58 along the TIR path1207 and an external path 1208 substantially parallel to the input beam path 1207. The transmitted and received laser beams are separated using beam splitting techniques that are well documented in the literature of laser sensors. The beams may be separated using polarization or angular selectivity. The detection system may employ heterodyne detection. The embodiment of FIG.4 may be based on ones disclosed in PCT/GB2014/000197 entitled HOLOGRAPHIC WAVEGUIDE EYE TRACKER, US Provisional Patent Application No. 62/071,534 entitled HOLOGRAPHIC WAVEGUIDE FOR TRACKING AN OBJECT IN 3D SPACE, PCT/GB2013/000210 entitled APPARATUS FOR EYE TRACKING, PCT Application No.:GB2013/000210 entitled APPARATUS FOR EYE TRACKING which are incorporated herein by reference in their entireties. Said filings address eye trackers using SBG column array waveguides for infrared eye tracking. With some implementation modifications that will be obvious to those skilled in the art the embodiments disclosed therein are equally applicable to LIDAR systems. Each receiver transmitter (R/T) SBG element has unique a unique K-vector which together with the MEMs scanner sweep defines a unique FOV tile. This eliminates the need for complex, bulk and expensive rotating optics. Singe the target surfaces are typically at long range the beams entering the receiver waveguide are substantially collimated allowing optimal matching of R/T channels at all angles. Desirably the grating elements are designed to make the received element apertures as large as possible while the apertures of the transmitter elements need to be large enough to accommodate the laser beam sweep from the beam scanner. The beam width will be very narrow, typically of the order

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of millimetres.

The beam scanner and detector modules may be coupled to the transmission and receiver waveguides by an optical fibre. Multiple waveguides may be stacked to provide a larger field of view or to implement a hyper-spectral LIDAR with each waveguide operating within a defined wavelength band.

In a further embodiment of the invention shown in FIG.5 a LIDAR system comprises a transmitter component 70 and a receiver component 80. The receiver component comprises a waveguide 71 containing a single row of switchable grating elements 72A-72F with an active grating indicated by 72D. Each grating has a unique k-vector corresponding to a unique beam diffraction direction. The transmitter component further comprises a pulsed laser emitting the beam 1210, collimation and beam expansion optics indicated schematically by 76 forming the beam 1211 and a beam scanner module 77 for scanning the beam 1212 in two orthogonal directions. The scanned beam enters the waveguide via a coupling element78 (typically a grating or prism). The component of the scanned beam in the waveguide X direction 1213 is shown for simplicity. The active grating element 74 deflects the beam 1213 in the direction 1214. Principal beam directions 1215-1217 corresponding to the active states of grating elements 72A-72C are indicated. Turning now to FIG.5B the detector waveguide 80 contains the SBG array 81 comprising elements such as 81 and 83 and a fold grating 80. To better understand the function of a fold grating note that the waveguide gratings in the previously discussed embodiments are tilted around an axis lying in the waveguide plane. Fold gratings have a more generalized tilt. In their simplest implementation, as used in the present invention they are tilted around an axis perpendicular to the waveguide plane such they deflect beams in

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the waveguide plane. More generally, they may have tilts defined by two rotation angles so that, for example, light can be coupled into the waveguide and deflected into an orthogonal direction inside the waveguide, all in one step. Of particular importance for the present invention, they can perform ninety degree turning and two-axis beam expansion in a single layer, avoiding orthogonal superimposed grating layers. Figure 5C is a plan view of the fold grating 82. When rays 1225 encounter the grating, they diffract in a manner that changes the direction of propagation by 90°. Unlike a conventional vertical extraction grating, the light does not leave the waveguide. Note that when a ray encounters the grating, regardless of whether it intersects the grating from above or below, a fraction of it changes direction and the remainder continues unimpeded. A typical ray will interact many times with vertically (in the Y direction) while some light will be moving laterally (in the X direction). From a design perspective, it is desirable to engineer the amount of light 1228 emerging from the output edge of the grating to be uniformly distributed laterally and the amount of light 1227 emerging from the side edge of the grating to be as small as possible. Referring to the Cartesian XY reference frame in the figure, the fold grating turns the TIR light 1225 through ninety degrees into the Y direction. The light 1226 emerging from the fold grating is coupled out of the waveguide (prisms, grating or edge) and focused onto a IR detector 86 by the lens 87. The detector is connected to a signal processor 84 by an electrical communication link 85. Element 83, which is shown in its active state, couples signals from regions 1221-1224 along the scan path 1225. For example, light from regions 1221,1222 scanned by the instantaneous beams 1224,1225 is coupled by active element 83 which deflects the light into the TIR path in the direction 1225 (X-axis). In a typical application the laser has pulse duration of 5 ns. The laser power will depend on the application. In a typical automotive application, a LIDAR output power in the region of 60W may be required. The

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MEMS scanner is typically a single element scanner. Desirably the device (with the laser) should allow 1200 x 600 resolution cells across the field of view with 60 Hz update. In one embodiment a LIDAR is based on an array of 6x3 SBG gratings each having a field of view of 10° x10° giving a total field of view of 60° x30°. During the detector element active period 200x200 elements are swept out over the 10° x10° resulting in an angular resolution of 0.05° .

FIG 6 illustrates the scanning geometry in more detail showing the scanned field of view regions formed by the transmitter which are labelled by 1230-1235. The backscatter signal from a reflective surface 90 is collected by a receiver over the angular range bounded by the rays 1236-1237. The beam scanner and the pulsed laser divide the field of view into discrete angular resolution elements such as 1236-1239. FIG.7 is a block diagram of the signal processor 92. The data communication link from the receiver component transmits the received signal to an analogue to digital converter (ADC) 93. The digitised signal is transmitted to a digital signal processor (DSP) module 94. Finally, the signal is communicated to peripheral devices via an Ethernet link 95. The modules operate under the control of the executive program 96.

The embodiment of FIG.8 is similar to the one of FIG.5 except in that the transmitter component uses a two dimensional array of SBG elements and the fold grating in the receiver components is replaced by a large aperture detector lens. A further distinction is that in the FIG.8 embodiment the transmitter and receiver components are integrated in one waveguide. The LIDAR 100 comprises a waveguide 101, a pulsed laser 102 emitted a beam 1240, a beam expansion/collimator lens system103 providing the beam 1241, a beam scanner 104 producing the scanned beam represented by 1242, and a beam steering module 105 which provides a

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multiplicity of beam paths into the transmitter waveguide one of which, namely the beam 1244, is shown being injected into the waveguide along the SBG element row labelled 109. The beam steering module is illustrated in more detail in FIG.8B. In one embodiment it comprises a set of three switchable fold grating elements 105A-105C and a non-switching fold grating 105D for steering the scanned beam 1243 of FIG.8A into the vertical (Y) direction. The vertical beam 1243A crosses each of the switching fold grating elements in turn. Each element is operative to switch the scanned beam into the X direction into the transmitter waveguide. In FIG.8B the element 105A is in its diffracting state and switches the beam into the output direction 1244. The elements 105B, 105C, which would otherwise switch the beam in the directions 1243B, 1243C shown by the dotted lines, are shown in their passive states. Not shown in FIG.8B is a means for coupling the scanned beam 1243 into the beam steering module and for coupling the out beams from the beam steering module into the transmitter waveguide. As already discussed the coupling means may comprise a prism or grating. Alternatively, the beam may be injected into the edge of the waveguide. The transmitter portion comprises a two dimensional array of SBG elements such as 106-108. The rows are labelled by 109-111. The elements each have a unique k-vector defining a discrete horizontal and vertical field of view region. The active element scanned beam portion extracted from the waveguide by the active SBG element 108 is represented by the set of rays 1245. The receiver waveguide contains a two dimensional array of SBG elements 112 with rows starting with the elements labelled 113-115. The return signal which is indicated by the set of rays 1246 incident on the active element 116 is diffracted in the TIR path 1247 along the element row 113 and is coupled in to detector module 117 comprising the large aperture lens 118 and the IR detector 119. The lens focuses the guided beams onto the detector to form a focal spot of size determined by the range of angles detected by the element

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116, as indicated by the dashed line rays 1248A,1248B. The full range of angles detected (for all SBG element rows) is indicated by the dashed lines 1249. In one embodiment the detector module 117 is fold back over the receiver waveguide by means of mirrors or prisms to provide a more compact configuration. In one embodiment the lens 118 is replaced by an equivalent mirror. In another embodiment the lens 118 may be replaced by a holographic optical element.

In one embodiment shown in FIG.9 the widths of SBG elements in the receiver component SBG array 120 increase from the centre of the array (122) to the edge (121) in order to maintain a fixed detection aperture at all angles.

The embodiment illustrated in FIG.10 provides a fiber optic LIDAR 130 in which the transmitter and receiver waveguides are coupled to the scanner module and the detector module by an optical fiber. The optical fiber may be based on GRIN technology. The apparatus comprises a receiver waveguide 131 containing grating elements such as 132 for receiving light over the ang8ular range 1262, a transmitter waveguide 133 containing grating elements such as 134 for beam scanning light over a predefined angular range. An optical fiber couples the input 1264 to the transmitter waveguide and the output 1261 from the receiver waveguide to a remote transmitter /receiver module comprising a beam scanner 138 and detector module 139 and a coupler for couple transmitted beam 1260 and the received beam 1265 between the transmitter/receiver module and the fiber. The waveguides and the transmitter /receiver module may be based on any of the above described embodiments. Techniques for coupling signals to fibers will be well known to those skilled in the art.

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So far we have considered transmitter and receiver waveguides that use switching grating elements. FIG.11 shows an embodiment in which the gratings elements are passive but are designed to operate within different TIR angle ranges. The apparatus 140 comprises a transmitter waveguide 141 containing grating elements 142-145. Each FOV range of the LIDAR corresponds to a unique SBG element and TIR range. The principal rays of three different TIR beams 1270-1272 and the diffraction of the TIR beams by the gratings 142,143,145 (in their diffracting states) into the transmitter beams 1273-1275 is shown. One way to ensure that the TIR angles are sufficiently well separated for this scheme to work is to design the grating to have a larger thickness and consequently a narrower angular bandwidth. Thick gratings are normally more difficult to switch, requiring higher switching voltages. A passive grating would be highly desirable in medical endoscopes. Note that FIG.11 also serves to illustrate a either a passive transmitter waveguide or a passive receiver waveguide (reversing the ray vectors).

In one embodiment shown in FIG.12 a LIDAR 150 comprises transmitter 151 and receiver 152 waveguides abutting end to end. The waveguides may be based on any of the above described embodiments. The transmitted and received beam directions are generally indicated by 1280,1281.

In one embodiment shown in FIG.13 there is provided an apparatus comprising a LIDAR 160 according to the principles of the invention, a waveguide display161 and a waveguide eye tracker 162. The transmitted and received beams at the LIDAR are indicated by 1300,1301. The field of view provided by the display is indicated by the rays 1302,1303. The eye tracker illuminates the eye 163 with the infrared beam indicated by 1306 and detects the backscatter

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signal indicated by 1305. The waveguide display may be based on any of the embodiments disclosed in US Patent Application No.13/506,389 entitled COMPACT EDGE ILLUMINATED DIFFRACTIVE DISPLAY, , United States Patent No. 8,233,204 entitled OPTICAL DISPLAYS, PCT Application No.: US2006/043938, entitled METHOD AND APPARATUS FOR PROVIDING A TRANSPARENT DISPLAY, PCT Application No.: GB2012/000677 entitled WEARABLE DATA DISPLAY, United States Patent Application No.: 13/317,468 entitled COMPACT EDGE ILLUMINATED EYEGLASS DISPLAY, United States Patent Application No.: 13/869,866 entitled HOLOGRAPHIC WIDE ANGLE DISPLAY, and United States Patent Application No.: 13/844,456 entitled TRANSPARENT WAVEGUIDE DISPLAY. The eye tracker may be based on any of the embodiments disclosed in PCT Application No.: PCT/GB2014/000197 entitled HOLOGRAPHIC WAVEGUIDE EYE TRACKER, US Provisional Patent Application No. 62/071,534 entitled HOLOGRAPHIC WAVEGUIDE FOR TRACKING AN OBJECT IN 3D SPACE, PCT/GB2013/000210 entitled APPARATUS FOR EYE TRACKING, PCT Application No.: GB2013/000210 entitled APPARATUS FOR EYE TRACKING.

In one embodiment shown in FIG.14 a LIDAR receiver component 170 comprises a first waveguide 172 for receiving light from a first field of view indicated by the set of principal rays 1310 and a second waveguide 171 for receiving light from a second field of view indicated by the set of principal rays 1311. It should be apparent from the drawing that FIG.14 may also be used to illustrate a LIDAR transmitter component (with the ray directions reversed).

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The invention provides a transparent, thin architecture, using single laser/detector. The LIDAR uses SBG arrays for dividing the receiver and transmitter fields of view into small selectively switched field of view regions that can be detected more efficiency than would be the case if a singe wide angle imaging optical system were used.

Any of the embodiments of the invention may be implemented using either one dimensional or two dimensional grating arrays. In any of the above embodiments the waveguides may be curved or formed from a mosaic of planar or curved facets. It should be emphasized that the drawings are exemplary and that the dimensions have been exaggerated. For example, thicknesses of the SBG layers have been greatly exaggerated.

A waveguide device based on any of the above-described embodiments may be implemented using plastic substrates using the materials and processes disclosed in PCT Application No.: PCT/GB2012/000680, entitled IMPROVEMENTS TO HOLOGRAPHIC POLYMER DISPERSED LIQUID CRYSTAL MATERIALS AND DEVICES.

Advantageously, the SBGs are recorded in a reverse mode HPDLC material in which the diffracting state of SBG occurs when an electric field is applied across the electrodes. An eye tracker based on any of the above-described embodiments may be implemented using reverse mode materials and processes disclosed in the above PCT application. While the invention may be applied with gratings of any type including switching or non-switching gratings based on Bragg (volume) holograms, or surface-relief gratings the preferred grating technology is a SBG, which offers the advantages of fast switching, high optical efficiency and transparency and high index modulation. It should also be noted that the gratings used in the above embodiments are not necessarily all switching gratings. Switching gratings may be used in combination with

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passive grating technologies. As has been indicated by the description and drawings more than one grating layer (lamina) may be used. The grating layers discussed above are SBGs disposed between internal waveguide surfaces (or in other words sandwiched between transparent substrates that combine to form the waveguide. However, in equivalent embodiments some of the gratings layers could be applied to external waveguide surfaces. This would apply in the case of surface relief gratings. The method of fabricating the SBG pixel elements and the ITO electrodes used in any of the above-described embodiments of the invention may be based on the process disclosed in the PCT Application No. US2006/043938, entitled METHOD AND APPARATUS FOR PROVIDING A TRANSPARENT DISPLAY.

It should be understood by those skilled in the art that while the present invention has been described with reference to exemplary embodiments, it is to be understood that the invention is not limited to the disclosed exemplary embodiments. Various modifications, combinations, sub-combinations and alterations may occur depending on design requirements and other factors insofar as they are within the scope of the appended claims or the equivalents thereof.

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CLAIMS

What is claimed is:

1. A waveguide sensor, comprising:

a source of first wavelength light;

at least one beam deflector for scanning said light;

a transmitter waveguide;

a receiver waveguide; and

a detector optically coupled to said receiver waveguide,

said beam deflector optically coupled to said transmitter waveguide and configured such that scanned light coupled into said transmitter waveguide executes angular sweeps about the principal diffraction directions of said grating elements,

said transmitter waveguide containing a multiplicity of grating elements disposed in at least one grating layer, each said element operative to diffract light into a predefined range of output directions

said receiver waveguide containing a multiplicity of grating elements disposed in at least one grating layer, each said element diffracting light reflected from external points and incident within a predefined angular range into a TIR path to said detector.

2. The apparatus of claim 1 wherein said grating elements in at least one of said transmitter waveguide or said receiver waveguide are elements of a two dimensional array.

3. The apparatus of claim 1 wherein said grating elements in at least one of said transmitter waveguide or said receiver waveguide are elements of a one dimensional array.

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4. The apparatus of claim 1 wherein said grating elements in at least one of said transmitter waveguide or said receiver waveguide are elongate elements with longer dimensions aligned orthogonally to the propagation direction of said waveguides.

5. The apparatus of claim 1 wherein said grating elements in at least one of said transmitter waveguide or said receiver waveguide are electrically switchable.

6. The apparatus of claim 1 wherein said grating elements in at least one of said transmitter waveguide or said receiver waveguide have at least one of aspect ratio or surface area varying across the waveguide.

7. The apparatus of claim 1 wherein said receiver waveguide and said transmitter waveguide substantially overlap.

8. The apparatus of claim 1 wherein said transmitter waveguide and said receiver waveguide each contain grating elements having at least two different grating vectors.

9. The apparatus of claim 1 at least one of said transmitter waveguide or said receiver waveguide contains grating layers operating over different angular ranges.

10. The apparatus of claim 1 wherein at least one of said transmitter waveguide or said receiver waveguide includes at least one grating layer containing a fold grating.

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11. The apparatus of claim 1 wherein said transmitter waveguide and said receiver waveguide are combined into a single waveguide containing a multiplicity of grating elements disposed in at least one grating letter, each said element operative to diffract said light into a predefined range of output directions, each said element diffracting light reflected from external points and incident within a predefined angular range into a TIR path to said detector.

12. The apparatus of claim 1 configured to detect a 3D point cloud.

13. The apparatus of claim 1 wherein coupling between said scanner and said transmitter waveguide is performed by one of a prism, a grating, a switchable grating, or via edge coupling.

14. The apparatus of claim 1 wherein said beam deflector is a micro-electro-mechanical system.

15. The apparatus of claim 1 wherein said source is an infrared light emitting diode or an infrared laser.

16. The apparatus of claim 1 wherein said first wavelength is approximately 1550 nm.

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17. The apparatus of claim 1 wherein said grating is one of a Bragg Grating, a surface relief grating or a switchable Bragg grating recorded in a HPDLC material, a uniform modulation HPDLC material or a reverse mode HPDLC material.

18. The apparatus of claim 1 forming a layer in a stack further comprising at least one of a waveguide HMD or a waveguide eye tracker.

19. The apparatus of claim 12 further comprising a beamsplitter for providing optical paths between said source and said transmitter waveguide and said detector and said receiver waveguide.

20. The apparatus of claim 1 wherein said detector is a heterodyne detection device.

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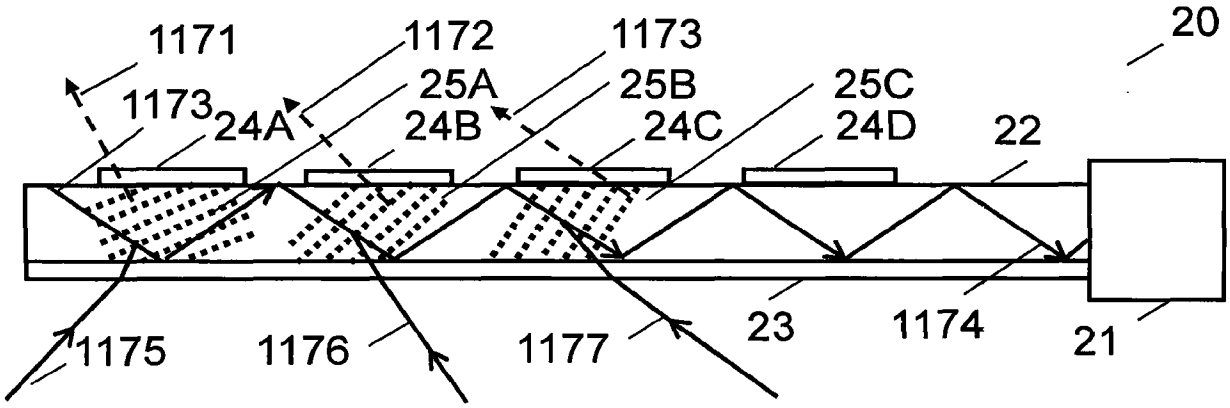


FIG.1

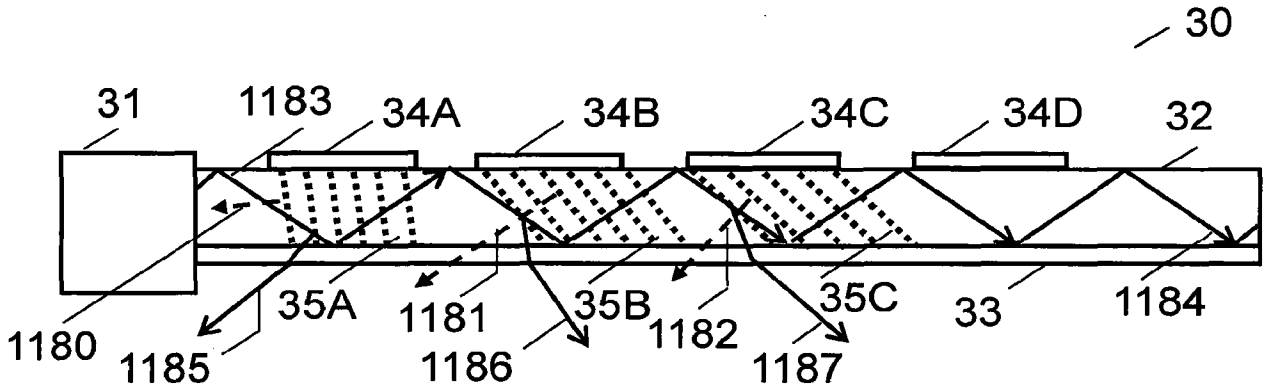


FIG.2

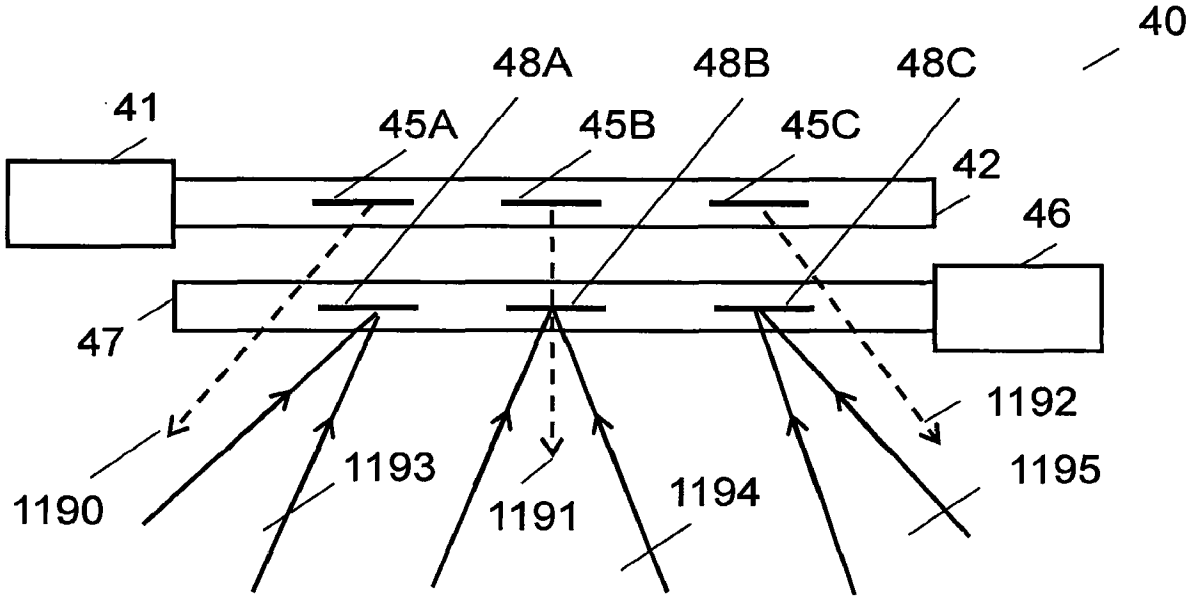


FIG.3

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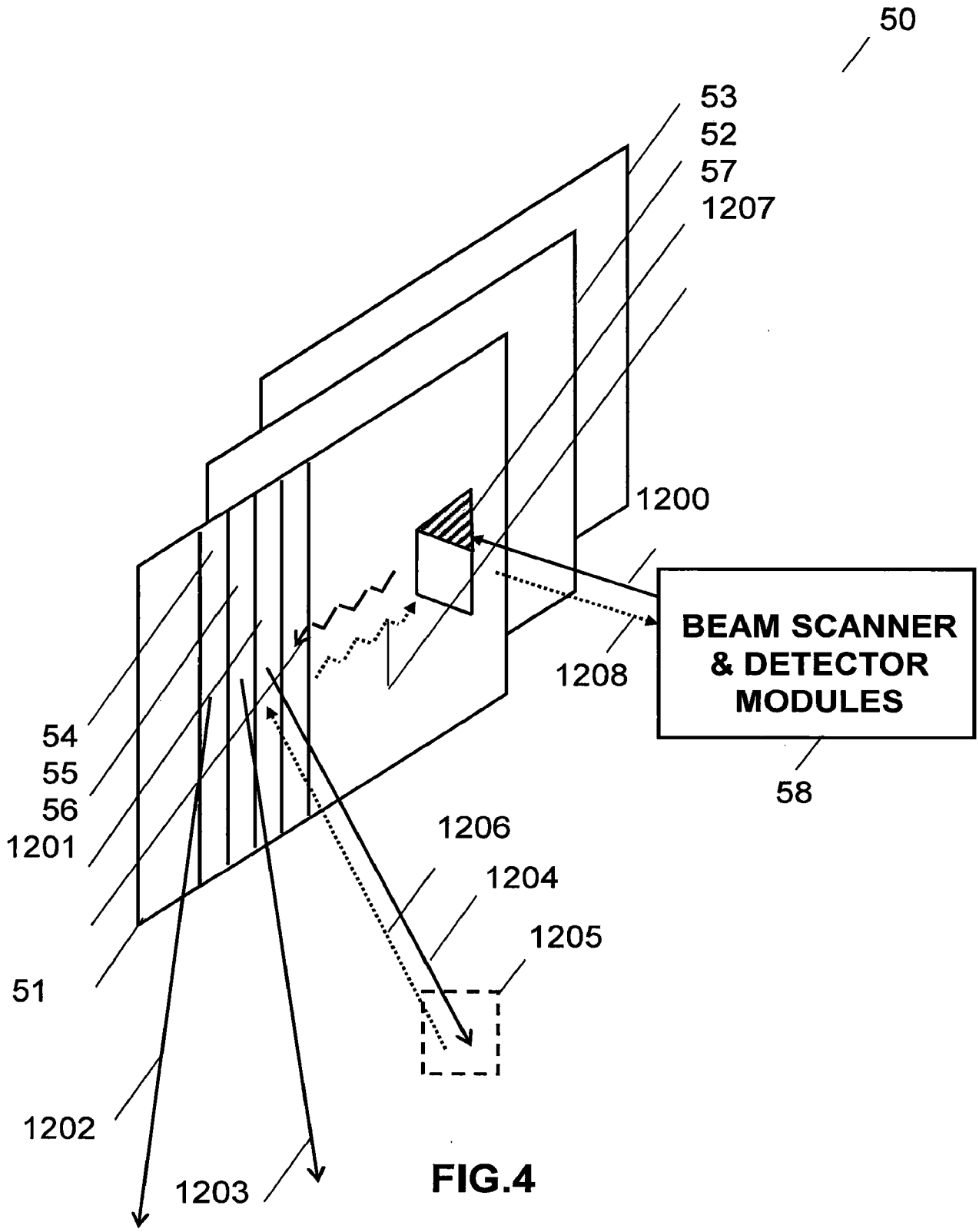


FIG.4

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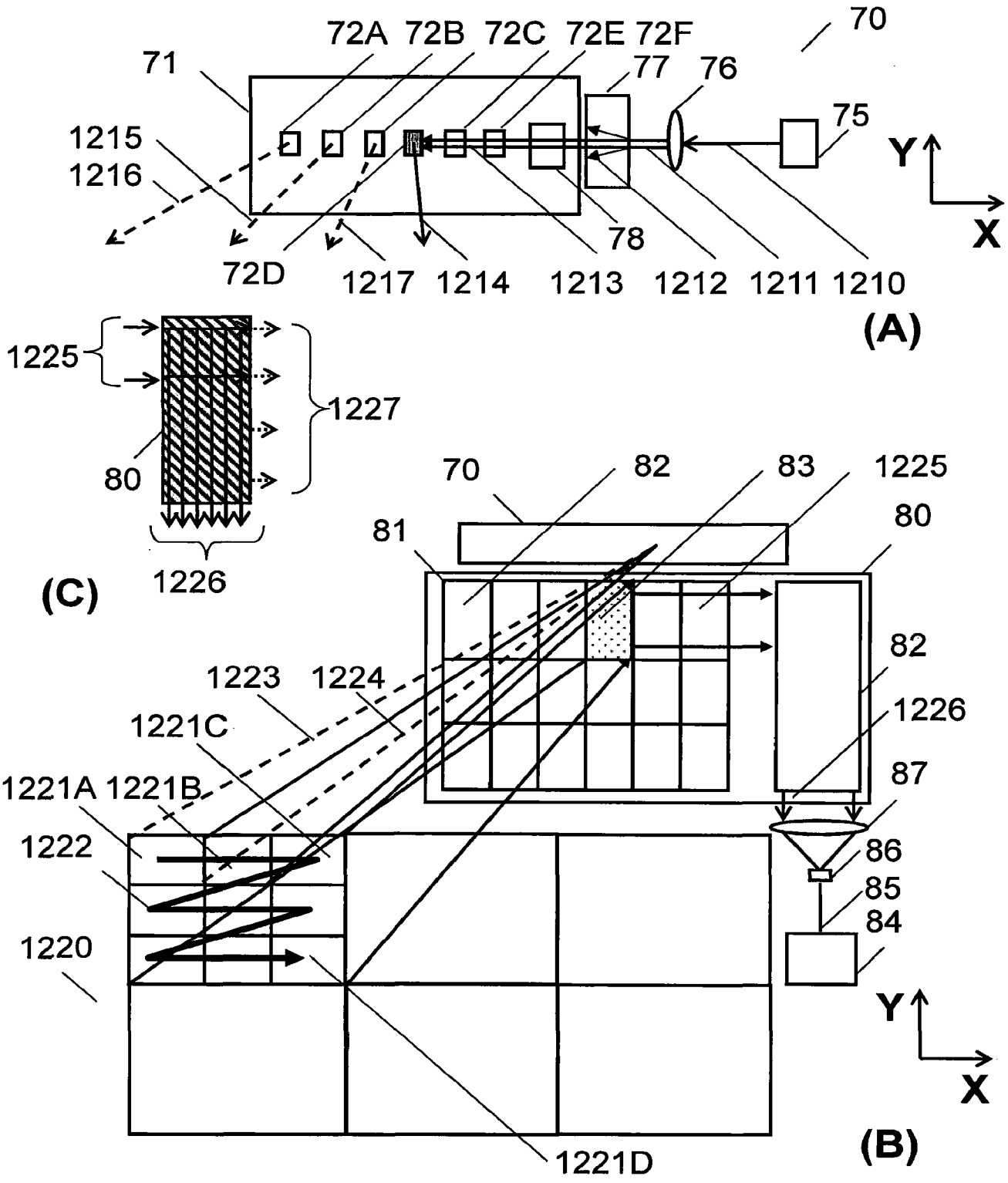

70
72A 72B 72C 72E 72F
71
77 76
75
1215
1216
Y
X
78
72D 1217 1214 1213 1212 1211 1210
(A)
1225
1227
80
1226
(C)
70 82 83 1225
81
80
82
1223 1224
1221C
1226
1221A 1221B
87
1222
86
85
84
1220
Y
X
1221D
(B)

FIG.5

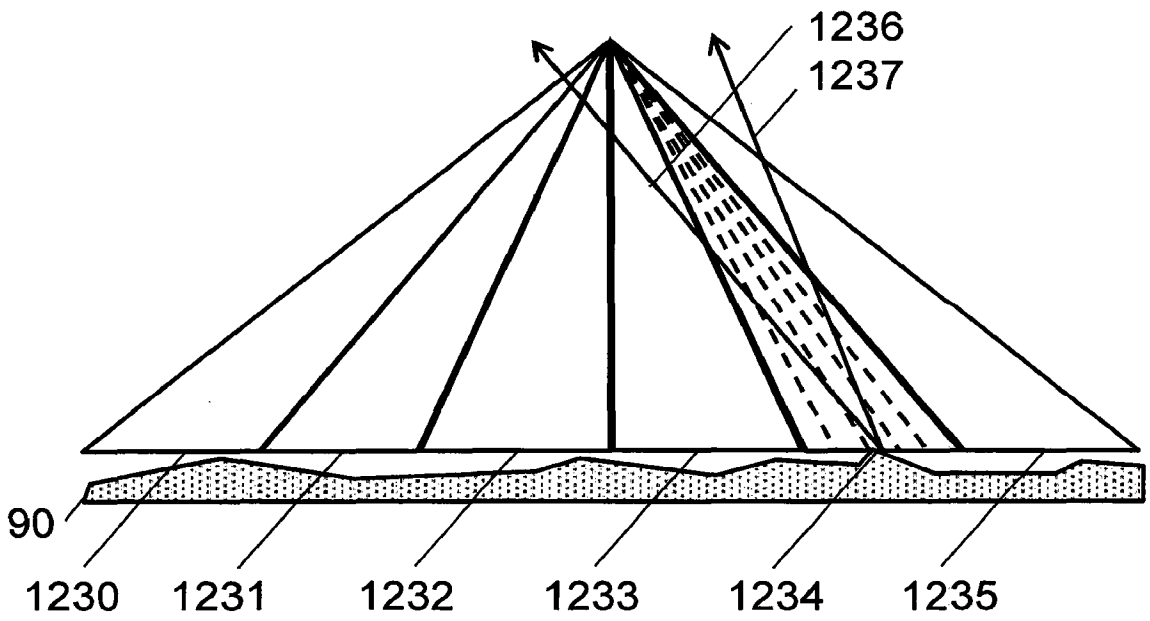


FIG.6

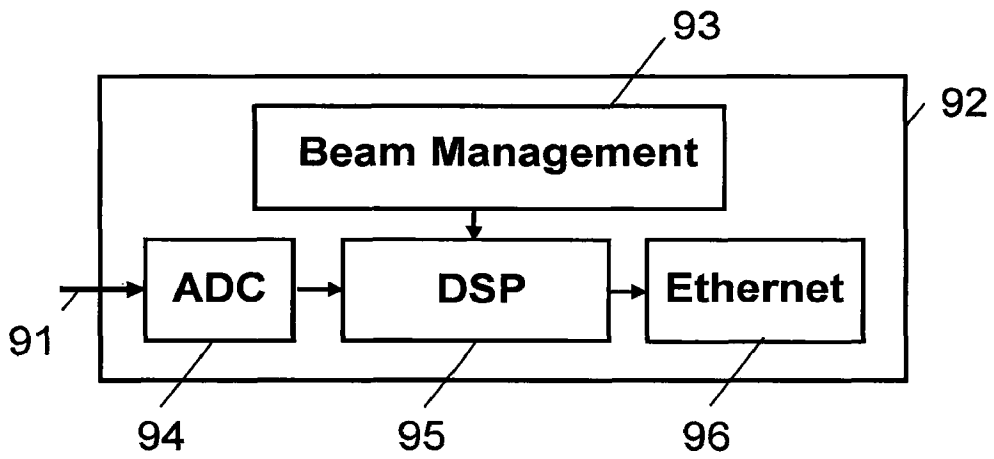


FIG.7

CONFIRMATION COPY

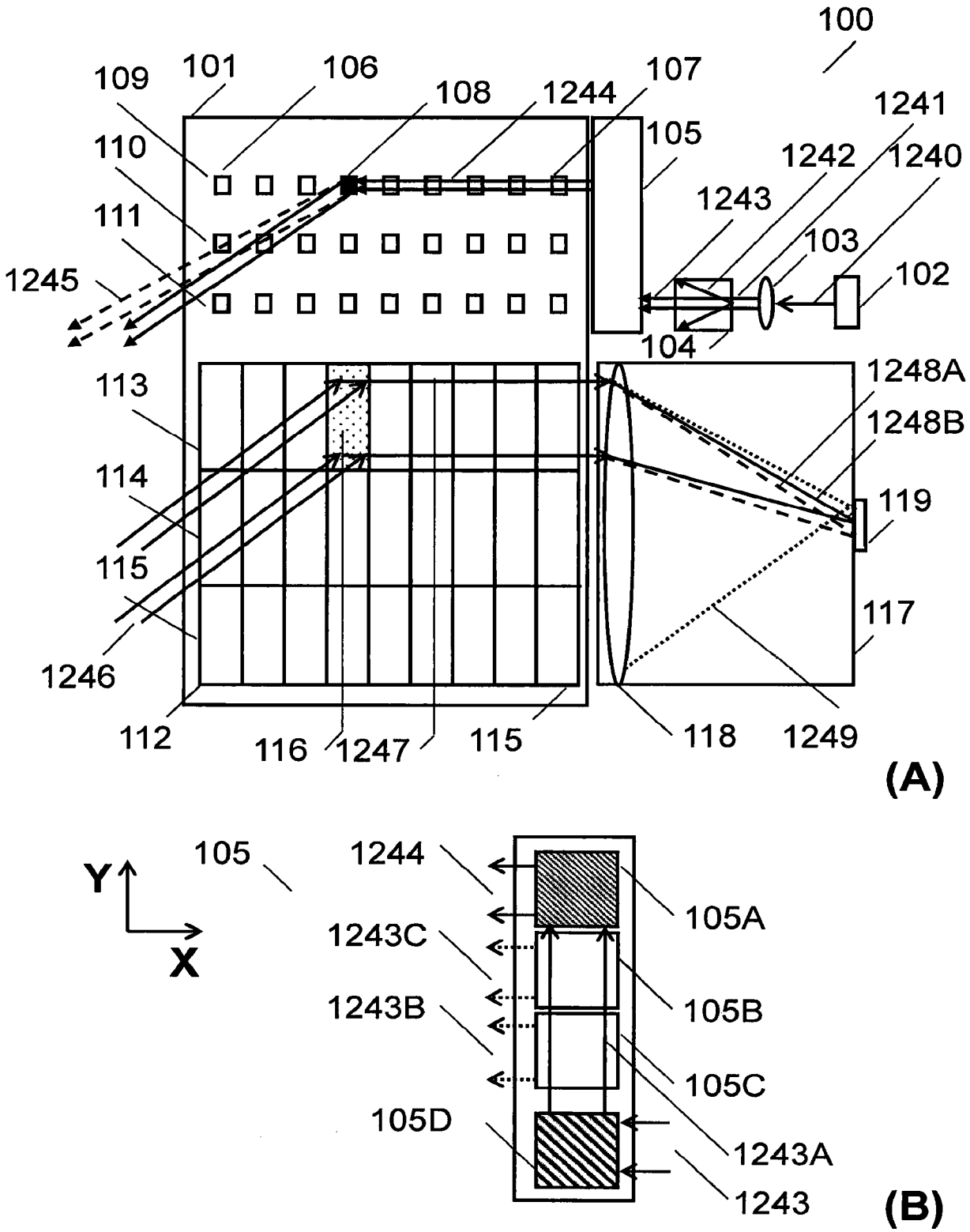


FIG.8

CONFIRMATION COPY

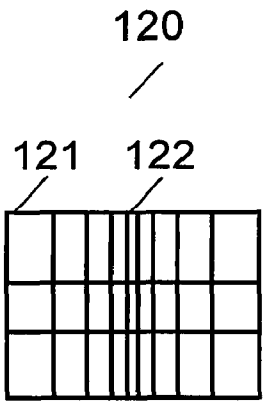


FIG.9

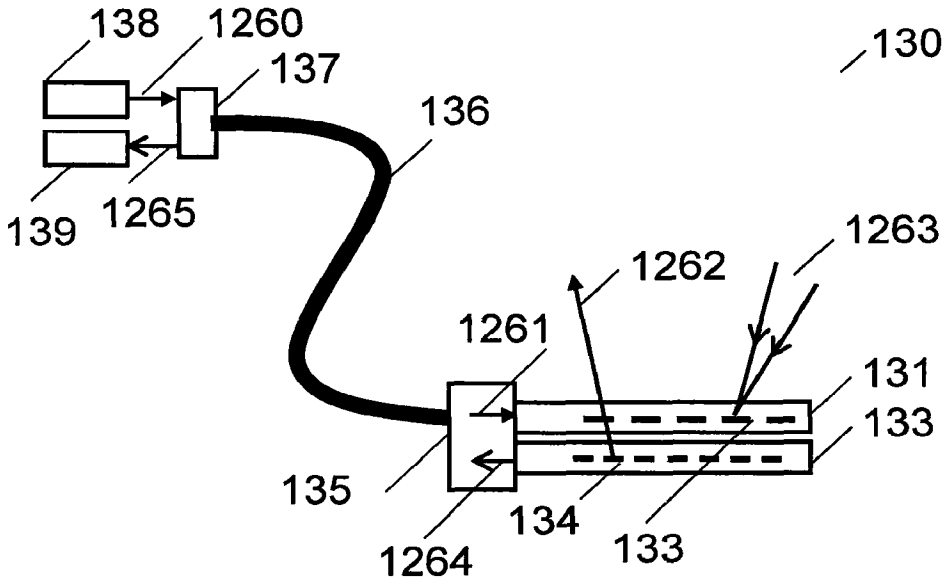


FIG.10

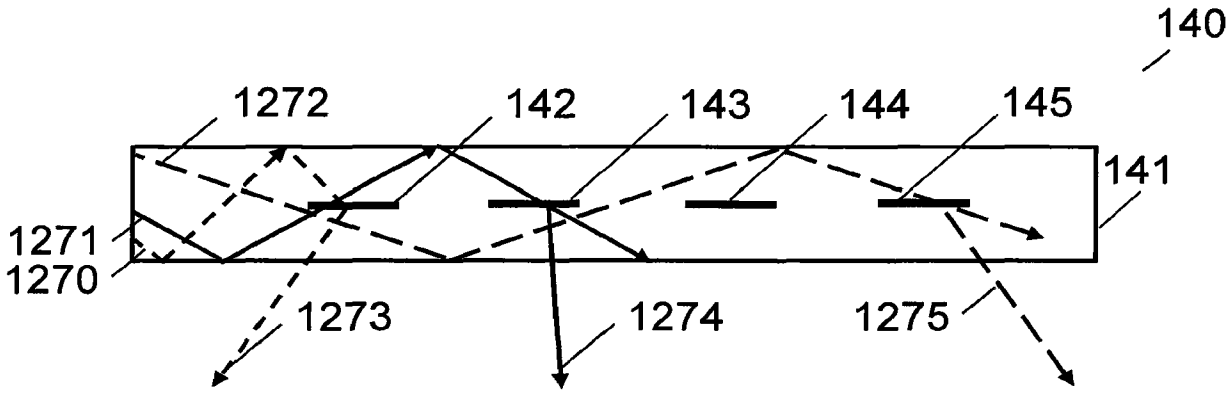


FIG.11

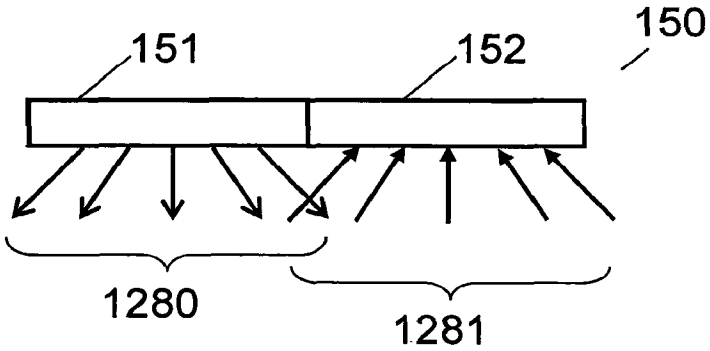


FIG.12

CONFIRMATION COPY

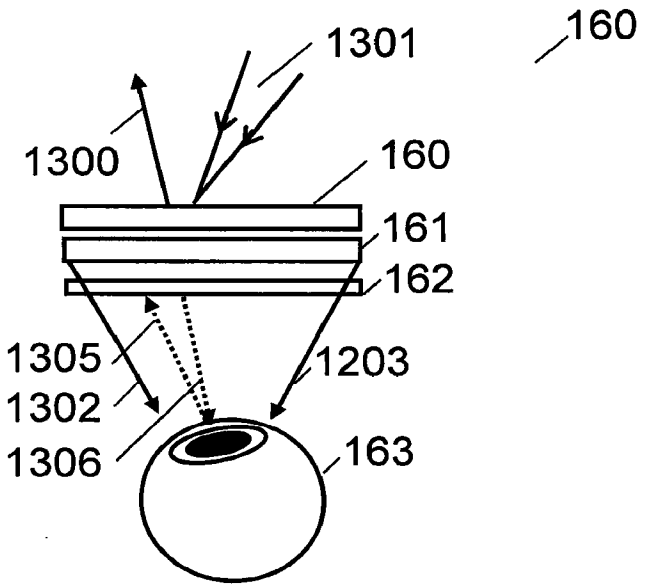


FIG.13

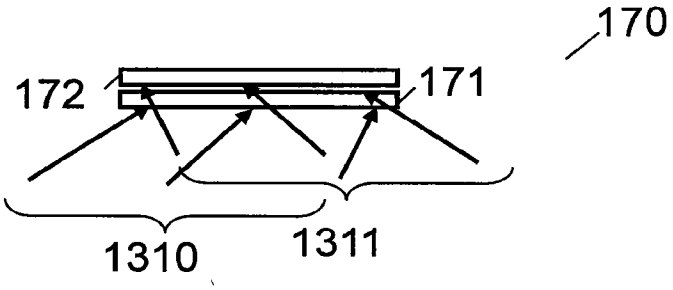


FIG.14

CONFIRMATION COPY

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2016/000014

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01S7/481 G01S17/42 G02B26/10
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G01S G02B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2013/077049 A1 (BOHN DAVID D [US]) 28 March 2013 (2013-03-28) paragraphs [0038] - [0045], [0077] - [0079]; figures 2B,7B	1,15
Y	WO 2014/188149 A1 (POPOVICH MILAN MOMCILO [GB]; WALDERN JONATHAN DAVID; GRANT ALASTAIR JO) 27 November 2014 (2014-11-27) cited in the application page 16, line 8 - page 22, line 1; figure 1 page 41, line 5 - page 42, line 17; figure 33	1-20
Y	WO 2012/172295 A1 (POPOVICH MILAN MOMCILO [GB]; WALDERN JONATHAN DAVID [US]) 20 December 2012 (2012-12-20) abstract; figures 1,19	1-20

-/--

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
27 June 2016	07/07/2016

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Fanjul Caudevilla, J

Form PCT/ISA/210 (second sheet) (April 2005)

HESAI EX1002, P.1082

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2016/000014

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	YAQOOB Z ET AL: "High-speed two-dimensional laser scanner based on Bragg gratings stored in photothermorefractive glass", APPLIED OPTICS, OPTICAL SOCIETY OF AMERICA, WASHINGTON, DC; US, vol. 42, no. 26, 10 September 2003 (2003-09-10), pages 5251-5262, XP002327305, ISSN: 0003-6935, DOI: 10.1364/AO.42.005251 the whole document -----	1-20

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/GB2016/000014

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2013077049 A1	28-03-2013	CN 102955255 A	06-03-2013
		HK 1180771 A1	22-01-2016
		TW 201314263 A	01-04-2013
		US 2013077049 A1	28-03-2013
		WO 2013049012 A1	04-04-2013
WO 2014188149 A1	27-11-2014	NONE	
WO 2012172295 A1	20-12-2012	NONE	

Electronic Acknowledgement Receipt

EFS ID:	32924139
Application Number:	15979266
International Application Number:	
Confirmation Number:	9761
Title of Invention:	SPINNING LIDAR UNIT WITH MICRO-OPTICS ALIGNED BEHIND STATIONARY WINDOW
First Named Inventor/Applicant Name:	Angus PACALA
Customer Number:	20350
Filer:	Stephen A. Mao/La Renda Meyer
Filer Authorized By:	Stephen A. Mao
Attorney Docket Number:	103033-P006US3-1086284
Receipt Date:	18-JUN-2018
Filing Date:	14-MAY-2018
Time Stamp:	14:34:26
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	no

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1	Transmittal Letter	IDS_Transmittal_P006US3-1086284.pdf	108612 7de0c9e5d70727d9a94246373d7b9120aa0a0c41	no	2

Warnings:

Information:					
2	Information Disclosure Statement (IDS) Form (SB08)	IDS_PTOSB08A_P006US3-1086284.pdf	192699 16301d7e4a0513aeb3f6a068a8f3740833030921	no	11
Warnings:					
Information:					
This is not an USPTO supplied IDS fillable form					
3	Non Patent Literature	Cova.pdf	569343 56d76bc672f942c5d8d23450cdc3cfe4c937d8b5	no	5
Warnings:					
Information:					
4	Foreign Reference	EP2124069.pdf	855824 0035751c441d49f4b6afd34ba200e1b4450b6df5	no	15
Warnings:					
Information:					
5	Foreign Reference	EP3002548.pdf	723120 720235988e6eafacd599817cf0e19c8a8088b094	no	16
Warnings:					
Information:					
6	Non Patent Literature	Ex_Kilpela_Reviews_Scientific_Instruments_April_2001.pdf	9734984 7f8734e55fe86df6b3786afb8136998edfd3bc24	no	13
Warnings:					
Information:					
7	Foreign Reference	JP_H36407_with_translation.pdf	1671706 49c26d10c47707670c752eb6d23a96f516b02647	no	15
Warnings:					
Information:					
8	Foreign Reference	Foreign_WO2017132704A1.PDF	1493306 2975caa78be9a3fbcebe7f56669110aff96e580b	no	43
Warnings:					
Information:					

9	Non Patent Literature	HDL-32E_webpage12-2017.pdf	2052396 eddf4a4ddc5a2a16fa951d80a8738e8f2d121383	no	5
Warnings:					
Information:					
10	Non Patent Literature	HDL-64E_DataSheet_2017.pdf	748606 65d3b3ad551c63745baefab11f73510a32ab6cc8	no	2
Warnings:					
Information:					
11	Non Patent Literature	ISR_WO_103033-000110PC-1059680.PDF	1015293 3bcd808353e3b1891ecdb56a1221f1d8f1bdc1e3	no	21
Warnings:					
Information:					
12	Non Patent Literature	NPL_HDL-64E_web_page_2017.pdf	1852175 8622ca525f3fdaea8d8820595c22cf4c1b881756	no	5
Warnings:					
Information:					
13	Non Patent Literature	NPL_Itzler_Geiger-mode_avalance.pdf	1794999 2e2cb4ff1ad6568706398e90bc70600d0db45367	no	14
Warnings:					
Information:					
14	Non Patent Literature	NPL_Puck_Hi-Res_Data_Sheet_Sept2016.pdf	511359 ae3aa2b93e83ef750cf9444c0c858f4e5ba2a741	no	2
Warnings:					
Information:					
15	Non Patent Literature	NPL_Puck_Hi-Res_User_Manual_Sept2016.pdf	6903338 31c21782c0d3260422bc34300ada96fee2b2d2dc	no	49
Warnings:					
Information:					

16	Non Patent Literature	NPL_Puck_LITE_Data_Sheet_Feb2016.pdf	494889 51ff47c273fa705d819cb9d1e84d2805ecefac01	no	2
Warnings:					
Information:					
17	Non Patent Literature	NPL_Puck_LITE_User_Manual_Feb2016.pdf	6903349 97c6dda6f438aeb1fddac40d7ff5ef01c550c30f	no	49
Warnings:					
Information:					
18	Non Patent Literature	NPL_VLP-16_Data_Sheet_2014.pdf	298900 aeb5d79adf812cb3ed3a51b4456f92783a1ae656	no	2
Warnings:					
Information:					
19	Non Patent Literature	NPL_VLP-16_web_page_2017.pdf	999238 009c6b30f689dcf2e08867a743e8a4df655aaf5e	no	5
Warnings:					
Information:					
20	Non Patent Literature	Velodyne_Lidar_HDL-32E_datasheet2010.pdf	900080 62c5b52ba02b57f8d4dcc5f5289515b918756c64	no	2
Warnings:					
Information:					
21	Non Patent Literature	Velodyne_Lidar_HDL-32E_UsersManual2010.pdf	2418730 9dc5036f6beea19cc9cfd7b625c90890f300d256	no	28
Warnings:					
Information:					
22	Non Patent Literature	VelodyneLidar_HDL-64E_Users Manual_2007.pdf	3181827 188ea89bbabe82bd4708d7446afacb1f23280bd9	no	43
Warnings:					
Information:					

23	Non Patent Literature	VelodyneLidarPuckHiResDataSheet.pdf	797857 0d424f72461e97f563b99fd1a7d07eb0b4ecc25c	no	2
Warnings:					
Information:					
24	Non Patent Literature	VelodyneLidarPuckLiteOurLightestSensorEver.pdf	901637 d75683a378498463ee1d4d3331628d5e063af3de	no	2
Warnings:					
Information:					
25	Non Patent Literature	VelodyneLidarPuckUsersManualandProgrammingGuide.pdf	3746167 0550fcc14f134f936ed06c7e60f1a5090b833bfc	no	49
Warnings:					
Information:					
26	Non Patent Literature	VelodyneLidarUltraPuckVLP32C.pdf	1585669 27ca824ea5841f6cdadfb23a5862ca6fb771bbb7	no	4
Warnings:					
Information:					
27	Foreign Reference	WO2015052616.pdf	1190671 c975d6ce1dcd56a817ab16392d453ab94078ea7a	no	20
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Information:					
28	Foreign Reference	WO2016116733.pdf	1443915 a982df6c2f020af9cea8e41913aaf5fb4160add e	no	41
Warnings:					
Information:					
			Total Files Size (in bytes):	55090689	

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New Applications Under 35 U.S.C. 111

If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

National Stage of an International Application under 35 U.S.C. 371

If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office

If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

I hereby certify that this correspondence is being filed via EFS-Web with the United States Patent and Trademark Office on June 18, 2018.

KILPATRICK TOWNSEND & STOCKTON LLP

By: /La Renda Meyer/

PATENT
Attorney Docket No.: 103033- P006US3-1086284
Client Ref. No.: P006US3

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of:	Confirmation No.: 9761
Angus PACALA	Examiner: Not yet assigned
Application No.: 15/979,266	Technology Center/Art Unit: Not yet assigned
Filed: May 14, 2018	
For: SPINNING LIDAR UNIT WITH MICRO-OPTICS ALIGNED BEHIND STATIONARY WINDOW	INFORMATION DISCLOSURE STATEMENT
Customer No.: 20350	

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Commissioner:

The references cited on attached form PTO/SB/08A are being called to the attention of the Examiner. In accordance with the provisions of 37 CFR §1.98(a)(2), copies of any cited U.S. Patent and U.S. Patent Application Publications are not provided. Copies of the remaining cited references are provided.

It is respectfully requested that the cited references be expressly considered during the prosecution of this application, and the references be made of record therein and appear among the "references cited" on any patent to issue therefrom.

As provided for by 37 CFR §1.97(g) and (h), no inference should be made that the information and references cited are prior art merely because they are in this statement and no representation is being made that a search has been conducted or that this statement encompasses all the possible relevant information.

This Information Disclosure Statement is being filed before the mailing date of the first Office Action on the merits.

Applicant believes that no fee is required for submission of this statement. However, if any additional fees are due for the submission of this Information Disclosure Statement, please deduct those fees from Deposit Account No. 20-1430.

Respectfully submitted,

/Stephen A. Mao/

Stephen A. Mao
Registration No. 73418

KILPATRICK TOWNSEND & STOCKTON LLP

PATENT APPLICATION FEE DETERMINATION RECORD

Substitute for Form PTO-875

Application or Docket Number: 15/979,266

APPLICATION AS FILED - PART I

FOR	(Column 1) NUMBER FILED	(Column 2) NUMBER EXTRA	SMALL ENTITY RATE($)	SMALL ENTITY FEE($)	OR	OTHER THAN SMALL ENTITY RATE($)	OTHER THAN SMALL ENTITY FEE($)
BASIC FEE (37 CFR 1.16(a), (b), or (c))	N/A	N/A	N/A	75		N/A	
SEARCH FEE (37 CFR 1.16(k), (i), or (m))	N/A	N/A	N/A	330		N/A	
EXAMINATION FEE (37 CFR 1.16(o), (p), or (q))	N/A	N/A	N/A	380		N/A	
TOTAL CLAIMS (37 CFR 1.16(i))	20 minus 20 =	*	x 50 =	0.00	OR		
INDEPENDENT CLAIMS (37 CFR 1.16(h))	3 minus 3 =	*	x 230 =	0.00			
APPLICATION SIZE FEE (37 CFR 1.16(s))	If the specification and drawings exceed 100 sheets of paper, the application size fee due is $310 ($155 for small entity) for each additional 50 sheets or fraction thereof. See 35 U.S.C. 41(a)(1)(G) and 37 CFR 1.16(s).			0.00			
MULTIPLE DEPENDENT CLAIM PRESENT (37 CFR 1.16(j))				0.00			
* If the difference in column 1 is less than zero, enter "0" in column 2.			TOTAL	785		TOTAL	

APPLICATION AS AMENDED - PART II

		(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA	SMALL ENTITY RATE($)	SMALL ENTITY ADDITIONAL FEE($)	OR	OTHER THAN SMALL ENTITY RATE($)	OTHER THAN SMALL ENTITY ADDITIONAL FEE($)
AMENDMENT A	Total (37 CFR 1.16(i))	*	Minus	**	=	x =		OR	x =	
	Independent (37 CFR 1.16(h))	*	Minus	***	=	x =		OR	x =	
	Application Size Fee (37 CFR 1.16(s))									
	FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))							OR		
						TOTAL ADD'L FEE		OR	TOTAL ADD'L FEE	

		(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA	RATE($)	ADDITIONAL FEE($)		RATE($)	ADDITIONAL FEE($)
AMENDMENT B	Total (37 CFR 1.16(i))	*	Minus	**	=	x =		OR	x =	
	Independent (37 CFR 1.16(h))	*	Minus	***	=	x =		OR	x =	
	Application Size Fee (37 CFR 1.16(s))									
	FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))							OR		
						TOTAL ADD'L FEE		OR	TOTAL ADD'L FEE	

* If the entry in column 1 is less than the entry in column 2, write "0" in column 3.
** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 20, enter "20".
*** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 3, enter "3".
The "Highest Number Previously Paid For" (Total or Independent) is the highest found in the appropriate box in column 1.

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United States Patent and Trademark Office
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APPLICATION NUMBER	FILING or 371(c) DATE	GRP ART UNIT	FIL FEE REC'D	ATTY.DOCKET.NO	TOT CLAIMS	IND CLAIMS
15/979,266	05/14/2018	2875	865	103033-P006US3-1086284	20	3

CONFIRMATION NO. 9761

FILING RECEIPT

20350
KILPATRICK TOWNSEND & STOCKTON LLP
Mailstop: IP Docketing - 22
1100 Peachtree Street
Suite 2800
Atlanta, GA 30309

OC000000100246573

Date Mailed: 06/14/2018

Receipt is acknowledged of this non-provisional patent application. The application will be taken up for examination in due course. Applicant will be notified as to the results of the examination. Any correspondence concerning the application must include the following identification information: the U.S. APPLICATION NUMBER, FILING DATE, NAME OF APPLICANT, and TITLE OF INVENTION. Fees transmitted by check or draft are subject to collection. Please verify the accuracy of the data presented on this receipt. **If an error is noted on this Filing Receipt, please submit a written request for a Filing Receipt Correction. Please provide a copy of this Filing Receipt with the changes noted thereon. If you received a "Notice to File Missing Parts" for this application, please submit any corrections to this Filing Receipt with your reply to the Notice. When the USPTO processes the reply to the Notice, the USPTO will generate another Filing Receipt incorporating the requested corrections**

Inventor(s)

Angus PACALA, San Francisco, CA;
Mark FRICHTL, San Francisco, CA;
Marvin SHU, San Francisco, CA;

Applicant(s)

Ouster, Inc., San Francisco, CA;

Assignment For Published Patent Application

Ouster, Inc., San Francisco, CA

Power of Attorney: None

Domestic Priority data as claimed by applicant

This appln claims benefit of 62/506,449 05/15/2017
and claims benefit of 62/506,437 05/15/2017
and claims benefit of 62/506,445 05/15/2017
and claims benefit of 62/515,291 06/05/2017

Foreign Applications for which priority is claimed (You may be eligible to benefit from the **Patent Prosecution Highway** program at the USPTO. Please see http://www.uspto.gov for more information.) - None.
Foreign application information must be provided in an Application Data Sheet in order to constitute a claim to foreign priority. See 37 CFR 1.55 and 1.76.

Permission to Access Application via Priority Document Exchange: Yes

Permission to Access Search Results: Yes

Applicant may provide or rescind an authorization for access using Form PTO/SB/39 or Form PTO/SB/69 as appropriate.

If Required, Foreign Filing License Granted: 06/12/2018

The country code and number of your priority application, to be used for filing abroad under the Paris Convention, is **US 15/979,266**

Projected Publication Date: 11/15/2018

Non-Publication Request: No

Early Publication Request: No

**** SMALL ENTITY ****

Title

SPINNING LIDAR UNIT WITH MICRO-OPTICS ALIGNED BEHIND STATIONARY WINDOW

Preliminary Class

362

Statement under 37 CFR 1.55 or 1.78 for AIA (First Inventor to File) Transition Applications: No

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Since the rights granted by a U.S. patent extend only throughout the territory of the United States and have no effect in a foreign country, an inventor who wishes patent protection in another country must apply for a patent in a specific country or in regional patent offices. Applicants may wish to consider the filing of an international application under the Patent Cooperation Treaty (PCT). An international (PCT) application generally has the same effect as a regular national patent application in each PCT-member country. The PCT process **simplifies** the filing of patent applications on the same invention in member countries, but **does not result** in a grant of "an international patent" and does not eliminate the need of applicants to file additional documents and fees in countries where patent protection is desired.

Almost every country has its own patent law, and a person desiring a patent in a particular country must make an application for patent in that country in accordance with its particular laws. Since the laws of many countries differ in various respects from the patent law of the United States, applicants are advised to seek guidance from specific foreign countries to ensure that patent rights are not lost prematurely.

Applicants also are advised that in the case of inventions made in the United States, the Director of the USPTO must issue a license before applicants can apply for a patent in a foreign country. The filing of a U.S. patent application serves as a request for a foreign filing license. The application's filing receipt contains further information and guidance as to the status of applicant's license for foreign filing.

Applicants may wish to consult the USPTO booklet, "General Information Concerning Patents" (specifically, the section entitled "Treaties and Foreign Patents") for more information on timeframes and deadlines for filing foreign patent applications. The guide is available either by contacting the USPTO Contact Center at 800-786-9199, or it can be viewed on the USPTO website at http://www.uspto.gov/web/offices/pac/doc/general/index.html.

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Title 37, Code of Federal Regulations, 5.11 & 5.15

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INFORMAL NOTICE

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- A properly executed inventor's oath or declaration has not been received for the following inventor(s):
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Questions about the contents of this notice and the requirements it sets forth should be directed to the Office of Data Management, Application Assistance Unit, at **(571) 272-4000** or **(571) 272-4200** or **1-888-786-0101**.

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PATENT APPLICATION

SPINNING LIDAR UNIT WITH MICRO-OPTICS ALIGNED BEHIND STATIONARY WINDOW

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SPINNING LIDAR UNIT WITH MICRO-OPTICS ALIGNED BEHIND STATIONARY WINDOW

CROSS REFERENCES TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. Provisional Patent Application No. 62/506,449, filed on May 15, 2017, U.S. Provisional Patent Application No. 62/506,437, filed on May 15, 2017, U.S. Provisional Patent Application No. 62/506,445, filed on May 15, 2017, and U.S. Provisional Patent Application No. 62/515,291, filed June 5, 2017, the disclosures of which are herein incorporated by reference in their entirety and for all purposes.

BACKGROUND

[0002] An imager detects light and creates a digital image of a scene based on that detected light. The image contains a fixed number of rows and columns of pixels where each pixel maps to a different field-of-view within the scene. Electronic imagers typically make use of photodetectors to convert light into electrical signals. Each photodetector is located at a different position on the focal plane and usually corresponds to a single pixel or a component of a pixel in the image. Electronic imagers can typically be classified as one of two types: a passive-illumination imager or an active-illumination imager. A passive-illumination imager collects ambient light such as sunlight reflected by objects in a scene, whereas an active-illumination imager illuminates the scene and collects reflected light generated by the active-illumination imager system itself.

[0003] A narrowband imager collects light within a limited wavelength range. This is in contrast to a traditional camera which detects light across the entire visible spectrum or into three different wide, RGB color bands, each of which may be 100 nm or wider. Narrowband imagers are harder to develop than traditional cameras due to the characteristics of the optical filters on which they rely. Optical filters serve to prevent some portion of the electromagnetic spectrum from reaching the photodetectors. Most narrowband filters rely on thin-film interference effects to selectively transmit or reflect light (such filters are often referred to as dielectric mirrors or Bragg mirrors). The spectral transmissivity of the narrowband filter depends on the number, thicknesses, ordering, and indices of refraction of the constituent layers forming the filter. The

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spectral transmissivity of the filter also depends upon the angle of incidence of the light upon the narrowband filter.

[0004] Current narrowband imagers have either a small field-of-view or are limited in their ability to filter wavelength bands narrower than around 50 nm. Optical filters are sensitive to the angle of incident light making it difficult to achieve a narrow range of wavelengths. For example, an optical filter may accept perpendicular light with wavelength at 940-945 nm and slightly oblique light at a wavelength of 930-935 nm. Since most photodetectors in a traditional camera have a large range of angles of light incident upon them, simply placing an optical filter in front of them would not actually achieve narrowband filtering. Constricting the angle of light incident upon the photodetector usually requires using a lens with a longer focal length, which constricts the field-of-view of the camera.

[0005] Imagers with a wide field-of-view have difficulty in generating uniformly clear visual images and in making uniform measurements across a scene. For example, the pixels at the center of the image may appear brighter or represent a different wavelength of light compared to the pixels at the scene extremities. A wide field-of-view is desirable for some applications because it provides better situational awareness. For example, a camera-based automotive safety system meant to detect pedestrians around a vehicle might require monitoring in a 360 degree field-of-view around the vehicle. Fewer wide field-of-view sensors are required to do the same job (i.e., generate images of the full 360 degree field-of-view) as many narrow field of view sensors, thereby decreasing the system cost.

[0006] Narrowband imagers have many applications including geographic mapping, astronomy and in LIDAR (Light Detection and Ranging). Narrowband imagers can detect characteristic light wavelengths such as those generated by plants with chlorophyll or by elements within stars. Narrowband imagers can be used, for example, to determine vegetation health or to discover oil deposits. Optical receiver systems, such as LIDAR, can be used for object detection and ranging. LIDAR systems measure the distance to a target or objects in a landscape, by irradiating a target or landscape with light, using pulses from a laser, and measuring the time it takes photons to travel to the target or landscape and return after reflection to a narrowband imager. Other LIDAR techniques, such as photo-demodulation, coherent LIDAR, and range-gated LIDAR, also rely on the transmission and reflection of photons, though

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they may not directly measure the time-of-flight of pulses of laser light. For many LIDAR applications, it is beneficial for physical sizes of transmitters and receivers to small and compact, and at the same time relatively low in cost. For applications where objects must be sensed with accuracy at long distances, it is beneficial to increase or maximize the number of photons emitted by the transmitter and reflected back toward the receiver while keeping laser energy emissions within mandated safety limits.

[0007] Micro-optical systems are systems that include miniaturized, optical components that are typically between a few micrometers and a millimeter in size. Micro-optical receivers arrayed adjacent to each other are susceptible to crosstalk. Stray light caused by roughness of optical surfaces, imperfections in transparent media, back reflections, etc., may be generated at various features within the receiver channel or external to receiver channel. When multiple receiver channels are arrayed adjacent to one another, this stray light in one receiver channel may be absorbed by a photosensor in another channel, thereby contaminating the timing, phase, or other information inherent to photons. Minimizing crosstalk is especially important in active-illumination systems. Light reflected from a nearby retro-reflector (e.g. a license plate) may be thousands or millions of time more intense than light reflected from a distant, dark, lambertian surface (e.g. black cotton clothing). Thus, the stray light photons from a retro-reflector could vastly outnumber photons reflected from other surfaces in nearby photosensors if crosstalk is not minimized. This can result in the inability of a LIDAR system to detect dark objects that occupy fields of view near the field of view occupied by a retro-reflector.

SUMMARY

[0008] Embodiments of the disclosure provide optical imager systems that achieve wide field-of-view, narrowband imaging with micro-optic receiver channel arrays that minimize crosstalk and allow tight spectral selectivity that is uniform across the receiver channel array. Some optical imager systems according to the disclosure can include a light transmission module that provides enhanced spot illumination such that a power level of light returning to a light sensing module is increased, while at the same time improving the spatial resolution of the measured image.

[0009] In some embodiments, an optical system for performing distance measurements includes a bulk transmitter optic, an illumination source, and a micro-optic channel array

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disposed between the illumination source and the bulk transmitter optic. The illumination source includes a plurality of light emitters aligned to project discrete beams of light through the bulk transmitter optic into a field ahead of the optical system. The micro-optic channel array defines a plurality of micro-optic channels where each micro-optic channel includes a micro-optic lens spaced apart from a light emitter from the plurality of light emitters with the micro-optic lens being configured to receive a light cone from the light emitter and generate a reduced-size spot image of the emitter at a focal point displaced from the emitter at a location between the emitter and the bulk transmitter optic. The micro-optic lens for each channel can be configured to receive a light cone from a light emitter and generate a reduced-size real spot image of the emitter at a focal point between the micro-optic lens and the bulk transmitter optic. A divergence of the light cone from the light emitter can be less than a divergence of a light cone from the second optical surface of the micro-optic lens for generating the reduced-size real spot image

[0010] In some additional embodiments, an optical system for performing distance measurements includes a light emission system and a light detection system. The light emission system includes a bulk transmitter optic, an illumination source comprising a plurality of light emitters aligned to project discrete beams of light through the bulk transmitter optic into a field ahead of the optical system, and a micro-optic channel array disposed between the illumination source and the bulk transmitter optic. The micro-optic channel array defines a plurality of micro-optic channels where each micro-optic channel includes a micro-optic lens spaced apart from a light emitter from the plurality of light emitters with the micro-optic lens being configured to receive a light cone from the light emitter and generate a reduced-size spot image of the emitter at a focal point displaced from the emitter at a location between the emitter and the bulk transmitter optic. The light detection system includes a bulk receiver optic configured to receive the discrete beams of light from the field, and an optical assembly having a plurality of micro-optic receiver channels defining a plurality of discrete, non-overlapping fields of view in the field. The optical assembly includes: an aperture layer having a plurality of discrete apertures arranged along a focal plane of the bulk receiver optic; an array of photosensors disposed behind the aperture layer; and a plurality of lenses positioned between the aperture layer and the array of photosensors.

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[0011] In certain embodiments, an optical system for performing distance measurements includes a stationary housing having an optically transparent window, and a light ranging device disposed within the housing. The light ranging device includes an optical transmitter coupled to a platform. The optical transmitter includes a bulk transmitter optic, an illumination source, and a micro-optic channel array disposed between the illumination source and the bulk transmitter optic. The illumination source including a plurality of light emitters aligned to project discrete beams of light through the bulk transmitter optic into a field ahead of the optical system. The micro-optic channel array can be disposed between the illumination source and the bulk transmitter optic, and the micro-optic channel array can define a plurality of micro-optic channels where each micro-optic channel can include a micro-optic lens spaced apart from a light emitter from the plurality of light emitters with the micro-optic lens being configured to receive a light cone from the light emitter and generate a reduced-size spot image of the emitter at a focal point displaced from the emitter at a location between the emitter and the bulk transmitter optic.

[0012] In some embodiments, an optical system includes a bulk receiver optic configured to receive light rays originating from a field external to the optical system, and an optical assembly having a plurality of micro-optic receiver channels defining a plurality of discrete, non-overlapping fields of view in the field. The optical assembly includes an aperture layer having a plurality of discrete apertures arranged along a focal plane of the bulk receiver optic, an array of photosensors disposed behind the aperture layer, and a non-uniform optical filter layer configured to allow different micro-optic channels to measure different ranges of wavelengths. The non-uniform optical filter can include a graduated optical filter that gradually increases in thickness in one dimension, or increases in thickness in a step-wise fashion in one direction such that each channel has a constant optical filter layer thickness, but where the thicknesses for different micro-optic channels are different.

[0013] In some additional embodiments, an optical system includes a bulk receiver optic configured to receive light from a field external to the optical system, an aperture layer disposed behind the bulk optic and including a plurality of apertures located at a focal plane of the bulk optic, a lens layer including a plurality of collimating lenses having a focal length, the lens layer disposed behind the aperture layer and separated from the aperture layer by the focal length, a

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non-uniform optical filter layer behind the lens layer, and a photosensor layer including a plurality of photosensors. The aperture layer, lens layer, non-uniform optical filter layer and photosensor layer are arranged to form a plurality of micro-optic channels defining a plurality of discrete, non-overlapping fields of view in the field with each micro-optic channel in the plurality of micro-optic channels including an aperture from the plurality of apertures, a lens from the plurality of lenses, a filter from the filter layer, and a photosensor from the plurality of photosensors and being configured to communicate light incident from the bulk receiver optic to the photosensor of the micro-optic channel. The non-uniform optical filter layer is configured to allow different micro-optic channels to measure different ranges of wavelengths.

[0014] In certain embodiments, an optical system includes a bulk receiver optic configured to receive light rays originating from a field external to the optical system, and an optical assembly having a plurality of micro-optic receiver channels defining a plurality of discrete, non-overlapping fields of view in the field. The optical assembly includes a monolithic ASIC including a processor, a memory, and a plurality of photosensors fabricated in the ASIC, an aperture layer having a plurality of discrete apertures arranged along a focal plane of the bulk receiver optic, the array of photosensors disposed behind the aperture layer; a plurality of lenses positioned between the aperture layer and the array of photosensors; and a non-uniform optical filter layer having different center wavelengths across its structure to allow at least two different micro-optic receiver channels to measure different ranges of wavelengths of light, wherein the aperture layer, plurality of lenses, and non-uniform optical filter layer are formed on the ASIC such that they form part of the monolithic structure of the ASIC.

[0015] In some embodiments, an optical system for performing distance measurements includes a stationary housing having an optically transparent window, a spinning light ranging device disposed within the housing, a motor disposed within the housing and operatively coupled to spin the light ranging device including the platform, optical transmitter, and optical receiver within the housing, and a system controller disposed within the housing, the system controller configured to control the motor and to start and stop light detection operations of the light ranging device. The light ranging device includes a platform, an optical transmitter coupled to the platform, and an optical receiver coupled to the platform. The optical transmitter includes a bulk transmitter optic and a plurality of transmitter channels, each transmitter channel including

a light emitter configured to generate and transmit a narrowband light through the bulk transmitter optic into a field external to the optical system. The optical receiver includes a bulk receiver optic and a plurality of micro-optic receiver channels, each micro-optic channel including an aperture coincident with a focal plane of the bulk receiver optic, an optical filter positioned along a path of light from the bulk receiver optic and axially aligned with the aperture, and a photosensor responsive to incident photons passed through the aperture and the optical filter.

[0016] In some additional embodiments, an optical system for performing distance measurements includes a stationary housing having a base, a top and an optically transparent window disposed between the base and the top, a spinning light ranging device disposed within the housing and aligned with the optically transparent window, a motor disposed within the housing and operatively coupled to spin the light ranging device including the platform, optical transmitter and optical receiver within the housing, and a system controller disposed within the housing, the system controller configured to control the motor and to start and stop light detection operations of the light ranging device. The light ranging device including a platform, an optical transmitter coupled to the platform, and an optical receiver coupled to the platform. The optical transmitter including an image-space telecentric bulk transmitter optic and a plurality of transmitter channels, each channel including a light emitter configured to generate and transmit a narrowband light through the bulk transmitter optic into a field external to the optical system. The optical receiver including an image-space telecentric bulk receiver optic and a plurality of micro-optic receiver channels, each micro-optic channel including an aperture coincident with a focal plane of the bulk receiver optic, a collimating lens behind the aperture, an optical filter behind the collimating lens and a photosensor responsive to incident photons passed through the aperture into the collimating lens and through the filter.

[0017] In certain embodiments, an optical system for performing distance measurements includes a stationary housing having a base, a top and an optically transparent window disposed between the base and the top, a light ranging device disposed within the housing and aligned with the optically transparent window, a motor disposed within the housing and operatively coupled to spin the light ranging device within the housing; and a system controller disposed within the housing, the system controller configured to control the motor and to start and stop

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light detection operations of the light ranging device. The light ranging device includes a platform, a plurality of vertical-cavity surface emitting lasers (VCSELs) arranged in an array, and an optical receiver coupled to the platform. Each VCSEL in the plurality of VCSELs are configured to generate and transmit discrete pulses of light into a field external to the optical system. The optical receiver including a bulk receiver optic, a plurality of photosensors, each photosensor comprising a plurality of single-photon avalanche diodes (SPADs) responsive to incident photons, and an optical filter disposed between the bulk receiver optic and the plurality of photosensors and configured to allow a band of light to pass through the filter to the plurality of photosensors while blocking light outside the band from reaching the plurality of photosensors.

[0018] In some embodiments, an optical system for performing distance measurements includes a rotatable platform, an optical transmitter coupled to the rotatable platform and comprising a bulk transmitter optic and a plurality of transmitter channels, an optical receiver coupled to the rotatable platform and comprising a bulk receiver optic and a plurality of micro-optic receiver channels, a motor disposed within the housing and operatively coupled to spin the platform, optical transmitter, and optical receiver, a system controller mounted to a stationary component of the optical system; and an optical communication link operatively coupled between the system controller and the optical receiver to enable the system controller to communicate with the optical receiver. Each transmitter channel includes a light emitter configured to generate and transmit a narrowband light through the bulk transmitter optic into a field external to the optical system. Each micro-optic channel includes an aperture coincident with a focal plane of the bulk receiver optic, an optical filter positioned along a path of light from the bulk receiver optic and axially aligned with the aperture, and a photosensor responsive to incident photons passed through the aperture and through the filter. The optical communication link can extend between the stationary component of the optical system and the rotatable platform to operatively couple the system controller with the optical receiver. The optical receiver can further include a collimating lens behind the aperture and directly coupled to the optical filter, the optical filter positioned behind the collimating lens.

[0019] In some additional embodiments, an optical system for performing distance measurements including a rotatable platform, an optical transmitter coupled to the rotatable

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platform and comprising an image-space telecentric bulk transmitter optic and a plurality of transmitter channels, an optical receiver coupled to the rotatable platform and comprising an image-space telecentric bulk receiver optic and a plurality of micro-optic receiver channels, a motor disposed within the housing and operatively coupled to spin the platform, optical transmitter and optical receiver, a system controller mounted to a stationary component of the optical system, and an optical communication link operatively coupled between the system controller and the optical receiver to enable the system controller to communicate with the optical receiver. Each transmitter channel includes a light emitter configured to generate and transmit a narrowband light through the bulk transmitter optic into a field external to the optical system. Each micro-optic channel includes an aperture coincident with a focal plane of the bulk receiver optic, a collimating lens behind the aperture, an optical filter behind the collimating lens and a photosensor responsive to incident photons passed through the aperture into the collimating lens and through the filter.

[0020] In certain embodiments, An optical system for performing distance measurements includes a rotatable platform, a plurality of vertical-cavity surface emitting lasers (VCSELs) arranged in an array and coupled to the rotatable platform, an optical receiver coupled to the rotatable platform, a motor disposed within the housing and operatively coupled to spin the platform, the plurality of VCSELs and the optical receiver; a system controller mounted to a stationary component of the optical system, and an optical communication link operatively coupled between the system controller and the optical receiver to enable the system controller to communicate with the optical receiver. Each VCSEL in the plurality of VCSELs are configured to generate and transmit discrete pulses of light into a field external to the optical system. The optical receiver including a bulk receiver optic and a plurality of photosensors, each photosensor comprising a plurality of single-photon avalanche diodes (SPADs) responsive to incident photons.

[0021] In some embodiments, an optical system for performing distance measurements includes a bulk receiver optic, an aperture layer including a plurality of apertures, a first lens layer including a first plurality of lenses, an optical filter layer configured to receive light after it passes through the bulk receiver optic and pass a band of radiation while blocking radiation outside the band, and a photosensor layer including a plurality of photosensors, Each

photosensor includes a plurality of photodetectors configured to detect photons, and a second plurality of lenses configured to focus incident photons received at the photosensor on the plurality of photodetectors. The optical system inclufdes a plurality of receiver channels with each receiver channel in the plurality of receiver channels including an aperture from the plurality of apertures, a lens from the plurality of first lenses, an optical filter from the optical filter layer, and a photosensor from the plurality of photosensors, with the aperture for each channel defining a discrete, non-overlapping field of view for its respective channel. For each receiver channel in the plurality of receiver channels, there can be a one-to-one correspondence between the plurality of photodetectors and the second plurality of lenses in the photosensor for that channel, where each of the lenses in the second plurality of lenses can be configured to focus photons on its corresponding lens in the second plurality of lenses

[0022] In some additional embodiments, an optical system for performing distance measurements includes a light emission system and a light detection system. The light emission system including a bulk transmitter optic and an illumination source. The illumination source including a plurality of light emitters aligned to project discrete beams of light through the bulk transmitter optic into a field ahead of the optical system. The light detection system including a bulk receiver optic, an aperture layer including a plurality of apertures, a first lens layer including a first plurality of lenses, an optical filter layer configured to receive light after it passes through the bulk receiver optic and pass a band of radiation while blocking radiation outside the band, and a photosensor layer including a plurality of photosensors. Each photosensor includes a plurality of photodetectors configured to detect photons, and a second plurality of lenses configured to focus incident photons received at the photosensor on the plurality of photodetectors. The optical system includes a plurality of receiver channels with each receiver channel in the plurality of receiver channels including an aperture from the plurality of apertures, a lens from the plurality of first lenses, an optical filter from the optical filter layer, and a photosensor from the plurality of photosensors, with the aperture for each channel defining a discrete, non-overlapping field of view for its respective channel.

[0023] In certain embodiments, an optical system for performing distance measurements including a stationary housing having an optically transparent window, a light ranging device disposed within the housing and aligned with the optically transparent window, a motor disposed

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within the housing and operatively coupled to spin the light ranging device including the platform, optical transmitter, and optical receiver within the housing, and a system controller disposed within the housing. The system controller configured to control the motor and to start and stop light detection operations of the light ranging device. The light ranging device including a platform, an optical transmitter coupled to the platform, an optical receiver coupled to the platform. The optical transmitter including a bulk transmitter optic and a plurality of transmitter channels, each transmitter channel including a light emitter configured to generate and transmit a narrowband light through the bulk transmitter optic into a field external to the optical system. The optical receiver including a bulk receiver optic, an aperture layer including a plurality of apertures, a first lens layer including a first plurality of lenses, an optical filter layer configured to receive light after it passes through the bulk receiver optic and pass a band of radiation while blocking radiation outside the band, and a photosensor layer including a plurality of photosensors. Each photosensor includes a plurality of photodetectors configured to detect photons, and a second plurality of lenses configured to focus incident photons received at the photosensor on the plurality of photodetectors. The optical system includes a plurality of receiver channels with each receiver channel in the plurality of receiver channels including an aperture from the plurality of apertures, a lens from the plurality of first lenses, an optical filter from the optical filter layer, and a photosensor from the plurality of photosensors, with the aperture for each channel defining a discrete, non-overlapping field of view for its respective channel.

[0024] A better understanding of the nature and advantages of embodiments of the present disclosure may be gained with reference to the following detailed description and the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0025] FIG. 1 is a block diagram of an exemplary passive optical imager system, according to some embodiments of the present disclosure.

[0026] FIG. 2 is a simplified diagram of an exemplary light detection system for a passive optical imager system, according to some embodiments of the present disclosure.

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[0027] FIGS. 3A and 3B are perspective views of a simplified diagram of different embodiments of micro-optic receiver layers with graduated filter layers, according to some embodiments of the present disclosure.

[0028] FIG 4 is a block diagram of a rotating LIDAR system, according to some embodiments of the present disclosure.

[0029] FIGS. 5A-5B are simple illustrations of exemplary implementations of solid state LIDAR systems, according to some embodiments of the present disclosure.

[0030] FIG. 6A-6B are simple illustrations of exemplary implementations of scanning LIDAR systems, according to some embodiments of the present disclosure.

[0031] FIG. 7 is an exemplary perspective view diagram showing an embodiment of a LIDAR system employing a 360 scanning architecture, according to some embodiments of the present disclosure.

[0032] FIG. 8 is an illustrative example of the light transmission and detection operation for a light ranging system, according to some embodiments of the present disclosure.

[0033] FIG. 9 is a flowchart illustrating a method of using coded pulses in an optical measurement system, according to embodiments of the present disclosure.

[0034] FIG. 10 is a simplified diagram illustrating a detailed view of an exemplary active optical imager system having a wide field-of-view and capable of narrowband imaging, according to some embodiments of the present disclosure.

[0035] FIGS. 11-14 are simplified cross-sectional view diagrams of various exemplary enhanced light emission systems, according to some embodiments of the present disclosure.

[0036] FIGS. 15A-15C are cross-sectional views of simplified diagrams of exemplary active imager systems having different implementations of corrective optical structures for astigmatism, according to some embodiments of the present disclosure.

[0037] FIG. 16A is a simplified cross-sectional view diagram of part of a light detection system 1600 where there is no cross-talk between channels.

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[0038] FIG. 16B is a simplified cross-sectional view diagram of part of a light detection system 1601 where there is cross-talk between channels.

[0039] FIG. 17 is a simplified cross-sectional diagram of an exemplary micro-optic receiver channel structure, according to some embodiments of the present disclosure.

[0040] FIGS. 18A-18D are simplified cross-sectional view diagrams of various aperture layers for a receiver channel, according to some embodiments of the present disclosure.

[0041] FIGS. 19A-19D are simplified cross-sectional view diagrams of various spacer structures between the aperture layer and the optical lens layer for a receiver channel, according to some embodiments of the present disclosure.

[0042] FIGS. 20A-20G are simplified cross-sectional view diagrams of various optical filter layers for a receiver channel, according to some embodiments of the present disclosure.

[0043] FIGS. 21A-21K are simplified cross-sectional view diagrams of various photosensor layers with diffusers for a receiver channel, according to some embodiments of the present disclosure.

[0044] FIGS. 22A-22I are simplified cross-sectional view diagrams of various hemispherical receiver structures for a receiver channel, according to some embodiments of the present disclosure.

[0045] FIGS. 23A-23E are simplified cross-sectional view diagrams of various bottom micro lens layers for a receiver channel, according to some embodiments of the present disclosure.

[0046] FIGS. 24 and 25 are simplified cross-sectional view diagrams of exemplary receiver channels, according to some embodiments of the present disclosure.

[0047] FIGS. 26-30 are simplified top view diagrams of exemplary micro-optical receiver arrays, according to some embodiments of the present disclosure.

DETAILED DESCRIPTION

[0048] Some embodiments of the disclosure pertain to optical imager systems that can generate an image from ambient light in a field and/or light emitted from an optical transmitter that has reflected off of an object in the field. For instance, in some embodiments an optical

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imager system can be a passive system that does not actively illuminate a scene or given area and instead detects ambient light in the scene or area reflected off of one or more objects in the scene or area. A passive optical imager system can include a light sensing module for receiving ambient light in the field. The light sensing module can be a wide field-of-view, narrowband optical imaging system (WFNBI) that collects imaging information. The light sensing module can include one or more bulk receiver optics, a micro-optic receiver system, and a system controller for operating the light sensing module. According to some embodiments of the present disclosure, the micro-optic receiver system can include one or more micro-optic receiver layers and one or more photosensors, each photosensor can include one or more photodetectors that can measured received light.

[0049] A bulk imaging optic as defined herein can be one or more optical surfaces, possibly including multiple lens elements, that have clear apertures greater than one millimeter and that is positioned to receive light projected from, or focus received light on, a micro-optic transmitter/receiver layer. A bulk imaging optic that projects light received from an optical emitter, such as a micro-optic transmitter layer, is sometimes referred to herein as a bulk transmitter optic or as an output bulk imaging optic. A bulk optic layer that focuses light received from a field onto an optical detector, such as a micro-optic receiver layer, is sometimes referred to herein as a bulk receiver optic or as an input bulk imaging optic. An input, image-space telecentric bulk imaging optic allows the system to measure narrowband light uniformly over a wide field-of-view (FOV). The micro-optic receiver layer can include a one- or two-dimensional array of micro-optic receiver channels where each micro-optic receiver channel has multiple components including one or more of an aperture, a collimating micro-lens, an optical filter, and a photosensor. In some instances, the micro-optical receiver channel structure has a columnar arrangement with enclosures having absorbent and/or reflective side walls and/or focusing funnels. The micro-optic receiver channel maximizes the collection of incoming rays through its aperture, collimates the light to make it perpendicular to the optical filter, and minimizes crosstalk with adjacent micro-optic receiver channels due to mixing of inputs from neighboring apertures, as will be discussed in detail below. In various instances, bulk imaging optics according to the present disclosure modify light or other radiation for an entire array of emitters or photosensors. Micro-optic structures can be included as part of the array and can modify light differently for different emitters and/or photosensors in the array. In some

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embodiments, there is one or more micro-optic elements for each individual array element (photosensor and/or emitter).

[0050] In some embodiments, the optical imager system can be an active system that can emit light into a field and then detect the emitted light after it has reflected off surfaces of an object in the field. An active optical imager system can include a light transmission module in addition to a light sensing module, and be configured as a light ranging device. The light transmission module can include a transmitter layer that is composed of an array of individual emitters where each emitter can be paired with a corresponding micro-optic receiver channel in the light sensing module, or it can be a uniform illuminator that spreads light evenly across the scene with no specific pairing between individual emitters and receiver channels. In some instances, the light transmission module can include a micro-optic transmitter channel array to enhance light outputted from the array of emitters. During operation, light outputted by the array of emitters (e.g., laser pulses) passes through the micro-optic transmitter channel array and enters a bulk transmitter optic having a large numerical aperture to better capture light from the micro-optic transmitter channel array. The light then exits the bulk transmitter optic and illuminates a plurality of spots at a distant field. The micro-optic transmitter channel array can improve the brightness of beams emanating from the bulk transmitter optic to provide enhanced spot illumination, while at the same time improving the spatial resolution of the measured image, as will be discussed in detail further herein.

[0051] According to some embodiments of the present disclosure, the imager system is a wide field-of-view, narrowband optical system. Thus, the imager can capture images and detect light across a FOV of at least 10 degrees. In certain embodiments, the imager can capture images and detect light across a FOV of at least 20, and across a FOV of at least 30 degrees in some embodiments. Furthermore, the imager can detect light at a wavelength of approximately 10 nm or less. In some particular embodiments, the light sensing module can detect light at a wavelength of approximately 5 nm or less. In some embodiments, the imager system can capture detect light at a wavelength of less than 5 nm across a FOV of approximately 32 degrees. The FOV can be in the vertical or horizontal direction, or any other angle in between.

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[0052] To better understand the function and configuration of passive and active optical imager systems according to embodiments of the disclosure, each will be discussed in detail herein.

I. PASSIVE OPTICAL IMAGER SYSTEMS

[0053] A passive optical imager system receives ambient light to generate an image. FIG. 1 is a block diagram of an exemplary passive optical imager system 100, according to some embodiments of the present disclosure. Passive optical imager system 100 includes a passive light capturing device 102 for capturing light existing within a field. Passive light capturing device 102 can include a system controller 104 and a light sensing module 106. Imaging data can be generated by passive light capturing device 102 by receiving light existing in a field in which passive optical imager system 100 is positioned. The received light can be light that exists naturally in the field, i.e., ambient light, as opposed to light emitted from a transmitter within system 100.

[0054] Light sensing module 106 can include a sensor array 108, which can be, e.g., a one-dimensional or two-dimensional array of photosensors. Each photosensor (also just called a "sensor" or sometimes referred to by one skilled in the art as a "pixel") can include a collection of photodetectors, e.g., SPADs or the like, or a sensor can be a single photon detector (e.g., an APD). Light sensing module 106 includes an optical sensing system 110, which when taken together with sensor array 108 can form a light detection system 112. In some embodiments, optical sensing system 110 can include a bulk receiver optic 114 and optical components 116, such as an aperture layer, a collimating lens layer and an optical filter, that can be combined with sensor array 108 to form an array of micro-optic receiver channels where each micro-optic receiver channel measures light that corresponds to an image pixel in a distinct field of view of the surrounding field in which system 100 is positioned. Further details of various embodiments of micro-optic receiver channels according to the present disclosure are discussed in detail in conjunction with FIGS. 17-30 below.

[0055] In some embodiments, sensor array 108 of light sensing module 106 is fabricated as part of a monolithic device on a single substrate (using, e.g., CMOS technology) that includes both an array of photosensors, a processor 118, and a memory 120 for signal processing the

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measured light from the individual photosensors (or groups of photosensors) in the array. The monolithic structure including sensor array 108, processor 118, and memory 120 can be fabricated as a dedicated ASIC. In some embodiments, optical components 116 can also be a part of the monolithic structure in which sensor array 108, processor 118, and memory 120 are a part. In such instances, optical components 116 can be formed, e.g., bonded (non-reversibly) with epoxy, on the ASIC so that it becomes part of the monolithic structure, as will be discussed further below. As mentioned above, processor 118 (e.g., a digital signal processor (DSP), microcontroller, field programmable gate array (FPGA), and the like) and memory 120 (e.g., SRAM) can perform the signal processing. As an example of signal processing, for each photosensor or grouping of photosensors, memory 120 of light sensing module 106 can accumulate detected photons over time, and these detected photons can be used to recreate an image of the field.

[0056] In some embodiments, the output from processor 118 is sent to system controller 104 for further processing, e.g., the data can be encoded by one or more encoders of the system controller 104 and then sent as data packets to user interface 115. System controller 104 can be realized in multiple ways including, e.g., by using a programmable logic device such an FPGA, as an ASIC or part of an ASIC, using a processor 122 with memory 124, and some combination of the above. System controller 104 can cooperate with a stationary base controller or operate independently of the base controller (via pre-programed instructions) to control light sensing module 106 by sending commands that include start and stop light detection and adjust photodetector parameters. In some embodiments, system controller 104 has one or more wired interfaces or connectors for exchanging data with light sensing module 106. In other embodiments, system controller 104 communicates with light sensing module 106 over a wireless interconnect such as an optical communication link.

[0057] Passive optical imager system 100 can interact with a user interface 115, which can be any suitable user interface for enabling a user to interact with a computer system, e.g., a display, touch-screen, keyboard, mouse, and/or track pad for interfacing with a laptop, tablet, and/or handheld device computer system containing a CPU and memory. User interface 115 may be local to the object upon which passive optical imager system 100 is mounted but can also be a remotely operated system. For example, commands and data to/from passive optical imager

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system 100 can be routed through a cellular network (LTE, etc.), a personal area network (Bluetooth, Zigbee, etc.), a local area network (WiFi, IR, etc.), or a wide area network such as the Internet.

[0058] User interface 115 of hardware and software can present the imager data from the device to the user but can also allow a user to control passive optical imager system 100 with one or more commands. Example commands can include commands that activate or deactivate the imager system, specify photodetector exposure level, bias, sampling duration and other operational parameters (e.g., emitted pulse patterns and signal processing), specify light emitters parameters such as brightness. In addition, commands can allow the user to select the method for displaying results. The user interface can display imager system results which can include, e.g., a single frame snapshot image, a constantly updated video image, and/or a display of other light measurements for some or all pixels.

[0059] As mentioned herein, one or more components of optical sensing system 110 can be part of a monolithic structure with sensor array 108, processor 118, and memory 120. For example, an aperture layer, collimating lens layer, and an optical filter layer of optical components 116 can be stacked over and bonded with epoxy to a semiconductor substrate having multiple ASICs fabricated thereon at the wafer level before or after dicing. For instance, the optical filter layer can be a thin wafer that is placed against the photosensor layer and then bonded to the photosensor layer to bond the optical filter layer with the photosensor layer to have the optical layer form part of the monolithic structure; the collimating lens layer can be injection molded onto the optical filter layer; and, the aperture layer can be formed by layering a non-transparent substrate on top of a transparent substrate or by coating a transparent substrate with an opaque film. Alternatively, the photosensor layer can be fabricated and diced, and the optical filter layer, collimating lens layer, and the aperture layer can be fabricated and diced. Each diced photosensor layer and optical layers can then be bonded together to form a monolithic structure where each monolithic structure includes the photosensor layer, optical filter layer, collimating lens layer, and the aperture layer. By bonding the layers to the ASIC, the ASIC and the bonded layers can form a monolithic structure. The wafer can then be diced into devices, where each device can be paired with a respective bulk receiver optic 114 to form light sensing module 106. In yet other embodiments, one or more components of light sensing module 106 can be external

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to the monolithic structure. For example, the aperture layer may be implemented as a separate metal sheet with pin-holes. A more detailed view of an optical sensing system and a sensor array according to an embodiment of the disclosure is discussed herein with respect to FIG. 2.

[0060] FIG. 2 is a simplified diagram of an exemplary light detection system 200 according to some embodiments of the present disclosure. Light detection system 200 can be representative of light detection system 112 discussed above with respect to FIG. 1. Light detection system 200 can include an optical sensing system and a sensor array. The optical sensing system can include bulk receiver optics, an aperture layer, a collimating lens layer, and an optical filter layer; and the sensor array can include an array of photosensors, where each photosensor can include one or more photodetectors for measuring light. According to some embodiments, these components operate together to receive light from a field. For instance, light detection system 200 can include a bulk receiver optic 202 and a micro-optic receiver (Rx) layer 204. During operation, light rays 206 enter bulk receiver optic 202 from multiple directions and gets focused by bulk receiver optic 202 to form light cones 208. Micro-optic receiver layer 204 is positioned so that apertures 210 coincide with the focal plane of bulk receiver optic 202. In some embodiments, micro-optic receiver layer 204 can be a one-dimensional or two-dimensional array of micro-optic receiver channels 212, where each micro-optic receiver channel 212 is formed of a respective aperture 210, collimating lens 214, and photosensor 216 positioned along the same axis in the direction of light flow, e.g., horizontal from left to right as shown in FIG. 2. Furthermore, each micro-optic receiver channel 212 can be configured various ways to mitigate interference from stray light between photosensors, as will be discussed further herein. During operation, each micro-optic receiver channel 212 measures light information for a different pixel (i.e., position in the field).

[0061] At the focal point of bulk receiver optic 202, light rays 206 focus and pass through apertures 210 in an aperture layer 211 and into respective collimating lenses 214. Each collimating lens 214 collimates the received light so that the light rays all enter the optical filter at approximately the same angle, e.g., parallel to one another. The aperture and focal length of bulk receiver optic 202 determine the cone angle of respective light rays that come to a focus at aperture 210. The aperture size and the focal length of collimating lenses 214 determine how well-collimated the admitted rays can be, which determines how narrow of a bandpass can be

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implemented in optical filter 218. Apertures 210 can serve various functions during the operation of light detection system 200. For instance, apertures 210 can (1) constrain the pixel FOV so it has tight spatial selectivity despite a large pitch at the photosensor plane, (2) provide a small point-like source at the collimating lens's focal plane to achieve tight collimation of rays before passing through the filter, where better collimation results in a tighter band that can pass through the filter, and (3) reject stray light.

[0062] Optical filter 218 blocks unwanted wavelengths of light. Interference-based filters tend to exhibit strong angle dependence in their performance. For example, a 1 nm wide bandpass filter with a center wavelength (CWL) of 900 nm at a zero-degree angle of incidence might have a CWL of 898 nm at a fifteen-degree angle of incidence. Imaging systems typically use filters several tens of nanometers wide to accommodate this effect, so that the shift in CWL is much smaller than the bandpass width. However, the use of micro-optic layer 204 allows all rays to enter optical filter 218 at approximately the same angle of incidence, thus minimizing the shift in CWL and allowing very tight filters (e.g. less than 10 nm wide) to be used. Photosensor 216 generates electrical currents or voltages in response to incident photons. In some embodiments, optical filter 218 is uniform across the entire array of micro-optic receiver channels 212 so that each individual micro-optic receiver channel 212 in the array receives the same range of wavelengths of light.

[0063] In some embodiments, photosensors 216 are positioned on a side opposite of collimating lenses 214 so that light rays 206 first pass through collimating lenses 214 and optical filter 218 before exposing on photosensors 216. Each photosensor 216 can be a plurality of photodetectors, such as a mini-array of multiple single-photon avalanche detectors (SPADs). An array of mini-arrays of SPADs can be fabricated on a single monolithic chip, thereby simplifying fabrication. In some alternative embodiments, each photosensor 216 can be a single photodetector, e.g., a standard photodiode, an avalanche photodiode, a resonant cavity photodiode, or another type of photodetector.

[0064] In some other embodiments, optical filter 218 is non-uniform. For example, a graduated filter allows different micro-optic channels to measure a different range of wavelengths. In other words, a graduated filter allows different micro-optic channels in an array of micro-optic channels to have different center wavelengths (CWL). A graduated filter

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typically gradually changes the range of allowed wavelengths in either one or two dimensions. However, a graduated filter could also encompass a filter where the range of allowed wavelengths changes rapidly (e.g., step-wise) in one or both dimensions. The different CWLs for the channels can be created in various ways. For instance, the thickness of the filter can change or the index of refraction can change. The index of refraction can be changed by modifying the filter layer, such as by altering its chemical composition, e.g., by modifying it to have a non-uniform doping concentration. As a result, each channel (or row/column of channels) can have an optical filter layer that has a different doping concentration, thereby resulting in a different CWL for each channel (or row/column of channels) without having a modified thickness. Rotating a one-dimensional array of micro-optic channels with a graduated optical filter allows the system to measure light at different wavelengths for each photosensor. Scanning a two-dimensional array of micro optic channels where the graduated filter is changing along the direction of the scan allows the passive optic imager system to measure light at multiple wavelengths for each position in space, but uses multiple photodetectors in the photosensor to do so. Such optical systems using graduated filters require synchronization of the photosensor sampling so that different wavelength measurements are taken for the same photosensor with the same field-of-view. Imaging systems that differentiate between many different wavelengths are sometimes referred to as hyperspectral imagers. A hyperspectral imager often requires that light from the wavelengths of interest all be focused in approximately the same plane. This can be achieved by using an achromatic, apochromatic, superachromatic, or similar lens that is designed to limit the effects of chromatic aberration.

[0065] Hyperspectral imagers collect information from multiple wavelength bands across the electromagnetic spectrum. The absolute or relative intensities of the wavelength bands can provide information about chemical concentrations. For example, chlorophyll content of certain crops can be estimated using only a few wavelength bands. Similar techniques can be used to find valuable minerals or identify toxins. Spectral information can also be used to assist in the classification of pedestrians, automobiles, and other objects similarly encountered in an automotive environment.

[0066] A graduated neutral-density filter has a transmission that varies spatially across the filter, but the transmission is largely independent of wavelength (e.g. just as transmissive to red

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light as to blue light) at any given location. In a scanning imaging system, a graduated neutral-density filter can be used to image the same point in space with varying degrees of attenuation, thereby enabling a composite measurement with higher dynamic range than would achievable with a non-graduated filter. A better understanding of a micro-optic receiver layer with graduated filter can be achieved with reference to FIGS. 3A and 3B.

[0067] FIGS. 3A and 3B are perspective views of a simplified diagram of different embodiments of micro-optic receiver layers with graduated filter layers, according to some embodiments of the present disclosure. Specifically, FIG. 3A is a perspective view of a simplified diagram of a micro-optic receiver layer 300 with a graduated filter layer 302, and FIG. 3B is a perspective view of a simplified diagram of a micro-optic receiver layer 301 with a graduated filter layer 312. As illustrated in FIGS. 3A and 3B, micro-optic receiver layer 300 and 301 each includes four micro-optic receiver channels 304, 306, 308 and 310 arranged in two dimensions as a 2 x 2 array. Although FIGS. 3A and 3B illustrate embodiments having only 2 x 2 arrays, one skilled in the art understands that such embodiments are not limiting and that other embodiments can be configured to have any number of micro-optic receiver channels. It is to be appreciated that in these diagrams, the thicknesses of filter layers 302 and 312 and the thicknesses of the surrounding layers, which are not drawn to scale, should be interpreted as the thicknesses of layers of refractive material in an interference filter. As these thicknesses change, the characteristics (e.g. passband CWL) of the interference filter change. These embodiments can be used in a hyperspectral passive optic imager system.

[0068] As shown in FIGS. 3A and 3B, graduated filter layer 302 has gradually increasing thickness in one dimension across multiple columns of micro-optic receiver channels, and graduated filter layer 312 has a step-wise-increasing thickness in one dimension that has a constant thickness for each micro-optic receiver channel. Micro-optic receiver channels 304 and 308 have the same filter thickness and detect the same wavelength of light. Micro-optic receiver channels 306 and 310 have the same filter thickness and detect the same wavelength of light. Micro-optic receiver channels 304 and 308 can have a different filter thickness than micro-optic receiver channels 306 and 310 and thus detect a different wavelength of light. During a first-time interval, the micro-optic receiver channels 304 and 308 measure the intensity of a first wavelength of light for two pixels respectively. In some embodiments, the hyperspectral passive

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optic imager system moves or rotates the micro-optic receiver layer so that during a second-time interval, micro-optic receiver channels 306 and 310 measure the intensity of a second wavelength of light for the same two pixels respectively. In other embodiments, a hyperspectral passive optic imager system according to the disclosure can include a stationary micro-optic receiver layer and scan a moving target.

II. ACTIVE OPTICAL IMAGER SYSTEMS

[0069] As discussed herein, optical imager systems can also be configured as active optical imager systems. Active optical imager systems can differ from passive optical imager systems in that active optical imager systems emit their own light into a field and detect the emitted light after it has reflected off surface(s) of an object in the field. In some embodiments, active optical imager systems can be utilized as LIDAR devices where emitted and received, reflected light can be correlated to determine a distance to the object from which the emitted light was reflected. A better understanding of an active optical imager system can be ascertained with reference to FIG. 4.

[0070] FIG. 4 illustrates a block diagram of a LIDAR system 400 according to some embodiments of the present disclosure. LIDAR system 400 can include a light ranging device 402 and a user interface 415. Light ranging device 402 can include a ranging system controller 404, a light transmission (Tx) module 406 and a light sensing (Rx) module 408. Ranging data can be generated by light ranging device 402 by transmitting one or more light pulses 410 from the light transmission module 406 to objects in a field of view surrounding light ranging device 402. Reflected portions 412 of the transmitted light are then detected by light sensing module 408 after some delay time. Based on the delay time, the distance to the reflecting surface can be determined. Other ranging methods can be employed as well, e.g. continuous wave, Doppler, and the like.

[0071] Tx module 406 includes an emitter array 414, which can be a one-dimensional or two-dimensional array of emitters, and a Tx optical system 416, which when taken together with emitter array 414 can form a light emission system 438. Tx optical system 416 can include a bulk transmitter optic that is image-space telecentric. In some embodiments, Tx optical system 416 can further include one or more micro-optic structures that increase the brightness of beams

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emanating from the bulk transmitter optic as discussed herein with respect to FIGS. 11-14 and/or for beam shaping, beam steering or the like. Emitter array 414 or the individual emitters can be laser sources. Tx module 406 can further include an optional processor 418 and memory 420, although in some embodiments these computing resources can be incorporated into ranging system controller 404. In some embodiments, a pulse coding technique can be used, e.g., Barker codes and the like. In such cases, memory 420 can store pulse-codes that indicate when light should be transmitted. In some embodiments, the pulse-codes are stored as a sequence of integers stored in memory.

[0072] Light sensing module 408 can be substantially similar in construction to light sensing module 106 discussed herein with respect to FIG 1. Thus, details of processor 422, memory 424, sensor array 426, and Rx optical system 428 (when taken together with sensor array 426 can form a light detection system 436) can be referenced herein with respect to FIG. 1, and only differences with respect to those components are discussed herein for brevity. For LIDAR system 400, each photosensor sensor (e.g., a collection of SPADs) of sensor array 426 can correspond to a particular emitter of emitter array 414, e.g., as a result of a geometrical configuration of light sensing module 408 and Tx module 406. For example, in some embodiments, emitter array 414 can be arranged along the focal plane of the bulk transmitter optic such that each illuminating beam projected from the bulk transmitter optic into the field ahead of the system is substantially the same size and geometry as the field of view of a corresponding receiver channel at any distance from the system beyond an initial threshold distance.

[0073] In some embodiments, processor 418 can perform signal processing of the raw histograms from the individual photon detectors (or groups of detectors) in the array. As an example of signal processing, for each photon detector or grouping of photon detectors, memory 424 (e.g., SRAM) can accumulate counts of detected photons over successive time bins, and these time bins taken together can be used to recreate a time series of the reflected light pulse (*i.e.*, a count of photons vs. time). This time-series of aggregated photon counts is referred to herein as an intensity histogram (or just histogram). Processor 418 can implement matched filters and peak detection processing to identify return signals in time. In addition, Processor 418 can accomplish certain signal processing techniques (e.g., by processor 422), such as multi-

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profile matched filtering to help recover a photon time series that is less susceptible to pulse shape distortion that can occur due to SPAD saturation and quenching. In some embodiments, all or parts of such filtering can be performed by processor 458, which may be embodied in an FPGA.

[0074] In some embodiments, the photon time series output from processor 418 are sent to ranging system controller 404 for further processing, e.g., the data can be encoded by one or more encoders of ranging system controller 404 and then sent as data packets to user interface 415. Ranging system controller 404 can be realized in multiple ways including, e.g., by using a programmable logic device such an FPGA, as an ASIC or part of an ASIC, using a processor 430 with memory 432, and some combination of the above. Ranging system controller 404 can cooperate with a stationary base controller or operate independently of the base controller (via pre-programed instructions) to control light sensing module 408 by sending commands that include start and stop light detection and adjust photodetector parameters. Similarly, ranging system controller 404 can control light transmission module 406 by sending commands, or relaying commands from the base controller, that include start and stop light emission controls and controls that can adjust other light-emitter parameters (e.g., pulse codes). In some embodiments, ranging system controller 404 has one or more wired interfaces or connectors for exchanging data with light sensing module 408 and with light transmission module 406. In other embodiments, ranging system controller 404 communicates with light sensing module 408 and light transmission module 406 over a wireless interconnect such as an optical communication link.

[0075] Light ranging device 402 can be used in both stationary and a scanning architectures. Electric motor 434 is an optional component in LIDAR system 400 that can be used to rotate system components, e.g., the Tx module 406 and Rx module 408, as part of a scanning LIDAR architecture. The system controller 404 can control the electric motor 434 and can start rotation, stop rotation and vary the rotation speed as needed to implement a scanning LIDAR system. Exemplary stationary LIDAR devices are discussed below with respect to FIGS. 5A and 5B, while exemplary scanning LIDAR devices are discussed further herein with respect to FIGS. 6A, 6B, and 7.

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[0076] LIDAR system 400 can interact with one or more instantiations of a user interface 415. The different instantiations can vary and can include, but not be limited to, a computer system with a monitor, keyboard, mouse, CPU and memory; a touch-screen in an automobile or other vehicle; a handheld device with a touch-screen; or any other appropriate user interface. User interface 415 can be local to the object upon which LIDAR system 400 is mounted but can also be a remotely operated system. For example, commands and data to/from LIDAR system 400 can be routed through a cellular network (LTE, etc.), a personal area network (Bluetooth, Zigbee, etc.), a local area network (WiFi, IR, etc.), or a wide area network such as the Internet.

[0077] User interface 415 of hardware and software can present the LIDAR data from the device to the user or to a vehicle control unit (not shown) but can also allow a user to control LIDAR system 400 with one or more commands. Example commands can include commands that activate or deactivate the LIDAR system, specify photodetector exposure level, bias, sampling duration and other operational parameters (e.g., emitted pulse patterns and signal processing), specify light emitters parameters such as brightness. In addition, commands can allow the user to select the method for displaying results. The user interface can display LIDAR system results which can include, e.g., a single frame snapshot image, a constantly updated video image, and/or a display of other light measurements for some or all pixels. In some embodiments, user interface 415 can track distances (proximity) of objects from the vehicle, and potentially provide alerts to a driver or provide such tracking information for analytics of a driver's performance.

[0078] In some embodiments, for example where LIDAR system 400 is used for vehicle navigation, user interface 415 can be a part of a vehicle control unit that receives output from, and otherwise communicates with light ranging device 402 and/or user interface 415 through a network, such as one of the wired or wireless networks described above. One or more parameters associated with control of a vehicle can be modified by the vehicle control unit based on the received LIDAR data. For example, in a fully autonomous vehicle, LIDAR system 400 can provide a real time 3D image of the environment surrounding the car to aid in navigation in conjunction with GPS and other data. In other cases, LIDAR system 400 can be employed as part of an advanced driver-assistance system (ADAS) or as part of a safety system that, e.g., can provide 3D image data to any number of different systems, e.g., adaptive cruise control,

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automatic parking, driver drowsiness monitoring, blind spot monitoring, collision avoidance systems, etc. When user interface 415 is implemented as part of a vehicle control unit, alerts can be provided to a driver or tracking of a proximity of an object can be tracked.

A. Solid State Architecture

[0079] LIDAR systems, according to some embodiments of the present disclosure, can be configured as a solid state LIDAR system that has a stationary architecture. Such LIDAR systems do not rotate, and thus do not need a separate motor, e.g., electric motor 434 in FIG. 4, to rotate the sensor and transmitter modules. Example solid state LIDAR systems are shown in FIGS. 5A and 5B.

[0080] FIGS. 5A and 5B are simple illustrations of exemplary implementations of solid state LIDAR systems. Specifically, FIG. 5A illustrates an implementation 500 where solid state LIDAR systems 502a-d are implemented at the outer regions of a road vehicle 505, such as an automobile, according to some embodiments of the present disclosure; and FIG. 5B illustrates an implementation 501 where solid state LIDAR systems 504a-b are implemented on top of road vehicle 505, according to some embodiments of the present disclosure. In each implementation, the number of LIDAR systems, the placement of the LIDAR systems, and the fields of view of each LIDAR system can be chosen to obtain a majority of, if not the entirety of, a 360 degree field of view of the environment surrounding the vehicle. Automotive implementations for the LIDAR systems are chosen herein merely for the sake of illustration and the sensors described herein may be employed in other types of vehicles, e.g., boats, aircraft, trains, etc., as well as in a variety of other applications where 3D depth images are useful, such as medical imaging, mobile phones, augmented reality, geodesy, geomatics, archaeology, geography, geology, geomorphology, seismology, forestry, atmospheric physics, laser guidance, airborne laser swath mapping (ALSM), and laser altimetry.

[0081] With reference to FIG. 5A, solid state LIDAR systems 502a-d can be mounted at the outer regions of a vehicle, near the front and back fenders. LIDAR systems 502a-d can each be positioned at a respective corner of vehicle 505 so that they are positioned near the outermost corners of vehicle 505. That way, LIDAR systems 502a-d can better measure the distance of vehicle 505 from objects in the field at areas 506a-d. Each solid state LIDAR system can face a

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different direction (possibly with partially and/or non-overlapping fields of views between units) so as to capture a composite field of view that is larger than each unit is capable of capturing on its own. Objects within the scene can reflect portions of light pulses 510 that are emitted from LIDAR Tx module 508. One or more reflected portions 512 of light pulses 510 then travel back to LIDAR system 502a and can be received by Rx module 509. Rx module 509 can be disposed in the same housing as Tx module 508.

[0082] Although FIG. 5A illustrates four solid state LIDAR systems mounted at the four corners of a vehicle, embodiments are not limited to such configurations. Other embodiments can have fewer or more solid state LIDAR systems mounted on other regions of a vehicle. For instance, LIDAR systems can be mounted on a roof of a vehicle 505, as shown in FIG. 5B. In such embodiments, LIDAR systems can have a higher vantage point to better observe areas 506a-d around vehicle 505.

B. Scanning Architecture

[0083] In some embodiments, LIDAR systems according to the present disclosure can employ a scanning architecture in which the LIDAR system oscillates between an angle that is less than 360 degrees. For instance, LIDAR systems 504a-b in implementation 501 of FIG. 5B can each employ a scanning architecture to scan the entire scene in front of, and/or behind, vehicle 505, e.g., in area 514 between field of view 506a and 506b and in area 516 between field of view 506c and 506d. The output beam(s) of one or more light sources (not shown, but can be a variety of different suitable sources for emitting radiation including, but not limited to lasers, in any wavelength spectrum suitable for LIDAR systems, such as in the infrared, near-infrared, ultraviolet, visible, e.g., green laser wavelength spectrum, and the like) located in the scanning LIDAR systems, can be outputted as pulses of light and scanned, e.g., rotated between an angle that is less than 360 degrees, to illuminate a scene around the vehicle. In some embodiments, the scanning, represented by rotation arrows 514 and 516, can be implemented by mechanical means, e.g., by mounting the light emitters to a rotating column or platform or through the use of other mechanical means, such as galvanometers. Chip-based beam steering techniques can also be employed, e.g., by using microchips that employ one or more MEMS based reflectors, e.g., such as a digital micromirror (DMD) device, a digital light processing (DLP) device, and the

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like. In some embodiments, the scanning can be effectuated through non-mechanical means, e.g., by using electronic signals to steer one or more optical phased arrays.

[0084] Other embodiments can implement a scanning architecture that scans through the entire 360 degrees of the environment surrounding a vehicle. Such scanning LIDAR systems can repetitively rotate continuously through 360 degrees in a clockwise or counter-clockwise direction, and thus may utilize a separate motor, e.g., electric motor 434 in FIG. 4, to rotate the sensor and transmitter modules. Exemplary rotating LIDAR systems are shown in FIGS. 6A and 6B.

[0085] FIG. 6A is a top-down view of a simplified diagram of an exemplary scanning LIDAR system 600 implemented for a vehicle 605, such as a car, and capable of continuous 360 degree scanning, according to some embodiments of the present disclosure. The output beam(s) of one or more light sources (such as infrared or near-infrared pulsed IR lasers, not shown) located in LIDAR system 600, can be scanned, e.g., rotated, to illuminate a continuous scene 620 around the vehicle. In some embodiments, the scanning, represented by rotation arrow 615, can be implemented by any suitable mechanical means discussed herein with respect to FIG. 5B, e.g., by mounting the light emitters to a rotating column or platform, or any other mechanical means, such as through the use of galvanometers or chip-based steering techniques. During operation, objects around vehicle 605 in any direction and within the view of LIDAR system 600 can reflect portions of light pulses 611 that are emitted from a transmitting module 608 in LIDAR system 600. One or more reflected portions 617 of light pulses 611 then travel back to LIDAR system 600 and can be detected by its sensing module 609. In some instances, sensing module 609 can be disposed in the same housing as transmitting module 608.

[0086] Although FIG. 6A illustrates solid state LIDAR systems mounted on a roof of a vehicle 605, embodiments are not limited to such configurations. Other embodiments can have solid state LIDAR systems mounted on other regions of a vehicle. For instance, LIDAR systems can be mounted at the corners of a vehicle, as shown in FIG. 6B. FIG. 6B illustrates an implementation 601 where solid state LIDAR systems 604a-d are implemented at the outer regions of a road vehicle, such as a car, according to some embodiments of the present disclosure. In this implementation, each LIDAR system 604a-d can be a spinning LIDAR system that can measure distances around the full 360 degrees. However, since at least some of

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those measurements will be measured with respect to vehicle 605, those measurements can be ignored. Thus, each LIDAR system 605a-d can only utilize a subset of the measurements from 360 degree scanning, e.g., only the angles covering regions 619a-d that do not capture vehicle 605 are utilized.

[0087] FIG. 7 is a simplified exemplary perspective view of a LIDAR system 700 that employs a 360 scanning architecture, according to some embodiments of the present disclosure. In some embodiments, LIDAR system 700 can include a light ranging device 701 that spins in a clockwise or counter-clockwise direction to observe the surrounding field around a vehicle. System 700 can include a stationary housing 702, an optically transparent window 704, and a stationary lid 706 for providing protection for the internal components of LIDAR system 700. Window 704 can extend fully around a periphery of stationary housing 702, which can be configured to have a cylindrical shape. The internal components of system 700 can include light ranging device 701, which can include a rotating platform 708 and sensing and transmitting modules 710 mounted on rotating platform 708. In some embodiments, light ranging device 701 is aligned with window 704 such that modules 710 are positioned to emit and receive light through window 704, and that emitted light is not emitted onto stationary housing 702 or stationary lid 706. For instance, in the aligned positioned, the horizontal center of light ranging device 701 coincides with the horizontal center of window 704. Sensing and transmitting modules 710 can be, for example, light sensing module 408 and light transmission module 406, and can optionally include a heat sink (not shown) to cool the micro-optic layers. LIDAR system 700 can also include a system controller 712 (e.g., controller 404) and electric motor 714 (e.g., motor 434) that reside within stationary housing 702. Electric motor 714 rotates platform 708, thereby rotating sensing and transmitting modules 710 in a spinning manner, e.g., continuously through 360 degrees in a clockwise or counter-clockwise direction. System controller 712 can communicate with sensing and transmitting modules 710 using an optical communication link 716. Optical communication link 716 allows sensing and transmitting modules 710 to communicate with stationary system controller 712, which is mechanically coupled to stationary housing 702 and does not rotate with platform 708, through optical communication link 716 without mechanical wear and tear. In some embodiments, system controller 712 can control the motor and to start and stop light detection operations of LIDAR system 700. System controller 712 can include two or more stacked planar circuit boards

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arranged in a parallel relationship, which is discussed in more detail in commonly-owned and concurrently-filed Patent Application entitled "Compact Lidar System", attorney docket number 103033-P010US1-1073278, which is herein incorporated by reference in its entirety for all purposes.

III. OPERATION OF ACTIVE IMAGER SYSTEMS

[0088] FIG. 8 is an illustrative example of the light transmission and detection operation for a light ranging system according to some embodiments. FIG. 8 shows a light ranging system 800 (e.g., solid state or and/or scanning system) collecting three-dimensional distance data of a volume or scene that surrounds the system. FIG. 8 is an idealized drawing to highlight relationships between emitters and sensors, and thus other components are not shown.

[0089] Light ranging system 800 includes a light emitter array 810 and a light sensor array 820. The light emitter array 810 includes an array of light emitters, e.g., an array of vertical-cavity surface-emitting lasers (VCSELs) and the like, such as emitter 812 and emitter 816. Light sensor array 820 includes an array of photosensors, e.g., sensors 822 and 826. The photosensors can be pixelated light sensors that employ, for each photosensor, a set of discrete photodetectors such as single photon avalanche diodes (SPADs) and the like. However, various embodiments can deploy other types of photon sensors.

[0090] Each emitter can be slightly offset from its neighbor and can be configured to transmit light pulses into a different field of view from its neighboring emitters, thereby illuminating a respective field of view associated with only that emitter. For example, emitter 812 emits an illuminating beam 814 (formed from one or more light pulses) into the circular field of view 832 (the size of which is exaggerated for the sake of clarity). Likewise, emitter 816 emits an illuminating beam 818 (also called an emitter channel) into the circular field of view 834. While not shown in FIG. 8 to avoid complication, each emitter emits a corresponding illuminating beam into its corresponding field of view resulting in a 2D array of fields of view being illuminated (21 distinct fields of view in this example).

[0091] Each field of view that is illuminated by an emitter can be thought of as a pixel or spot in the corresponding 3D image that is produced from the ranging data. Each emitter channel can be distinct to each emitter and be non-overlapping with other emitter channels, *i.e.*, there is a

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one-to-one mapping between the set of emitters and the set of non-overlapping fields or view. Thus, in the example of FIG. 8, the system can sample 21 distinct points in the 3D space. A denser sampling of points can be achieved by having a denser array of emitters or by scanning angular position of the emitter beams over time such that one emitter can sample several points in space. As described above, scanning can be accomplished by rotating the entire emitter/sensor assembly.

[0092] Each sensor can be slightly offset from its neighbor and, like the emitters described above, each sensor can see a different field of view of the scene in front of the sensor. Furthermore, each sensor's field of view substantially coincides with, e.g., overlaps with and is the same size as a respective emitter channel's field of view.

[0093] In FIG. 8, the distance between corresponding emitter-receiver channels is exaggerated relative to the distance to objects in the field of view. In practice, the distance to the objects in the field of few is much greater than the distance between corresponding emitter-receiver channels and thus the path of light from the emitter to the object is approximately parallel to the path of the reflected light back from the object to the sensor (i.e., it is almost "back reflected"). Accordingly, there is a range of distances in front of the system 800 over which the fields of view of individual sensors and emitters are overlapped.

[0094] Because the fields of view of the emitters are overlapped with the fields of view of their respective sensors, each receiver channel ideally can detect the reflected illumination beam that originates from its respective emitter channel with ideally no cross-talk, i.e., no reflected light from other illuminating beams is detected. Thus, each photosensor can correspond to a respective light source. For example, emitter 812 emits an illuminating beam 814 into the circular field of view 832 and some of the illuminating beam reflects from the object 830. Ideally, a reflected beam 824 is detected by sensor 822 only. Thus, emitter 812 and sensor 822 share the same field of view, e.g., field of view 832, and form an emitter-sensor pair. Likewise, emitter 816 and sensor 826 form an emitter-sensor pair, sharing field of view 834. While the emitter-sensor pairs are shown in FIG. 8 as being in the same relative locations in their respective array, any emitter can be paired with any sensor depending on the design of the optics used in the system.

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[0095] During a ranging measurement, the reflected light from the different fields of view distributed around the volume surrounding the LIDAR system is collected by the various sensors and processed, resulting in range information for any objects in each respective field of view. As described above, a time-of-flight technique can be used in which the light emitters emit precisely timed pulses, and the reflections of the pulses are detected by the respective sensors after some elapsed time. The elapsed time between emission and detection and the known speed of light is then used to compute the distance to the reflecting surface. In some embodiments, additional information can be obtained by the sensor to determine other properties of the reflecting surface in addition to the range. For example, the Doppler shift of a pulse can be measured by the sensor and used to compute the relative velocity between the sensor and the reflecting surface. The pulse strength can be used to estimate the target reflectivity, and the pulse shape can be used to determine if the target is a hard or diffuse material.

[0096] In some embodiments, the LIDAR system can be composed of a relatively large 2D array of emitter and receiver channels and operate as a solid state LIDAR, i.e., it can obtain frames of range data without the need to scan the orientation of the emitters and/or sensors. In other embodiments, the emitters and sensors can be scanned, e.g., rotated about an axis, to ensure that the fields of view of the sets of emitters and sensors sample a full 360 degree region (or some useful fraction of the 360 degree region) of the surrounding volume. The range data collected from the scanning system, e.g., over some predefined time period, can then be post-processed into one or more frames of data that can then be further processed into one or more depth images or 3D point clouds. The depth images and/or 3D point clouds can be further processed into map tiles for use in 3D mapping and navigation applications.

[0097] According to some embodiments, a light ranging system (also called a coded-pulse optical receiver system) can transmit multiple pulses of light. In some embodiments, each coded-pulse has an embedded positive-valued pulse-code formed by the light intensity. The system can determine the temporal position and/or amplitude of optical pulses in the presence of background light by creating an intensity histogram of detected, reflected light at different time bins. For each time bin, the system adds a weighted value to the intensity histogram that depends on the intensity of detected light. The weighted values can be positive or negative and have varying magnitudes.

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[0098] By selecting different combinations of positive-valued pulse-codes and applying different weights, the system can detect positive-valued and negative-valued codes suitable for standard digital signal processing algorithms. This approach gives a high signal-to-noise ratio while maintaining a low uncertainty in the measured temporal position of the reflected light pulses.

[0099] FIG. 9 is a flowchart illustrating a method 900 of using coded pulses in an optical measurement system according to embodiments of the present disclosure. The optical measurement system may be a light ranging system. Method 900 can detect the temporal position of a reflected pulse from a target using multiple coded-pulses. In a real-time three-dimensional application, method 900 can constantly detect distances to objects in the surrounding environment. Method 900 may be implemented by any of the optical measurement systems described herein.

[0100] At 910, a coded-pulse optical system (CPOS) performs an initialization. For example, the CPOS can respond to user interface commands for starting, stopping, and changing parameters. The CPOS can initialize an optical transmitter to indicate parameters, e.g., pulse-codes, light power level, and various time intervals (e.g., for a detection interval, an interval for pausing between detection intervals, and an overall measurement time interval). The CPOS can initialize a light sensing module to indicate parameters such as pulse-time-interval and light-sampling-interval. The CPOS can also clear histogram values.

[0101] At 920, a pulse train is transmitted from a light source (e.g., a laser) as part of an optical measurement. The pulse train can be transmitted as part of N pulse trains transmitted for the measurement. The N pulse trains can reflect from an object, thereby allowing a ranging measurement to the object. Each of the N pulse trains can include one or more pulses from the light source (e.g., VCSELs) and correspond to a different time interval that is triggered by a start signal.

[0102] In some embodiments, the CPOS can wait for a specified time to allow a previous pulse train (coded-pulse transmission) to dissipate. The CPOS can then transmit a next pulse train of the N pulse trains of a measurement, where the N pulse trains form a code. Once a measurement is complete, e.g., a last of the N pulse train has dissipated (e.g., after a predetermined time

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expected for any reflections), the CPOS can then start the first/next coded-pulse transmission using the appropriate pulse-code. N can be an integer greater than one, e.g., 2, 3, 4, 5, or higher.

[0103] At 930, optical detection can be started, e.g., in response to the start signal that triggers the pulse train to be transmitted. Thus, the CPOS can start light detection at the same time that it started coded-pulse transmission. As part of the optical detection, a pulse train can be detected by a photosensor (e.g., corresponding to a pixel) of the optical measurement system, thereby generating data values at a plurality of time points. In some embodiments, the photosensor is a collection of photodetectors (e.g., SPADs). The data values may be of various forms, e.g., counts of a number of SPADs that triggered at a time point (e.g., within a time bin of a histogram). As other examples, the data values can be a digitized value from an ADC that follows an analog photosensor (e.g., an APD). Both examples can correspond to an intensity. In total, N pulse trains can be detected. Further, the process can be performed separately for each photosensor of the optical measurement device.

[0104] At 940, a weight is assigned to the data values at time points within the time interval corresponding to the pulse train, thereby obtaining weighted values. A weight can be assigned for each of the N pulse trains. Some of such weights for different pulse trains can be the same as other pulse trains. In some embodiments, at least two of the N pulse trains are assigned different weights and have a different pulse pattern. Two pulse trains can have some similarity (e.g., portions of pulses can overlap), but there is at least some times where one pulse train is ON and the other pulse train is OFF. Such different pulse patterns can have a similar shape but have a different delay, e.g., {1, 0, 1, 1, 0} has a similar shape of non-zero values to {0, 1, 0, 1, 1}, but they are different pulse patterns due to an offset as may be achieved by a delay in the second signal relative to the first signal.

[0105] Accordingly, the CPOS can detect light and create a digitized intensity value for each light-sampling-interval. For each light-sampling-interval, the CPOS can apply a pulse-weight to the digitized intensity value and add the result to the appropriate time-bin of the intensity histogram.

[0106] At 950, the CPOS tests if it has sent the required number of coded-pulses. If the CPOS has sent the required number of coded-pulses it continues at block 960, otherwise it loops back to block 920.

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[0107] At 960, a histogram corresponding to the weighted values in a plurality of time bins is determined. As described above, a counter of the histogram at a particular time bin can be determined by accumulating the weighted values at time points within the particular time bin across a plurality of time intervals.

[0108] At 970, the histogram is used to detect a signal corresponding to the N pulse trains. For example, the CPOS can determine whether the histogram has a sequence of values that match the match-code (filter). The CPOS can report whether the match-code was found and the amplitude of the match. The match may allow detection of the desired signal relative to noise or interference from other light sources.

[0109] As an example, a filter can include a set of values to be applied to a window of time bins of a histogram. The filter can be slid over the histogram to calculate a filtered histogram having counters corresponding to different sliding positions of the profile filter relative to the histogram. Each of the counters of the filtered histogram can correspond to an overlap of the profile filter and the histogram at a particular sliding position. A maximum value of the counters of the filtered histogram can be identified, thereby allowing detection, e.g., when the maximum value is above a threshold. The particular sliding position for the maximum value of the counters can correspond to the received time, which may be used for ranging measurements.

[0110] In some embodiments, the signal may be a reflected signal caused by the N pulse trains reflecting from an object, e.g., when the optical measurement system is configured to perform ranging measurements. In other embodiments, the signal may be a communication signal, e.g., when the light source is at one location and the photosensors are at a different location. Such a configuration can be used for communication purposes. For example, a microwave transmission tower can transmit data to a receiving tower. The transmitted data can include coded pulses, which may help to reduce errors in data reception as may be caused by noise or interference from other sources. The receiving tower can identify pulse trains and create a histogram by selecting an arbitrary time between two pulse trains as a start time for a first time bin. A match filter can then be applied (e.g., by sliding over the histogram); and if a sufficient match is found, then that communication signal can be detected. A sufficient match can be measured by the maximum value obtained the filtered histogram. As a further embodiment, the system can detect an interference signal from another CPOS in a similar manner used to detect the communication

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signal. If interference is measured, some implementations can change the transmitted code, e.g., of the interference code is similar to the code currently being used.

[0111] At 980, a distance to the object can be determined. For example, a received time corresponding to the N pulse trains relative to the start signal can be determined. A distance to the object can be determined using the received time. The received time may be offset from the transmission times of the pulse trains, but such an offset can be taken into account. Accordingly, the CPOS can report the time at which it was detected. The distance can corresponds to a round trip time between the received time and a start time of the start signal, and thus the distance may be expressed in time.

[0112] The detected signal can be used for other purposes than ranging. For example, the quality of the detected signal can be used to measure the reflectivity of an object. For example, if the detected signal has a strong intensity, then the system can determine that the object has a high reflectivity. Implementations for communications and interference measurements are discussed above. For detection of interference from another light source, the detected signal would be from another set of pulse trains transmitted by the interfering light source.

[0113] As a generalization, embodiments can transmit N+1 unique codes with N+1 unique weights to generate an N dimensional vector space histogram. For example, instead of a bin holding a signed number, the bin can hold a 1-D vector (e.g., equivalent to a signed number), by transmitting at least two unique codes: one positive and one negative. To store a 2-D vector (e.g., in polar or Cartesian coordinates), the system can transmit at least three unique codes, which could be weighted with three different polar angles and sum to a single 2-D vector. An N-D vector (defined with N separate numbers all held within a single "bin") would require N+1 different codes, each weighted at a different angle (in other worlds having a component to its weight that is orthogonal to all other weights) when doing the vector summation. By increasing the dimensionality, more advanced coding techniques like quadrature phase coding or code division multiple access (CDMA) that are used in RF communications may be used. An N-dimensional matched filter can be used in this context.

[0114] As a LIDAR system implements method 900 during its operation, the LIDAR system can continuously measure distances to objects in the field. Accordingly, once the distance to an object is determined, method 900 can loop back to block 920 to begin another series of emitting

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pulse trains and detecting the emitted pulse trains to determine a histogram for determining a distance to an object in the field. Distances may need to be constantly measured by method 900 because the LIDAR system may need to be constantly measuring distances to objects in the field, such as when the LIDAR system is used for navigational purposes and the LIDAR system is moving within the field.

[0115] In some embodiments, after determining the distance to the object at block 980, method 900 can determine whether an exit command has been received by CPOS at block 990. If an exit command has been received, then method 900 can stop measuring distances at block 999, otherwise method 900 can continue measuring distances to objects by looping back to block 920.

[0116] As mentioned above, method 900 can be used to reduce interference among channels. For example, method 900 can be repeated for a plurality of channels of light sources and photosensors as part of a plurality of optical measurements. The plurality of optical measurements can overlap in time, e.g., performed substantially simultaneously. Thus, each channel can perform a measurement at the same time. To reduce interference, the codes can be different for at least some of the channels. For example, the pulse patterns of the N pulse trains of at least two channels of the plurality of channels can be different, thereby causing different histogram patterns for different channels. In addition or instead, the weights assigned to the N pulse trains of at least two channels of the plurality of channels can be different, thereby causing different histogram patterns for different channels.

IV. CONSTRUCTION OF ACTIVE IMAGER SYSTEMS

[0117] FIG. 10 is a simplified diagram illustrating a detailed view of an exemplary active optical imager system 1000 having a wide field-of-view and capable of narrowband imaging, according to some embodiments of the present disclosure. Active optical imager system 1000 can employ solid state or scanning architectures as aforementioned herein. In some embodiments, active optical imager system 1000 can include a light detection system 1001 and a light emission system 1002, which is unlike passive optical imager systems. Light emission system 1002 provides active illumination of at least a portion of a field in which system 1000 is positioned with narrowband light rays 1004. Light detection system 1001 detects the narrowband light emitted from the light emission system 1002 after it has been reflected by

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objects in the field as reflected light rays 1006. Light detection system 1001 can be substantially similar to light detection system 200 discussed herein with respect to FIG 2. Thus, details of bulk receiver optic 1008, light cone 1010, micro-optic receiver channel 1012 in micro-optic receiver layer 1014, and photodetectors 1016 can be referenced herein with respect to FIG. 2, and are not discussed herein for brevity.

[0118] In some embodiments, light emission system 1002 includes a bulk transmitter optic 1018 and a light emitting layer 1020 formed of a one- or two-dimensional array of light emitters 1022. Each light emitter 1022 can be configured to generate discrete beams of narrowband light. In some embodiments, light emitting layer 1020 is configured to selectively project the discrete beams of light through bulk transmitter optic 1018 according to an illumination pattern that matches, in size and geometry across a range of distances from light emission system 1002, the fields of view of the receiver channels in micro-optic receiver channel array 1014. Light emitters 1022 can be any suitable light emitting device, such as a vertical-cavity surface-emitting lasers (VCSELS) integrated on one or more monolithic chip, or any other type of laser diode. Light emitters 1022 can produce cones of narrowband light 1024 that are directed to bulk transmitter optic 1018, which can collimate cones of light 1024 and then output the collimated light to distant targets in the field as emitted light rays 1004. In some embodiments, bulk transmitter optic 1018 is image-space telecentric.

[0119] In additional and alternative embodiments, light rays 1004 from light cones 1024 are focused on an intermediate plane in space by a micro-optic transmitter layer (not shown) before being directed to distant targets by the bulk transmitter optic 1018 to enhance the brightness and intensity of light emitted from light emission system 1002. In such embodiments, embodiments, light emission system 1002 and light detection system 1001 are configured such that each micro-optic transmitter channel (not shown) is paired with a corresponding micro-optic receiver channel 1012 and the centers of their fields-of-view are aligned to be overlapping at a certain distance from the sensor or their chief rays are made parallel. In further additional and alternative embodiments, the far-field beams of light emitted by light emission system 1002 are of similar size and divergence angle to the far-field fields-of-view of each micro-optic receiver channel 1012. Details of light emission systems 1002 having the micro-optic transmitter layer for enhancing brightness and intensity of outputted light will be discussed in detail below.

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[0120] As is evident from the illustration of parallel light rays 1004 and 1006 in FIG. 10, each micro-optic receiver channel 1012 has a non-overlapping field of view beyond a threshold distance. As shown in FIG. 10, each micro-optic receiver channel 1012 includes an aperture from the plurality of apertures, a lens from the plurality of lenses, and a photodetector from the plurality of photodetectors, where the aperture of each channel defines a discrete field of view for the pixel in the channel that is non-overlapping beyond a threshold distance within the fields of view of the other micro-optic receiver channels. That way, each micro-optic receiver channel receives reflected light corresponding to a discrete position in the field that is not measured by any other micro-optic receiver channel in micro-optic receiver channel layer 1014.

A. Enhancing Brightness and Intensity of Transmitters in Active Imager Systems

[0121] Embodiments of the present disclosure pertain to a LIDAR sensor that can, among other uses, be used for obstacle detection and avoidance in autonomous vehicles. Some specific embodiments pertain to LIDAR sensors that include design features that enable the sensors to be manufactured cheaply enough and with sufficient reliability and to have a small enough footprint to be adopted for use in mass-market automobiles, trucks and other vehicles. For example, some embodiments include a set of vertical-cavity surface-emitting lasers (VCSELs) as illumination sources that emit radiation into a field and include arrays of single-photon avalanche diode (SPAD) detectors as a set of photosensors (detectors) that detect radiation reflected back from a surface in the field. Using VCSELs as the emitters and SPADs as the detectors enables multiple measurements to be taken at the same time (i.e., the VCSEL emitters can be fired simultaneously) and also enables the set of emitters and the set of photosensors to each be fabricated using standard CMOS processes on a single chip, greatly simplifying the manufacturing and assembly process.

[0122] Using VCSELs and SPADs in certain embodiments presents challenges, however, that various embodiments of the present disclosure overcome. For example, VCSELs are much less powerful than typical lasers used in existing LIDAR architectures and SPADs are much less efficient than the typical detectors used in the existing LIDAR architectures. To address these challenges, as well as challenges presented by firing multiple emitters simultaneously, certain embodiments of the disclosure include various optical components (e.g., lenses, filters, and an aperture layer), which may work in concert with multiple arrays of SPADs, each array

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corresponding to a different pixel (e.g., position in the field), as described herein. For example, as discussed herein with respect to FIG. 2, a light detection system 200 can include a micro-optic receiver layer 204 for enhancing the light detected by photosensors 216, e.g., SPADs.

[0123] Because VCSELs are less powerful than typical lasers in existing LIDAR architectures, in some embodiments, light emission system 1002 can be configured to improve the ability of imager system 1000 to perform light ranging functionality. That is, the quality of light emitted by light emission system 1002 can be enhanced to improve light ranging accuracy and efficiency. The quality of transmitted light for light ranging and imaging purposes can be defined in terms of brightness and intensity. The brightness and intensity of light rays 1004 emitted from bulk transmitter optic 1018 can be enhanced by modifying and/or implementing one or more optic transmitter layers, as will be discussed further herein.

[0124] Brightness of a transmitting light can be defined by the optical power (in watts) per solid angle. Thus, light sources that output light with tight collimation, i.e., low divergence, produce light that are high in brightness. Conversely, light sources that output light with high divergence produce light that are low in brightness. Intensity of light can be defined by the optical power per area, meaning light emitted with a certain power will have higher intensity if it tightly compacted in a small area. Accordingly, light sources that output light in a tightly compacted ray will have higher intensity than light sources that output light in a less compacted ray, even if both light sources output light that has low divergence. As will be appreciated herein, transmitter components for LIDAR systems in embodiments of the present disclosure can be configured with micro-optical components that enable the transmitter to output light that has enhanced brightness and intensity as compared to a similar transmitter without the micro-optical components.

[0125] FIG. 11 is a simplified cross-sectional view diagram of a first exemplary enhanced light emission system 1100, according to some embodiments of the present disclosure. Light emission system 1100 can include a light emitter array 1102 having light emitters 1104 that for example may comprise without limitation any of LEDs, laser diodes, VCSELs, or the like for emitting light 1113. A VCSEL is a type of semiconductor laser diode with laser beam emission perpendicular from the top surface. Note that the linear array shown in FIG. 11 can be any

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geometric form of emitter array, including and without limitation circular, rectangular, linear, or any other geometric shape.

[0126] Enhanced light emission system 1100 can include a micro-optic transmitter channel array 1106 separated from light emitter array 1102 by an open space 1118. Each micro-optic transmitter channel 1108 is paired with a corresponding receiver channel (e.g., receiver channel 1012 in FIG. 10) and the centers of their fields-of-view are aligned to be overlapping at a certain distance from the optical imager system. Micro-optic transmitter channel array 1106 can be formed of a substrate 1119 sandwiched between a first optical surface 1120 positioned on a side facing light emitter array 1102 and a second optical surface 1121 positioned on an opposite side facing away from light emitter array 1102. Both first and second optical surfaces 1120 and 1121 can each be configured as an array of convex, micro-optic lenses where each convex lens of first optical surface 1120 is configured to be optically aligned with a respective convex lenses of second optical surface 1120 so that light transmitting through first optical surface 1120 can subsequently be transmitted through second optical surface 1121. The corresponding convex lenses from first and second optical surfaces 1120 and 1121 can face away from one another as shown in FIG. 11. In certain embodiments, convex lenses of first optical surface 1120 have a first optical power and convex lenses of second optical surface 1121 have a second optical power different from the first optical power. For instance, the second optical power can be greater than the first optical power such that the focal length of the second optical power is shorter than the focal length of the first optical power. Substrate 1119 can be formed of any suitable material that is transmissive in the wavelength range of the light emitters 1104 such silicon, silicon dioxide, borosilicate glass, polymer, and the like. First and second optical surfaces 1120 and 1121 can be formed of a transparent polymer that is imprinted on respective opposite surfaces of substrate 1119.

[0127] In some embodiments, micro-optic transmitter channel array 1106 can be formed of a monolithic array of micro-optic transmitter channels 1108. Each micro-optic transmitter channel 1108 can include a first convex lens from first optical surface 1120, a corresponding second convex lens from second optical surface 1121, and a corresponding portion of substrate 1119 positioned between the two convex lenses. Each micro-optic transmitter channel 1108 can correspond with a respective light emitter 1104 so that light outputted from the light emitter 1104

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first passes through the first convex lens, through the corresponding region of substrate 1119, and then through the second convex lens during operation.

[0128] Once light emits out of the second convex lens of second optical surface 1121, the light forms a miniature spot image 1110 that is a real image of the corresponding light emitter 1104 but a reduced-size of the corresponding light emitter 1104. In some embodiments, miniature spot images 1110 are positioned between micro-optic transmitter channel array 1106 and bulk transmitter optic 1114. For instance, miniature spot images 1110 can be formed within respective apertures of an aperture layer 1109. Each aperture can be a pin hole in a reflective or opaque layer in which emitted light focuses to form miniature spot images 1110. From there, continuing away from both the light emitter and micro optic channel, the light forms a light cone 1112 reaching out towards bulk transmitter optic 1114.

[0129] According to some embodiments of the present disclosure, the degree of divergence of emitted light 1113 can be smaller than the degree of divergence of light cone 1112. This discrepancy in divergence can be created by a micro-optic transmitter channel 1108, specifically by the optical power of second optical surface 1121. Because the divergence of light out of micro-optic transmitter channel 1108 is larger than the divergence of emitted light 1113 from light emitters 1104, miniature spot image 1110 can be a real image of light emitter 1104 but a multitude smaller than the size of light emitter 1104 and with the same number of photons as emitted light 1113. The resulting light cone 1112 formed after the real spot images are formed then gets projected into the field as discrete beams of light for each light emitter 1104 after passing through bulk transmitter optic 1114. The resulting light rays emanating out of light emission system 1100 are highly collimated beams of light that have a small cross-sectional area (smaller than the surface area of light emitter 1104), thereby resulting in a light emission system 1100 that can output light having enhanced brightness and intensity.

[0130] Note that bulk transmitter optic 1114 can include either a single lens or a cluster of lenses where two or more lenses function together to form bulk transmitter optic 1114. The use of multiple lenses within the bulk transmitter optic 1114 could increase the numerical aperture, reduce the RMS spot size, flatten the image plane, improve the telocentricity, or otherwise improve the performance of bulk transmitter optic 1114. Note also that for some embodiments, light cones 1112 may overlap forming cone overlap region 1116.

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[0131] To better understand the operation and effectiveness of micro-optic transmitter channel array 1106, a more detailed explanation of the operation of light emission system 1100 is discussed. For enhanced light emission systems 1100 utilizing a light emitter array formed of VCSEL emitters, an exemplary initial radius for an emitter might be 12.5 um with light admitted in a 10° half angle cone. Such emitters would typically output 50 uW per square micron of active area. A diverging light cone from each emitter 1104 is accepted into a micro-optic transmitter channel 1108, and then a converging light cone is output by that same micro optic channel to produce a converging light cone with a half angle of for example 20°. Thus for some embodiments, the cone angle produced by an emitter 1104 is smaller than the cone angle produced by a corresponding micro-optic transmitter channel 1108. The converging light cone emanated by micro-optic transmitter channel 1108 then produces a miniature spot image 1110 of the emitter. For the embodiment according to FIG. 11, miniature spot image 1110 is a real image and has a size that is smaller than the size of a corresponding light emitter 1104. Note that all rays from a given emitter may not all be focused into an arbitrarily small spot. The miniature spot image size is typically controlled by an "optical invariant":

$$\Theta\_s * r\_s >= \Theta\_e * r\_e$$

where Θ_s is the marginal ray half angle of the focused spot, r_s is the radius of the focused spot, Θ_e is the marginal ray half angle of the original emitter, and r_e is the radius of the original emitter. So, in this example, the smallest miniature spot image radius that could be formed (while still capturing all the rays from the emitter) is:

$$10/20 * 12.5 \text{ um} = 6.25 \text{ um}$$

[0132] Note that this smaller spot will have one fourth the area of the original emitter, and thus has a power density of 200 uW per square micron of spot area. Each micro-optic transmitter channel 1108 typically has one or more optical surfaces, having characteristics that may for example and without limitation include a focal length of 50 um, and a lens diameter of 80 um. For some embodiments, the distance between light emitter 1104 and a corresponding micro-optic transmitter channel 1108 may be for example and without limitation 150 um. Open space 1118 between emitter array 1102 and micro-optic transmitter channel array 1106 as shown in FIG. 11 may be, for example and without limitation an air gap such as that produced by methods

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typically used to manufacture MEMS devices. The distance between emitter array 1102 and micro-optic transmitter channel array 1106 for example may be 150 um.

[0133] Bulk transmitter optic 1114 is positioned in front of the micro-optic and emitting layers such that the focal plane of the bulk imaging optic coincides with miniaturized spot images 1110. Bulk transmitter optic 1114 accepts divergent light cone(s) 1112 and outputs a collimated beam. Its numeric aperture can be at least large enough to capture the full range of angles in the divergent ray cone(s), so for example and without limitation the Numerical Aperture (NA) = 0.34 in this example. Also, bulk transmitter optic 1114 can be image-space telecentric, since light cone(s) 1112 exiting the micro-optic layer may all be parallel (rather than having their center axes aimed towards the center of the bulk optic). In one embodiment, light can exit bulk transmitter optic 1114 approximately collimated. Note that the quality of beam collimation relates to the size of the "emitting object" (miniature spot images 1110) at the focal plane. Since this "emitting object" size has been reduced by using a micro-optic stack, a better collimation angle is obtained than if the emitter object was simply imaged directly.

[0134] Although FIG. 11 shows an enhanced light emission system having a micro-optic channel array formed of a substrate sandwiched between first and second optical surfaces, and positioned a distance away from a light emitter array by an open space to improve the brightness and intensity of light outputted by the light emission system, embodiments are not limited to such configurations. Rather, other embodiments may not necessarily implement an open space or two optical surfaces, as discussed further herein with respect to FIG. 12.

[0135] FIG. 12 is a simplified cross-sectional view diagram of a second exemplary enhanced light emission system 1200, according to some embodiments of the present disclosure. Similar to first exemplary enhanced light emission system 1100, second exemplary enhanced light emission system 1200 can include bulk imaging optic 1214 and light emitter array 1202. However, unlike first exemplary light emission system 1100, second exemplary light emission system 1200 can include a micro-optic transmitter channel array 1206 that is positioned directly upon an emission surface of light emitter array 1202 instead of being separated by an open space/air gap, as shown in FIG. 12.

[0136] In such embodiments, micro-optic transmitter channel array 1206 can be formed of a substrate 1219 and an optical surface 1220. Optical surface 1220 can be positioned on a first

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surface 1230 of substrate 1219. Second surface 1231 of substrate 1219 can be located opposite of first surface 1230 and positioned against light emitter array 1202 so that light emitted from emitters 1204 can first pass through substrate 1219 before passing through optical surface 1220. Optical surface 1220 can be configured as an array of convex lenses where each convex lens of optical surface 1220 is configured to be optically aligned with a respective light emitter 1204 so that light outputted by the respective light emitter 1204 can transmit through the respective convex lens of optical surface 1220. Convex lenses from optical surface 1220 can face away from their respective light emitters 1204 as shown in FIG. 12 so that their focal points are positioned further from light emitter 1204. In certain embodiments, convex lenses of optical surface 1220 have an optical power suitable for converging the emitted light into real miniature spot images 1210 that are real images of corresponding light emitters 1204 but reduced-size images of the corresponding light emitters 1204 like the convex lenses of second optical surface 1121 in FIG. 11. Optical surface 1120 enables the emitted light to diverge into light cones 1212 before projecting through bulk imaging optic 1214. Substrate 1219 and optical surface 1220 can be formed of similar materials as substrate 1119 and optical surfaces 1120 and 1121 discussed herein with respect to FIG. 11. In some embodiments, light cones 1212 may overlap forming cone overlap region 1216.

[0137] Embodiments herein can also implement micro-optic channel arrays that do not include convex lenses and that do not generate real images of the light emitters. Rather, some embodiments may implement concave surfaces to generate virtual images of the light emitters, as discussed further herein with respect to FIG. 13.

[0138] FIG. 13 is a simplified cross-sectional view diagram of a third exemplary enhanced light emission system 1300, according to some embodiments of the present disclosure. Similar to first and second exemplary enhanced light emission systems 1100 and 1200, third exemplary enhanced light emission system 1300 can include bulk imaging optic 1314 and light emitter array 1302. However, unlike first and second exemplary light emission systems 1100 and 1200, third exemplary light emission system 1300 can include a micro-optic transmitter channel array 1306 that includes an array of concave surfaces instead of an array of convex lenses, as shown in FIG. 13.

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[0139] In such embodiments, micro-optic transmitter channel array 1306 can be formed of a substrate 1319 and an optical surface 1320. Optical surface 1320 can be a first surface 1330 of substrate 1319 positioned toward bulk imaging optic 1314 and away from light emitters 1304. Second surface 1331 of substrate 1319 can be located opposite of first surface 1330 and positioned against light emitter array 1302 so that light emitted from emitters 1304 can first pass through substrate 1319 before passing through optical surface 1320. Optical surface 1320 can each be configured as an array of concave surfaces where each concave surface of optical surface 1320 is configured to be optically aligned with a respective light emitter 1304 so that light outputted by the respective light emitter 1304 can transmit through the respective concave surface of optical surface 1320. In certain embodiments, the concave surfaces of optical surface 1320 have an optical power suitable for forming virtual miniature spot images 1310 that are virtual images of corresponding light emitters 1304 but reduced-size images of the corresponding light emitters 1304, and further enable the emitted light to diverge into light cones 1312 before projecting through bulk imaging optic 1314. In some embodiments, virtual miniature spot images 1310 are formed within substrate 1319 as shown in FIG. 13. In some embodiments, light cones 1312 may overlap forming cone overlap region 1316. Substrate 1319 can be formed of similar materials as substrate 1119 discussed herein with respect to FIG. 11.

[0140] Note that the lens configurations for the micro-optic channels for embodiments described in each of FIGS. 11, 12 and 13 differs with respect to how many surfaces have optical power and the shapes of those surfaces. The first embodiment shown in Fig. 11 benefits from the ability to use two optical power surfaces on opposite sides of a substrate, which could allow each surface to be shallower, spherical rather than aspherical, or otherwise more easily manufactured. This embodiment includes a spacer structure (not shown) to maintain an offset between the micro-optic channel array 1106 and the light emitter array 1102. An example of such a spacer structure would be a silicon wafer with channels formed via deep reactive ion etching. The second embodiment shown in FIG. 12 benefits from having only one optical power surface on a substrate that is attached to the light emitter array. This type of configuration simplifies fabrication while also achieving enhanced brightness and intensity. The third embodiment shown in FIG. 13 shares the benefits of the embodiment shown in FIG. 12 but has a single optical surface that is formed of concave surfaces rather than convex lenses; concave features can often be easier to fabricate at the micro-scale.

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[0141] In some embodiments, bulk imaging optics for light emission systems can include one or more aperture stops to reduce stray light emitted by the system. For instance, FIG. 14 is a simplified cross-sectional view diagram of an exemplary enhanced light emission system 1400 configured with bulk optics that have aperture stops, according to some embodiments of the present disclosure. FIG. 14 is substantially similar to FIG. 1 with the addition of aperture stop variants 1403, 1405, and 1406 for bulk transmitter optic 1414. Aperture stop(s) shown in FIG. 14 can be used with any of FIGS. 11 through 13. In FIG. 14, aperture stops 1403, 1405, and 1407, can have circular or oval openings for light to pass through, although any opening shape may be utilized without deviating from the spirit and scope of the present disclosure.

[0142] In some embodiments, aperture stop 1403 can be located on a side of bulk transmitter optic 1414 facing away from light emitter array 1402 and micro-optic transmitter channel array 1406. In some additional and alternative embodiments, aperture stop 1405 can be located on a side of bulk transmitter optic 1414 facing toward light emitter array 1402 and micro-optic transmitter channel array 1406. In yet some additional and alternative embodiments where bulk receiver optic 114 includes a plurality of lenses working together, aperture stop 1407 can be formed of one or more aperture stops placed within the plurality of lenses that form bulk transmitter optic 1414.

[0143] The various configurations and locations of aperture stops 1403, 1405, and 1407 can dictate the way each aperture stop functions in the light emitting system. For example, if all the light cones 1412 are compressed to be substantially overlapping near the location of aperture stop 1407, then the size of the aperture stop 1407 would be able control both the initial diameter of the emitted collimated beams as well as reject the marginal rays emitted by light emitters 1404. Rejecting certain ray angles could effectively narrow the spectrum of light emitted out of the bulk optic, since the wavelength of light emitted by many types of lasers varies with angle. Alternatively, perhaps this best location for the aperture stop would occur at 1402 or 1403, depending upon the design of the bulk transmitter optic 1414. Multiple aperture stops may be used simultaneously – e.g. 1402, 1403, and 1404 all in one bulk transmitter optic 1414 – to reduce stray light emitted by light emitting system 1400.

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B. Optical Corrections for Astigmatism

[0144] As mentioned herein with respect to FIG. 7, light detection systems and light emission systems can be enclosed within the same protective structure, e.g., stationary housing 702, optically transparent window 704, and stationary lid 706 in FIG. 7. Light emitted from the light emission system, in some embodiments, exits out of transparent window 704, and light detected by light detection system may first enter into transparent window 704. The curvature of transparent window 704 can induce some optical aberrations, such as astigmatism. Because the transparent window can have a cylindrical structure and be well-controlled, it can be corrected with one or more additional optical structures. In some embodiments, light emission and/or detection systems can be configured with corrective optical structures to compensate for the astigmatism caused by the transparent window, as discussed further herein.

[0145] FIGS. 15A-15C are cross-sectional views of simplified diagrams of exemplary active imager systems having different implementations of corrective optical structures for astigmatism, according to some embodiments of the present disclosure. Specifically, FIG. 15A is a simplified cross-sectional view diagram of an active imager system 1500 having a corrective optical structure as part of the bulk imaging optic, FIG. 15B is a simplified cross-sectional view diagram of an active imager system 1501 having a corrective optical structure as part of the micro-optic receiver channel array, and FIG. 15C is a simplified cross-sectional view diagram of an active imager system 1502 having a corrective optical structure as part of the micro-optic transmitter channel array. Active imager systems 1500, 1501, and 1502 each include a light detection system 1504 and a light emission system 1506. Components of active imager systems 1500, 1501, and 1502 are substantially similar to active optical imager system 1000 in FIG. 10 with the addition of the corrective optical structures. Thus, the components that are shared with active optical imager system 1000 are not discussed for brevity.

[0146] As shown in FIG. 15A, active imager system 1500 can be housed within an enclosure containing a transparent window 1508. Transparent window 1508 is at least transparent to the wavelength of light at which emitters 1510 operate. The curved shape of transparent window 1508 can induce an optical aberration, such as an astigmatism, in light rays 1511 emitted from light emission system 1506 when light rays 1511 exit the enclosure through transparent window 1508. Light rays 1512 then enter back into the enclosure through transparent window 1508 after

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reflecting off of an object in the field, which can induce an additional optical aberration to the received light rays. To correct for these optical aberrations, light detection system 1504 can include corrective bulk imaging optic 1514 specifically designed to compensate for the expected astigmatism induced by transparent window 1508. For example, corrective bulk imaging optic 1514 can include a corrective lens 1516 in addition to bulk receiver optic 1518. Corrective lens 1516 can be any suitable lens capable of negating the astigmatism caused by transparent window 1508, such as a cylindrical lens. Corrective lens 1516 can be positioned between transparent window 1508 and bulk receiver optic 1518 in some embodiments, or between bulk receiver optic 1518 and micro-optical receiver channel array 1505 in some other embodiments. Similarly, a corrective bulk optic could be included in the bulk transmitter optic of the light emission system 1506.

[0147] Instead of incorporating the corrective optics into the bulk imaging optics, the corrective optics can be implemented into a micro-optical receiver channel array in some embodiments. For instance, with reference to FIG. 15B, light detection system 1504 can include a corrective lens array 1520 in front of apertures 1522, e.g., on the opposite side of apertures 1522 from where photosensors 1526 are positioned. That way, light cones 1524 can propagate through respective corrective lenses to compensate for astigmatism caused by transparent window 1508 before projecting on photosensors 1526. In some embodiments, corrective lens array 1520 is formed of an array of cylindrical lenses that can negate the astigmatism caused by transparent window 1508. Each corrective lens of corrective lens array 1520 can be positioned in alignment with a respective aperture 1522 so that corrective lens array 1520 can negate the astigmatism caused by transparent window 1508 for light received by each photosensor 1526.

[0148] Although FIGS. 15A and 15B illustrate ways in which a light detection system portion of a LIDAR system can be modified to correct for astigmatism caused by transparent window 1508, embodiments are not limited to such configurations and corrective optics can be implemented in light emission systems as well. For example, with reference to FIG. 15C, active imager system 1502 can include a corrective lens array 1528 in front of aperture layer 1530, e.g., on the opposite side of aperture layer 1530 from where light emitters 1510 are positioned. That way, light emitted from light emitters 1510 can propagate through respective corrective lenses 1528 before emitting to bulk transmitter optics 1534. In this case, respective corrective lenses

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1528 can induce a corrective degree of astigmatism in the emitted light in anticipation of, and to compensate for, the astigmatism caused by transparent window 1508 as light is emitted out of light emission system 1506. In some embodiments, corrective lens array 1528 is formed of an array of biconical lenses that can induce an equal but opposite degree of astigmatism caused by transparent window 1508. Thus, the amount of astigmatism induced by corrective lens layer 1528 can be offset by the degree of astigmatism caused by transparent window 1508, thereby effectively achieving little to no net astigmatism during operation of active imager system 1502. Each corrective lens of corrective lens array 1528 can be positioned in alignment with a respective aperture 1532 so that corrective lens array 1528 can induce a corrective degree of astigmatism to negate the astigmatism caused by transparent window 1508 for light received by each photosensor 1526. In some embodiments, corrective lens array 1528 may not be needed. Instead, optical surface 1536 can be an array of biconical lenses instead of an array of cylindrical lenses. The biconical structure of the lenses can induce an amount of astigmatism to offset the degree of astigmatism caused by transparent window 1508. In these embodiments, corrective lens array 1528 may not be implemented in light emission system 1506. Furthermore, in some embodiments, instead of (or in conjunction with) a corrective micro-optic lens array, a corrective bulk cylindrical lens can be implemented with bulk receiver optic 1534 (similar to the embodiment shown in FIG. 15A for light detection system 1504). Thus, light emission system 1506 can include a corrective bulk imaging optic in front of its bulk receiver optic 1534 to negate the astigmatism caused by transparent window 1508.

V. MITIGATING RECEIVER CHANNEL CROSS-TALK

[0149] As can be appreciated by disclosures herein, channels in the micro-optic receiver and are positioned very close to one another, often times within microns of one another. This small spacing between each channel can invite the opportunity for problems to arise. For instance, light propagating through bulk imaging optic can occasionally cause stray light to bleed into neighboring channels, thereby resulting in inaccurate readings of reflected light for each pixel in the field. Ideally, no stray light should be received by any channel, as shown in FIG. 16A.

[0150] FIG. 16A is a simplified cross-sectional view diagram of part of a light detection system 1600 where there is no cross-talk between channels. During operation, perpendicular light rays 1602 and chief ray 1604 enter the bulk imaging optic 1606 and produce light cone

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1608. Light rays 1602 and 1604 enter an aperture of aperture layer 1610 and enter collimating lens 1611. Collimating lens 1611 accepts a limited range of incident light angles. For example, collimating lens 1611 can accept light rays at incident angles between +25 to -25 degrees relative to the perpendicular. FIG. 16A shows light cone 1608 with incident angles between +25 to -25 degrees. The chief ray 1604 is the light ray that passes through the center of the aperture. In this example, the chief ray 1604 has an incident angle of 0 degrees on the collimating lens 1611.

[0151] FIG. 16B is a simplified cross-sectional view diagram of part of a light detection system 1601 where there is cross-talk between channels. In this case, during operation, oblique light rays 1612 and chief ray 1614 enter bulk receiver optic 1616 and later enter collimating lens 1621. In this example, collimating lens 1621 belongs to a micro-optic channel that corresponds to a photosensor further from the center of the image. In this example, chief ray 1614 has an incident angle of -12 degrees and the cone of focused light has incident angles between +12 degrees to -35 degrees. Collimating lens 1621 rejects some of the light rays because it only accepts light with incident angles between +25 to -25 degrees. Additionally, the rays that are outside of the collimating lens acceptance cone can travel to other optical surfaces and become stray light. Thus, a non-telecentric bulk imaging optic will deliver significantly fewer signal photons to the photodetector, while potentially polluting other channels with errant light rays 1622. A telecentric bulk imaging optic, on the other hand, will produce light cones with incident angles approximately between +25 to -25 degrees and chief rays with incident angles on the collimating lens of approximately 0 degrees, regardless of the angle of the oblique rays 1612 and chief ray 1614. A telecentric bulk imaging optic has similar benefits for the transmitter when the lasers are telecentric (their chief rays are all parallel) as is the case for VCSELS or a side emitter diode laser bar.

[0152] In some embodiments, the light detection system of a light sensing module uses an input image-space telecentric bulk imaging optic. In some other embodiments, for example where cost or increased field of view is more important than performance, the light detection system may use a more standard input bulk imaging optic such as a bi-convex lens. For any given input field into an image-space telecentric lens, the resulting chief rays are parallel to the optical axis, and the image-side ray cones all span approximately the same set of angles. This allows micro-optic channels far from the optical axis in the light detection system to achieve

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similar performance to the on-axis micro-optic channel. The light detection system does not need perfect image space telecentricity for this to work, but the closer to perfect telecentricity the better. For a micro-optic receiver optical layer lens that can only accept +/-25 degree light, the preference is that the input bulk imaging optic produce image-side rays that are no greater than 25 degrees in angle for every point on the focal plane.

[0153] In certain embodiments, specific light detection systems having wide field of view and narrowband imaging can have an input image-space telecentric bulk imaging optic with a numerical aperture (NA) equal to 0.34 and focal length of 20 mm. Similarly, some other embodiments could have a 1 nm wide bandpass filter, thereby enabling it to detect light of a very specific wavelength. The light detection system is capable of supporting FOVs greater than 30 degrees.

[0154] According to some embodiments of the present disclosure, the design of each channel of the micro-optic receiver channel array can be specifically configured to have features that minimize the intrusion of stray light onto a respective photodetector, thereby reducing or eliminating any detrimental effects caused by the occurrence of stray light. FIG. 17 is a simplified cross-sectional diagram of an exemplary micro-optic receiver channel structure 1700, also called a micro-optic receiver channel in discussions herein. Receiver channel 1700 can be representative of micro-optic receiver channels 232 and 1032, among others, shown in FIGS. 2 and 10, respectively, and serves to accept an input cone of light containing a wide range of wavelengths, filters out all but a narrow band of those wavelengths centered at the operating wavelength, and allows photosensor 1771 to detect only or substantially only photons within the aforementioned narrow band of wavelengths. According to some embodiments of the present disclosure, micro-optic receiver channel structures, such as receiver channel 1700, can include the following layers:

- An input aperture layer 1740 including an optically transparent aperture 1744 and optically non-transparent stop region 1746 configured to define a narrow field of view when placed at the focal plane of an imaging optic such as bulk receiver optic 202 or 1008 (shown in FIGS. 2 and 10, respectively; not shown in FIG. 17). Aperture layer 1740 is configured to receive the input marginal ray lines 1733. The term "optically transparent" herein refers to as allowing most or all light to pass through. Light herein

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refers to spectrum of light in the near-ultraviolet, visible, and near-infrared range (e.g. 300 nm to 5000 nm). Optically non-transparent herein refers to as allowing little to no light to pass through, but rather absorbing or reflecting the light. Aperture layer 1740 can include optically transparent apertures separated from each other by optically non-transparent stop regions. The apertures and stop regions can be built upon a single monolithic piece such as an optically transparent substrate. Aperture layer 1740 can optionally include a one-dimensional or two-dimensional array of apertures 1744.

- An optical lens layer 1750 including a collimating lens 1751 characterized by a focal length, offset from the plane of aperture 1744 and stop region 1746 by the focal length, aligned axially with aperture 1744, and configured to collimate photons passed by the aperture such that they are traveling approximately parallel to the axis of collimating lens 1751 which is aligned with the optical axis of receiver channel 1700. Optical lens layer 1750 may optionally include apertures, optically non-transparent regions and tube structures to reduce cross talk.

- An optical filter layer 1760 including an optical filter 1761, typically a Bragg reflector type filter, adjacent to collimating lens 1751 and opposite of aperture 1744. Optical filter layer 1760 can be configured to pass normally incident photons at a specific operating wavelength and passband. Optical filter layer 1760 may contain any number of optical filters 1761. Optical filter layer 1760 may optionally include apertures, optically non-transparent regions and tube structures to reduce cross talk.

- A photosensor layer 1770 including a photosensor 1771 adjacent to optical filter layer 1760 and configured to detect photons incident on photosensor 1771. Photosensor 1771 herein refers to a single photodetector capable of detecting photons, e.g.,, an avalanche photodiode, a SPAD (Single Photon Avalanche Detector), RCP (Resonant Cavity Photo-diodes), and the like, or several photodetectors, such as an array of SPADs, cooperating together to act as a single photosensor, often with higher dynamic range, lower dark count rate, or other beneficial properties as compared to a single large photon detection area. Each photodetector can be an active area that is capable of sensing photons, i.e., light. Photosensor layer 1770 refers to a layer made of photodetector(s) and contains optional structures to improve detection efficiency and reduce cross talk with neighboring

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receiver structures. Photosensor layer 1770 may optionally include diffusers, converging lenses, apertures, optically non-transparent tube spacer structures, optically non-transparent conical spacer structures, etc.

[0155] Stray light may be caused by roughness of optical surfaces, imperfections in transparent media, back reflections, and the like, and may be generated at many features within the receiver channel 1700 or external to receiver channel 1700. The stray light may be directed: through the filter region 1761 along a path non-parallel to the optical axis of collimating lens 1751; reflecting between aperture 1744 and collimating lens 1751; and generally taking any other path or trajectory possibly containing many reflections and refractions. If multiple receiver channels are arrayed adjacent to one another, this stray light in one receiver channel may be absorbed by a photosensor in another channel, thereby contaminating the timing, phase, or other information inherent to photons. Accordingly, receiver channel 1700 may feature several structures to reduce crosstalk between receiver channels.

[0156] As will be understood further herein, each layer of a micro-optic channel layer structure can be designed a specific way to mitigate the detrimental effects of stray light. Various different designs for each layer will now be discussed in further detail below.

A. Aperture Layer

[0157] In an embodiment having aperture layer 1740, as shown in FIG. 17, optically transparent aperture 1744 and optically non-transparent stop region 1746 can be formed from a single monolithic piece, such as a metal foil with a pinhole or from a single layer of a deposited opaque or reflective material having apertures etched therethrough.

[0158] FIG. 18A is a simplified cross-sectional view diagram of a different embodiment 1800 where aperture layer 1840 has two apertures 1844. Both the optically transparent apertures 1844 and corresponding optically non-transparent optical stop regions 1846 are supported on an optically transparent substrate 1845. Bottom aperture 1844 can be smaller and be positioned at the focal plane of the bulk optic. Aperture layer 1840 can be followed by optically transparent spacer structure 1856 positioned between aperture 1844 and collimating lens 1851 in the receiver channel. Optically transparent spacer structure 1856 forms a tube of substantially similar or larger diameter to collimating lens 1851.

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[0159] FIG. 18B is a simplified cross-sectional view diagram of a different embodiment 1801 of aperture layer 1840. Optically transparent aperture 1844 and optically non-transparent stop region 1846 are supported on optically transparent substrate 1845. Optically transparent spacer structure 1856 that follows aperture layer 1840 and positioned between aperture 1844 and collimating lens 1851 forms a tube of substantially similar or larger diameter to collimating lens 1851.

[0160] FIG. 18C is a simplified cross-sectional view diagram of an embodiment 1802 of aperture layer 1840 consisting of multiple optically non-transparent stop regions 1846 that are supported on optically transparent substrate 1845. These layers (stop regions 1846) follow the contour of marginal light rays (not shown, but similar to light rays 1733 in FIG. 17) to reduce stray light into the receiver channel. Optically transparent spacer structure 1856 below aperture layer 1840 forms a tube of substantially similar or larger diameter to collimating lens 1851.

[0161] FIG. 18D is a simplified cross-sectional view diagram of an embodiment 1803 of aperture layer 1840 having multiple optically non-transparent stop layers 1846 supported on multiple optically transparent substrate 1845. Aperture layer 1840 follows the contour of marginal light rays (not shown, but similar to light rays 1733 in FIG. 17) to reduce stray light into the receiver channel. Optically transparent spacer structure 1856 below aperture layer 1840 forms a tube of substantially similar or larger diameter to collimating lens 1851.

[0162] In some other embodiments of the present disclosure, spacer structure 1856 shown in FIGS. 18A-D, can be optically non-transparent. The optically non-transparent spacer structure in this instance could be formed by etching a silicon or glass wafer and may be coated with an optically non-transparent material (e.g. black chrome). Additionally, the spacer structure in this instance would prevent any light in the spacer region from traveling outside the receiver channel.

B. Spacer Structure Between Aperture Layer and Optical Lens Layer

[0163] FIG. 19A is a simplified cross-sectional view diagram of an embodiment 1900 of the present disclosure with an optically non-transparent spacer structure between the aperture layer and the lens layer. FIG. 19A depicts an optically non-transparent spacer structure 1956 positioned between aperture 1944 and collimating lens 1951 in the receiver channel. Optically non-transparent spacer structure 1956 forms a tube of substantially similar or larger diameter to

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collimating lens 1951 and prevents any light from traveling outside the receiver channel in the region between aperture 1944 and collimating lens 1951. Optically non-transparent spacer structure 1956 could be formed by etching a silicon or glass wafer and may be coated with an optically non-transparent material (e.g. black chrome). Alternatively, optically non-transparent spacer structure 1956 could be a solid non-transparent structure that is fabricated from molded polymer or any other suitable method. FIG. 19A shows the aperture layer having optically transparent substrate 1945 on the top, followed by the optically non-transparent stop region 1946 and aperture 1944, and then by optically non-transparent spacer structure 1956.

[0164] FIG. 19B is a simplified cross-sectional view diagram of an embodiment 1901 of the present disclosure with an optically non-transparent structure between the aperture layer and the lens layer. FIG. 1901 depicts an optically non-transparent spacer structure 1956 positioned between aperture 1944 and collimating lens 1951. Optically non-transparent spacer structure 1956 forms a tube of substantially similar or larger diameter to collimating lens 1951 and prevents any light from traveling outside of the receiver channel in the region between aperture 1944 and collimating lens 1951. FIG. 19B shows multiple optically non-transparent stop regions 1946 supported on optically transparent substrate 1945.

[0165] FIG. 19C is a simplified cross-sectional view diagram of an embodiment 1902 of aperture layer 1940 where aperture 1944 is conically aligned, and where the conical structure as an optically non-transparent layer coated on an optically transparent material.

[0166] FIG. 19D is a simplified cross-sectional view diagram of an embodiment 1903 of aperture layer 1940 where the aperture 1944 is conically aligned, and where the conical structure is a solid structure formed of an optically non-transparent material. As shown in FIGS. 19C and 19D the optically transparent aperture 1944 and optically non-transparent stop region 1946 are combined into a monolithic layer with a conical cavity aligned with the optical axis of the receiver channel and configured to conform to the shape of marginal ray lines (not shown, but similar to light rays 1733 in FIG. 17).

C. Optical Filter Layer

[0167] FIG. 20A is a simplified cross-sectional view diagram of an embodiment 2000 of filter layer 2060 for a receiver channel, according to some embodiments of the present disclosure.

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Optical filter layer 2060 can include a single optical filter 2061 supported on an optically transparent substrate 2065. Optical filter layer 2060 can be placed on top of optically transparent substrate 2065 or below optically transparent substrate 2065. Optical filter 2061 can be a bandpass filter that blocks incident light outside of a defined set of wavelengths (e.g. 945-950nm). However, in some other embodiments, optical filter 2061 can be an edge pass filter or any other suitable type of filter that selectively allows light within a wavelength range to pass through itself.

[0168] FIG. 20B is a simplified cross-sectional view diagram of an embodiment 2001 of filter layer 2060 for a receiver channel, according to some embodiments of the present disclosure. Optical filter layer 2060 can include two optical filters 2061 sandwiching and supported by an optically transparent substrate 2065. Optical filter layer 2060 can contain any number of optical filters 2061 on any number of substrates 2065. One of the optical filters 2061 as shown in FIG. 20B can be a bandpass filter and can be positioned on either on top of or directly below optically transparent substrate 2065 that blocks all of the incident light for a defined set of wavelengths (e.g. 900-945 nm and 950-995nm). The other optical filter 2061 placed on the opposite side of the optical substrate 2065 can be a wide spectrum blocking filter (except for the region covered by the bandpass filter), for example covering 200-915 nm and 980-1600 nm. The bandpass filter and blocking filter are designed such that there is no leakage in the transition region between the two filters. However, the filters could be two edge pass filters designed to work in conjunction as a bandpass filter or any other types of filters.

[0169] In some other embodiments of the present disclosure, the bandpass filter and wide spectrum blocking filter are merged into a single optical filter 2061 and placed on either the top or bottom of optically clear substrate 2065.

1. Filter Layer with Apertures

[0170] FIG. 20C is a simplified cross-sectional view diagram of an embodiment 2002 of filter layer 2060 for a receiver channel, according to some embodiments of the present disclosure. Optical filter layer 2060 can have an additional aperture 2049 on top and an additional aperture 2054 on the bottom of optical filter layer 2060 along with the corresponding optically non-transparent stop regions 2063 & 2055. Aperture 2049 defines the maximal cylinder of light

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desired to be passed into optical filter layer 2060 by optical filter 2061, and stop region 2063 an absorb or reflect any incident stray light outside the diameter of aperture 2049. Aperture 2054 defines the maximal cylinder of light desired to be passed out of optical filter layer 2060 and stop region 2055 absorbs or reflects any incident stray light outside the diameter of aperture 2054. Optical filters 2061 can be supported on an optically transparent substrate 2065.

[0171] In some embodiments of the present disclosure, filter layer 2060 can have a single aperture 2049 placed on the top of the optical filter layer 2060. In some additional and alternative embodiments of the present disclosure, filter layer 2060 can have a single aperture 2054 placed on the bottom of optical filter layer 2060.

[0172] FIG. 20D is a simplified cross-sectional view diagram of an embodiment 2003 of filter layer 2060 for a receiver channel, according to some embodiments of the present disclosure. Optical filter layer 2060 can include multiple optically transparent substrates 2065, and multiple optically non-transparent aperture layers between them in an alternating order. FIG. 20D shows an additional aperture 2049 and corresponding optically non-transparent stop region 2063 positioned on top of optical filter 2061 and supported by optically transparent substrates 2065. Aperture 2049 can define the maximal cylinder of light desired to be passed into optical filter layer 2060 by optical filter 2061, and stop region 2063 absorbs or reflects any incident stray light outside diameter of aperture 2049. FIG. 20D shows an additional aperture 2054 and corresponding optically non-transparent stop region 2055 positioned between optical filter layer 2060 and a photosensor layer (not shown, but similar to photosensor layer 1770 in FIG. 17). Aperture 2054 can define the maximal cylinder of light desired to be passed out of optical filter layer 2060 toward the photosensor, and stop region 2055 can absorb or reflect any incident stray light outside the diameter of aperture 2054. Collectively, these interleaved layers prevent stray light in one optical filter layer 2060 from traveling into an optical filter region of an adjacent receiver channel in a multi receiver channel system.

2. Filter Layer with Tube Structure

[0173] FIG. 20E is a simplified cross-sectional view diagram of an embodiment 2004 of filter layer 2060 for a receiver channel, according to some embodiments of the present disclosure. Optical filter layer 2060 can include optical filter 2061 and optically transparent substrate 2065

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and be surrounded by an optically non-transparent tube structure 2111, which prevents stray light in one optical filter layer 2060 from traveling into an optical filter region of an adjacent receiver channel in a multi receiver channel system. Tube structure 2111 can be formed of a variety of materials, including but not limited to silicon, metals, polymers, or glasses.

[0174] FIG. 20F is a simplified cross-sectional view diagram of an embodiment 2005 of filter layer 2060 for a receiver channel, according to some embodiments of the present disclosure. Optical filter layer 2060 can include optical filter 2061 and optically transparent substrate 2065 and is surrounded by an optically non-transparent tube structure 2111, which prevents stray light in one optical filter layer 2060 from traveling into an optical filter region of an adjacent receiver channel in a multi receiver channel system. Tube structure 2111 can be formed of a variety of materials, including but not limited to silicon, metals, polymers, or glasses. As shown in FIG. 20F, tube structure 2111 may only pass partially through optical filter layer 2060. This type of structure can be formed by performing deep anisotropic etches on each side of filter substrate 2065 and selectively depositing metal or polymer afterwards.

[0175] FIG. 20G is a simplified cross-sectional view diagram of an embodiment 2006 of filter layer 2060 for a receiver channel, according to some embodiments of the present disclosure. Optical filter layer 2060 can include two optical filters 2061 supported on optically transparent substrates 2065 and surrounded by an optically non-transparent tube structure 2111, which prevents stray light in one optical filter layer 2060 from traveling into an optical filter region of an adjacent receiver channel in a multi receiver channel system. However, the optical filter region may contain any number of optical filters 2061 on any number of substrates 2065 within the optical filter layer 2060. FIG. 20G illustrates an additional aperture 2049 and corresponding optically non-transparent stop region 2063 positioned on top of optical filter 2061 and supported by optically transparent substrate 2065. Aperture 2049 can define the maximal cylinder of light desired to be passed into optical filter layer 2060 and stop region 2063 can absorb or reflect any incident stray light outside the diameter of aperture 2049.

[0176] Embodiment 2006 of optical filter layer 2060 in FIG. 20G can have an additional aperture 2054, and corresponding optically non-transparent stop region 2055 can be positioned between optical filter layer 2060 and the photosensor layer (not shown, but similar to photosensor layer 1770 in FIG. 17). Aperture 2054 can define the maximal cylinder of light

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desired to be passed out of optical filter layer 2060 toward the photosensor, and stop region 2055 can absorb or reflect any incident stray light outside the diameter of aperture 2054. Tube structure 2111 can be formed of a variety of materials, including but not limited to silicon, metals, polymers, or glasses.

D. Photosensor Layer

[0177] As can be appreciated herein, various different photosensor layer designs can be implemented in a micro-optic receiver channel.

1. Photosensor Layer with Diffuser

[0178] FIG. 21A is a simplified cross-sectional view diagram of an embodiment 2100 of receiver channel 2132 containing an optional diffuser 2181 located in photosensor layer 2170 between optical filter 2161 and photosensor 2173, according to some embodiments of the present disclosure. Diffuser 2181 can be configured to spread collimated photons that are output from collimating lens 2151 and passed by optical filter region 2160, across the full width of a corresponding photosensor 2173. Photosensor 2173 may be non-square or non-circular in geometry (e.g., short and wide) in order to extend the sensing area of photosensor 2173 to be wider or taller than width or height of the other components in receiver channel 2132.

[0179] Diffuser 2181 is configured to spread light rays across the area of photosensor 2173 such that photosensor 2173 is able to detect the incident photons across its full width and height, thereby increasing the dynamic range of receiver channel 2132, even where the overall height of receiver channel 2132 has to be limited for practical considerations. In particular, in this embodiment, receiver channel 2132 may include widened photosensors exhibiting greater photodetectors 2171 (i.e., areas sensitive to incident photons) and a diffuser 2181 arranged over photosensor 2173 that spreads light passed by optical filter 2161 across the full area of photosensor 2173, thereby yielding increased dynamic range.

[0180] In some embodiments, photosensor 2173 includes an array of single-photon avalanche diode detectors 2171 (hereinafter "SPADs"). The height and width of the receiver channel (usually defined by the diameter of collimating lens 2151) may accommodate only a relatively small number of (e.g., two) vertically-stacked SPADs. Photosensor 2173 can therefore define an

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aspect ratio greater than 1:1, and diffuser 2181 can spread light rays passed by the optical filter region 2160 according to the geometry of photosensor 2173 in order to accommodate a larger sensing area per photosensor. By incorporating more SPADs per photosensor, the dynamic range of the photosensor can be increased, as it less likely for all SPADs to be unable to detect photons (i.e., to be "dead") simultaneously.

[0181] In some other embodiments, photosensor 2173 includes an array of photodetectors 2171. The height and width of the receiver channel (usually defined by the diameter of collimating lens 2151) may accommodate only a relatively small number of (e.g., two) vertically-stacked photodiodes. Photosensor 2173 can therefore define an aspect ratio greater than 1:1, and diffuser 2181 can spread light rays passed by the optical filter region 2160 according to the geometry of photosensor 2173 in order to accommodate a larger sensing area per photosensor. By incorporating more photodiodes per photosensor, the dynamic range of the photosensor can be increased, as it is unlikely for all photodiodes to be saturated simultaneously.

[0182] Receiver channel 2132 can additionally or alternatively include an aperture layer interposed between optical filter region 2160 and diffuser 2181 or between the optical filter region 2160 and photosensor 2173, where aperture 2144 is aligned with a corresponding collimating lens 2151. In this variation, aperture 2144 can absorb or reflect errant light rays passed by the light filter or reflected by the photosensor to further reduce crosstalk between receiver channels, thereby further increasing SNR (Signal to Noise Ratio) of the system.

2. Photosensor Layer with Converging Lens Set

[0183] FIG 21B is a simplified cross-sectional view diagram of an embodiment 2101 of receiver channel 2132, according to some embodiments of the present disclosure. A photosensor layer 2170 of embodiment 2100 can include a photosensor 2173 formed of a set of discrete photodetectors 2171 (e.g., SPADs) and a set of inactive regions 2172 (e.g., integrated logic) encompassing the set of photodetectors, where each photodetector is configured to detect incident photons. Photosensor layer 2170 can also include a converging lens set 2191 interposed between optical filter region 2160 and photosensor 2173 with photodetectors 2171, and including one converging lens 2191 per discrete photodetector 2171 within photosensor 2173, where each lens of the converging lens set 2191 is configured to focus incident photons passed by optical

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filter region 2160 onto a corresponding discrete photodetector 2171. Each converging lens can exhibit a common focal length, and converging lens set 2191 can be offset above photosensor 2173 by this common focal length (or by a distance substantially similar to this common focal length), and each converging lens can converge incident light – collimated in optical lens layer 2150 and passed by optical filter region 2160 – onto a corresponding photodetector 2171 in photosensor 2173.

[0184] In some embodiments, converging lens set 2191 interposed between optical filter region 2160 and photosensor 2173 with photodetectors 2171 employs diffracting elements in addition to or replacement of refractive elements.

3. Photosensor Layer with Converging Lens Set and Additional Apertures

[0185] FIG. 21C is a simplified cross-sectional view diagram of an embodiment 2102 of photosensor layer 2170, according to some embodiments of the present disclosure. Photosensor layer 2170 can include a converging lens set 2191, and a set of apertures 2157, wherei each aperture 2157 is aligned with a corresponding converging lens 2191. In this variation, each aperture 2157 can absorb or reflect errant light rays passed by the light filter or reflected by the photosensor to further reduce crosstalk between receiver channels, thereby further increasing the SNR of the system. Set of apertures 2157 and corresponding optically non-transparent stop regions 2159 are built on an optically transparent substrate 2158.

[0186] FIG. 21D is a simplified cross-sectional view diagram of an embodiment 2103 of photosensor layer 2170, according to some embodiments of the present disclosure. Photosensor layer 2170 can include converging lens set 2191, and set of apertures 2157, where each aperture 2157 is aligned with a corresponding converging lens 2191. Apertures 2157 and corresponding optically non-transparent stop regions 2159 are built on an optically transparent substrate 2158. In this variation, apertures 2157 do not go all the way through to photodetector 2171.

[0187] FIG. 21E is a simplified cross-sectional view diagram of an embodiment 2104 of photosensor layer 2170, according to some embodiments of the present disclosure. An additional set of apertures 2157 and corresponding optically non-transparent stop regions 2159 defining desired maximal light cones can be positioned between lens set 2191 and photodetector

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2171. Set of apertures 2157 and corresponding non-transparent stop regions 2159 define a light cone for every lens in lens set 2191 and function to absorb or reflect any stray light traveling along a path not encompassed by the desired light cones. The apertures may be fabricated using standard semiconductor processes.

4. Photosensor Layer with Converging Lens Set and Spacer Structure Between the Lens Set and the Photosensor

[0188] FIG. 21F is a simplified cross-sectional view diagram of an embodiment 2105 of photosensor layer 2170, according to some embodiments of the present disclosure. Here, an optically non-transparent spacer structure 2163 is positioned between lens set 2191 and photosensor 2173 having photodetectors 2171 in receiver channel 2132. Optically non-transparent spacer structure 2163 forms a tube of substantially similar or larger diameter to a collimating lens (e.g., collimating lens 1751 shown in FIG. 17) and prevents any light from traveling outside of receiver channel 2132 in the region between lens set 2191 and photosensor 2173. Optically non-transparent spacer structure 2163 could be made from optically non-transparent bulk media (e.g. silicon or polymer).

[0189] FIG. 21G is a simplified cross-sectional view diagram of an embodiment 2106 of photosensor layer 2170, according to some embodiments of the present disclosure. Here, optically non-transparent spacer structure 2163 is positioned between lens set 2191 and photosensor 2173, and is made from an optically non-transparent coating on an optically transparent substrate (e.g. black chrome on glass). Optically non-transparent spacer structure 2163 forms a tube of substantially similar or larger diameter to collimating lens 2151 and prevents any light from traveling outside of receiver channel 2132 in the region between lens set 2191 and photodetector 2171.

5. Photosensor Layer Spacer Structure Between the Filter Layer and the Photosensor Layer

[0190] FIG. 21H is a simplified cross-sectional view diagram of an embodiment 2107 of photosensor layer 2170, according to some embodiments of the present disclosure. Optically non-transparent spacer structure 2163 can be positioned between an optical filter layer (e.g., any of the above-mentioned optical filter layers) and photosensor layer 2170. Optically non-

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transparent spacer structure 2163 forms a tube of substantially similar or larger diameter to a collimating lens (e.g., collimating lens 1751 in FIG. 17) and prevents any light from traveling outside of the receiver channel (e.g., channel 1700 in FIG. 17) in the region between the optical filter layer and photosensor layer 2170. Optically non-transparent spacer structure 2163 can be formed by etching a silicon or glass wafer and may be coated with an optically non-transparent material (e.g. black chrome). Alternatively, optically non-transparent spacer structure 2163 can be fabricated from molded polymer. In this embodiment, lens set 2191 is directly bonded to photosensor 2173. Similar to its function in previous embodiments, lens set 2191 serves to focus light onto photodetectors 2171 of photosensor 2173, rather than the inactive areas. These lenses could be integrated directly on top of an ASIC containing photosensor 2173 in a wafer fabrication process, easing production.

6. Photosensor Layer with Conical Spacer Structures

[0191] FIG. 21I is a simplified cross-sectional view diagram of an embodiment 2108 of photosensor layer 2170, according to some embodiments of the present disclosure. In this embodiment, photosensor layer 2170 includes a set of conical, optically non-transparent spacer structures 2164 that is positioned between a lens set (not shown but, e.g., lens set 2191 in FIGS. 21F and 21G) and photosensor 2173. Set of conical, optically non-transparent spacer structures 2164 can form tapered tubes, each with substantially similar entrance diameter to individual lenses in the lens set, and each with substantially similar exit diameter to the individual photodetectors 2171 of photosensor 2173. Set of conical, optically non-transparent spacer structures 2164 prevents any light from traveling outside of the receiver channel in regions between the lens set and photosensor 2173 and also guide light toward the photodetectors 2171 of photosensor 2173. The set of conical, optically non-transparent spacer structures 2164 can be formed by etching a silicon or glass wafer and may be coated with an optically non-transparent material (e.g. black chrome). Alternatively, set of conical, optically non-transparent spacer structures 2164 can be fabricated from molded polymer.

[0192] FIG. 21J is a simplified cross-sectional view diagram of an embodiment 2109 of photosensor layer 2173, according to some embodiments of the present disclosure. In this embodiment, photosensor layer 2173 includes a set of conical, optically non-transparent spacer structures 2164 that is positioned between a lens set (not shown but, e.g., lens set 2191 in FIGS.

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21F and 21G) and photodetector 2171. The inner walls of the set of conical, optically non-transparent spacer structures 2164 are coated with a reflective material (e.g. chrome) in order to further enhance the structures' ability to act as a light pipe. Set of conical, optically non-transparent spacer structures 2164 form tapered tubes, each with substantially similar entrance diameter to individual lenses in the lens set, and each with substantially similar exit diameter to the individual photodetectors 2171 of photosensor 2173. Set of conical, optically non-transparent spacer structures 2164 prevents any light from traveling outside of the receiver channel in regions between the lens set and photosensor 2171 and also guide light toward the photodetectors 2171 of photosensor 2173.

7. Photosensor Layer with Resonant Photo-Cavity Diodes

[0193] FIG. 21K is a simplified cross-sectional view diagram of a receiver channel 2132 including an embodiment 2110 of photosensor layer 2170, according to some embodiments of the present disclosure. In this embodiment, photosensor layer 2170 is configured with a resonant cavity around a photo sensitive diode to improve the photon detection efficiency. Each photosensor 2173 includes one or more resonant photo-cavity diodes. Each photosensor 2173 includes one or more photo-diodes 2174 (photodetectors) along with highly-reflective (e.g., partially-mirrored) surfaces facing the top and bottom of the area (the resonant cavity). Generally, an photodetector of a non-resonant cavity diode may have a relatively low quantum efficiency. To improve the percentage of photons detected by the photodetector, resonant photo-cavity diode 2174 is used that includes: a first mirrored surface 2175 below and facing the photodetector; and a second partially mirrored surface 2176 above and facing the photodetector, that also allows light to enter the cavity as shown in FIG. 21K. Thus, when a photon passes through and is not detected by an photodetector of resonant photo-cavity diode 2174, first mirrored surface 2175 surrounding the photodetector of resonant photo-cavity diode 2174 reflects the photon back toward top reflective surface 2176 of the cavity and through the photodetector again, which may detect the photon upon its second transition through the photodetector. However, if the photodetector fails to detect the photon upon this second collision, the reflection process is repeated with the second mirrored surface reflecting the photon back toward the photodetector, which again may detect the photon upon its third collision with the photodetector. This process may repeat until the photon is detected by the photodetector

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of the photosensor or the photon escapes or is absorbed by the cavity. Resonant photo-cavity diode 2174 can thus achieve a relatively high rate of photon detection (i.e. approaching 100%). Note that a particle interpretation of light is used in the preceding description, but consideration of wave interference effects are critical for a complete description of resonant cavity photodiodes. Also note that the active region of resonant photo-cavity diode 2174 may be comprised of a standard photodiode, an avalanche photodiode, a SPAD, or any other photosensor.

[0194] FIG. 21K further shows that one or more resonant cavity photodiodes (or "RCPs") 2174 may be combined with aperture 2144, collimating lens 2151, optical filter region 2160, and any combination of the aforementioned diffusers, converging lens sets, or crosstalk mitigation structures to form a variant of receiver channel 2132. A typical RCP will have similar wavelength sensitivity as optical filter region 2160 and can be designed to be sensitive to a similar set of wavelengths of light as optical filter region 2160. However, due to fabrication or other limitations, the RCP may have more part-to-part variability of the center wavelength of the RCP's operating spectrum and thus necessitate a broader operating wavelength band in order for every photosensor to be capable of detecting photons at the system's operating wavelength. Alternatively, it may simply be impossible to reliably fabricate an RCP with an operating wavelength band as narrow as the filter passband. For instance, optical filter region 2160 may have a passband as narrow as 0.1 nm, while the RCP may have an operating band of 10 nm. With the optical filter region 2160 on top of the RCP 2174, the combined filter and RCP system has an effective operating wavelength band substantially similar to optical filter region 2160. In addition, the RCP performance is improved when sensing collimated light, as opposed to focused light, which is provided as a result of collimating lens 2151 as depicted in FIG. 21K. In this way, a system employing aperture 2144, collimating lens 2151, optical filter region 2160, and RCP 2174 may achieve high photon detection efficiency and narrow wavelength selectivity to maximize the SNR within receiver channel 2132.

E. Hemispherical Receiver Structures

[0195] FIG. 22A is a simplified cross-sectional view diagram of an embodiment 2200 of a receiver channel 2232, according to some embodiments of the present disclosure. Receiver channel 2232 of embodiment 2200 can include convex hemispheres supported on an optically

non-transparent material. In this embodiment, an aperture layer 2240 is combined with an optical filter 2261 coated on a convex hemisphere 2267, with the center of hemisphere 2267 located at or near the focal point of incoming light (marginal ray lines 2233). The center of hemisphere 2267 also corresponds to, or nearly corresponds to, the center of aperture 2244. In some embodiments, hemisphere 2267 can be below aperture 2244, as shown in FIG. 22A. An advantage of the embodiment is that for a sufficiently well-focused cone of rays, any ray lines 2233 will pass through optical filter 2261 normal to the filter's surface, thereby eliminating CWL (Center Wave Length) shift due to variations in incident angle of the light (e.g. light rays 2233) on optical filter 2261, thereby allowing the use of very narrow bandpass (e.g. 850-852 nm) filters.

[0196] This is further illustrated in FIG. 22B, which is a simplified cross-sectional view diagram of an embodiment 2201 of receiver channel 2232, according to some embodiments of the present disclosure. Unlike embodiment 2200 in FIG. 22A, embodiment 2201 in FIG. 2B can be configured so that hemisphere 2267 is positioned above aperture 2244 to achieve similar functionality but with a less compact footprint. As shown in FIG. 22B, the angle of incidence on optical filter 2261 is normal for marginal ray lines 2233 (and all other ray lines not shown explicitly in FIG. 22B) that pass through the center of hemisphere 2267. Note that, while not shown in FIG. 22B or 22C, the rays will refract upon exiting the hemisphere structure since they are not normal to the planar exit surface. Similarly, in FIG. 22A, there will be some amount of refraction when rays enter the flat side of the hemispherical structure.

[0197] As illustrated in FIGS. 22A to 22B, receiver channel 2232 includes sidewalls 2263 between optically non-transparent stop region 2246 and photosensor layer 2270 with photodetectors 2271 to reduce crosstalk. Sidewalls 2263 can be made up of optically non-transparent material or made up of optically transparent material. In addition, sidewalls 2263 can also be coated with reflective or absorptive material.

[0198] A close-up view of the convex hemispherical surface is shown in FIG. 22C, which is a simplified cross-sectional view diagram of convex hemisphere 2267 of FIGS. 22A and 22B. Convex hemisphere 2267 can be coated with optical filter 2261 and positioned on a self-supporting, optically non-transparent stop region 2246 such as metal, silicon, polymer etc. In some embodiments where the convex hemispherical surfaces of the micro-optic channels are

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used for hyperspectral imagers, optical filter 2261 can be configured to be non-uniform. For example, optical filter 2261 can be a graduated filter increasing gradually or in a step-wise manner in one direction (e.g., the thickness direction) that different micro-optic channels have different optical filter layers that have different thicknesses. This allows different micro-optic channels to measure a different range of wavelengths as discussed herein with respect to FIGS. 3A and 3B.

[0199] FIG. 22D is a simplified cross-sectional view diagram of an embodiment 2202 of a receiver channel 2232, according to some embodiments of the present disclosure. Receiver channel 2232 of embodiment 2202 can include convex hemisphere 2267 supported on a rigid optically transparent layer. In this embodiment, aperture layer 2240 is combined with optical filter 2261 and coated on convex hemisphere 2267, where the center of hemisphere 2267 is located at or near the focal point of incoming light (ray lines 2233). The center of hemisphere 2267 also corresponds to, or nearly corresponds to, the center of the aperture 2244. As shown in FIG. 22D, hemisphere 2267 can be below aperture layer 2240. In some other embodiments, hemisphere 2267 can be above aperture layer 2240, as shown in FIG. 22E.

[0200] FIG. 22E is a simplified cross-sectional view diagram of an embodiment 2203 of a receiver channel 2232, according to some embodiments of the present disclosure. Unlike embodiment 2202 in FIG. 22D, embodiment 2215 in FIG. 2E can be configured so that hemisphere 2267 is positioned above aperture 2244 to achieve similar functionality as embodiment 2202 but with a more compact footprint.

[0201] FIGS. 22D and 22E show convex hemisphere 2267 as being coated with optical filter 2261 and imprinted on aperture layer 2240 that is supported on a rigid optically transparent layer 2245 (e.g. glass, polymer) with aperture 2244 along with the corresponding optically non-transparent stop regions 2246. As illustrated in FIGS. 22D and 22E, receiver channel 2232 includes sidewalls 2263 between optically transparent layer 2245 and photosensor layer 2270 with photodetectors 2271 to reduce crosstalk. Sidewalls 2263 can be made up of optically non-transparent material or made up of optically transparent material. In addition, sidewalls 2263 can also be coated with reflective or absorptive material. Note that, while not shown in FIGS. 22D and 22E, there may be refraction of rays 2233 entering and exiting the rigid optically transparent layer 2245.

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[0202] FIG. 22F is a simplified cross-sectional view diagram of an embodiment 2204 of a receiver channel 2232, according to some embodiments of the present disclosure. Embodiment 2204 can include a concave hemisphere 2267 made of optically transparent material (e.g. glass, polymer) with a coated optical filter 2261. Self-supported aperture layer 2240 can overhang concave hemisphere 2267 and can be perforated or etched with an optically non-transparent rigid material (e.g. metal film) to form the optically non-transparent stop regions 2246. As shown in FIG. 22F, hemisphere 2267 can be positioned below aperture layer 2240. The center of aperture 2244 can be located at or near the focal point of the incoming light (rays 2233). Additionally, the center of the hemisphere 2267 can be located at or near the focal point of the incoming light (rays 2233). As illustrated in FIG. 22F, receiver channel 2232 includes sidewalls 2263 between optically transparent layer 2245 and photosensor layer 2270 with photodetectors 2271 to reduce crosstalk. Sidewalls 2263 can be made up of optically non-transparent material or made up of optically transparent material. In addition, sidewalls 2263 can also be coated with reflective or absorptive material.

[0203] FIG. 22G is a simplified cross-sectional view diagram of an embodiment 2205 of receiver channel 2232, according to some embodiments of the present disclosure. Unlike embodiment 2204 in FIG. 22F, embodiment 2205 in FIG. 2G can be configured so that hemisphere 2267 is positioned above aperture 2244 to achieve similar functionality as embodiment 2204, but embodiment 2204 may have a more compact footprint.

[0204] FIG. 22H is a simplified cross-sectional view diagram of an embodiment 2206 of receiver channel 2232, according to some embodiments of the present disclosure. Receiver channel 2232 of embodiment 2206 can include a concave hemisphere 2267 and aperture layer 2240 supported by a rigid, optically transparent layer 2245. In some embodiments, concave hemisphere 2267 can be below the aperture layer 2240 as shown in FIG. 22H. Concave hemisphere 267 can be made of optically transparent material (e.g. glass, polymer) with a coated optical filter 2261. Aperture layer 2240 with optically transparent aperture 2244 and corresponding optically non-transparent stop regions 244 is supported by optically transparent layer 2245 on both top and bottom sides of aperture layer 2240. The center of aperture 2244 is located at or near the focal point of the incoming light (rays 2233). Additionally, the center of concave hemisphere 2267 is located at or near the focal point of the incoming light (rays 2233).

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As illustrated in FIG. 22H, receiver channel 2232 includes sidewalls 2263 between optically transparent layer 2245 and photosensor layer 2270 with photodetectors 2271 to reduce crosstalk. Sidewalls 2263 can be made up of optically non-transparent material or made up of optically transparent material. In addition, sidewalls 2263 can also be coated with reflective or absorptive material.

[0205] FIG. 22I is a simplified cross-sectional view diagram of an embodiment 2207 of receiver channel 2232, according to some embodiments of the present disclosure. Unlike embodiment 2206 in FIG. 22H, embodiment 2207 in FIG. 2I can be configured so that hemisphere 2267 is positioned above aperture 2244 to achieve similar functionality as embodiment 2206.

F. Bottom Micro-Lens Layer

[0206] FIG. 23A is a simplified cross-sectional view diagram of an embodiment 2300 of a receiver channel 2332, according to some embodiments of the present disclosure. Receiver channel 2332 of embodiment 2300 can include a Bottom Micro-Lens Layer (BMLL), which consists of one or more micro-lenses 2391 that are configured to guide divergent light rays into active portion of the photosensors. The BMLL performs ray angle correction to guide light from dissimilar angles into evenly spaced photosensors. Ray angle correction can be achieved by controlling the lateral offset between lens center and the photosensor center, tilting of the lens, or adjusting the form of the lens. A better illustration of this operation can be seen in FIG. 23B.

[0207] FIG. 23B is a simplified cross-sectional view diagram of a close-up view of the propagation of light during ray angle correction by a BMLL, according to some embodiments of the present disclosure. As illustrated, the pitch of the micro-optics is either not constant or is not equal to the pitch of lenses 2391 in order to steer the divergent rays (2333) to active portions of photodetectors 2371 in the photosensor layer. With reference back to FIG. 23A, each micro-lens 2391 can be positioned to correspond with a respective photodetector 2371.

[0208] FIG. 23C is a simplified cross-sectional view diagram of an embodiment 2301 of a receiver channel 2332, according to some embodiments of the present disclosure. Receiver channel 2332 of embodiment 2301 can include a single micro-lens 2391, instead of a plurality of micro-lenses as shown in FIG. 23A. Single micro-lens 2391 can be positioned over and centered

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to a single photodetector 2371. Micro-lens 2391 can be configured to guide light to single photodetector 2371.

[0209] FIGS. 23D and 23E is a simplified cross-sectional view diagram of embodiments 2302 and 2303, respectively, of a receiver channel 2332, according to some embodiments of the present disclosure. Receiver channel 2332 of embodiment 2302 can include a BMLL positioned on the underside of an optically transparent layer 2345 supporting aperture layer 2340 and hemisphere 2367 with optical filter 2361 coated. As shown in FIG. 23D, the BMLL can be formed of multiple lenses 2393 for guiding divergent light to multiple photodetectors 2371. As shown in FIG. 23E, the BMLL can be formed of a single micro-lens 2391 for guiding divergent light to photodetector 2371.

[0210] Embodiments 2302 and 2303 in FIGS. 23D and 23E each include a convex hemisphere 2367 supported on a rigid optically transparent layer 2345. In these illustrations, an aperture layer 2340 is combined with an optical filter 2361 coated on hemisphere 2367, where the center of hemisphere 2367 is located at or near the focal point of incoming light (marginal ray lines 2333). The center of hemisphere 2367 can also correspond to, or nearly correspond to, the center of aperture 2344. Convex hemisphere 2367 can be coated with optical filter 2361 and imprinted on aperture layer 2340 that is supported on rigid optically transparent layer 2345 (e.g. layer formed of glass, polymer) and the corresponding optically non-transparent stop regions 2346. As illustrated in FIGS. 23D and 23E, receiver channel 2332 includes sidewalls 2363 between optically transparent layer 2345 and photosensor layer 2370 to reduce crosstalk. Sidewalls 2363 can be made up of optically non-transparent material or made up of optically transparent material. In addition, sidewalls 2363 can also be coated with reflective or absorptive material.

G. Additional Exemplary Receiver Channels

[0211] It is to be appreciated that a receiver channel is a structure at the micro-optic level, e.g., a micro-optic receiver channel discussed above, that can be formed from multiple layers including one or more of an aperture layer, an optical lens layer below the aperture layer, an optical filter layer below the aperture and optical lens layer, and a photosensor layer below all the other layers. Each such layer can be configured in various ways to mitigate cross-talk. i.e., exposing stray light to adjacent receiver channels, as discussed herein with respect to FIGS. 17-

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23E. Various examples of receiver channels are discussed above with respect to FIGS. 17, 22A-22I, and 23A-23E. Two other examples of receiver channels according to the present disclosure are illustrated in FIGS. 24 and 25. Embodiments of the present disclosure are not limited to the particular receiver channels described herein. Instead, based on the present disclosure a person of skill in the art will appreciate that in other embodiments a receiver channel according to the disclosure can include, among other options, an aperture layer as described above with respect to any of FIGS. 18A-18D or 19A-19D, a filter layer as described above with respect to any of FIGS. 20A-20G, and/or a photosensor layer as described above with respect to any of FIGS. 21A-21K.

[0212] FIG. 24 is a simplified cross-sectional view diagram of an exemplary embodiment of a receiver channel 2400, according to some embodiments of the present disclosure. Receiver channel 2400 can include an aperture layer 2440 composed of first and second apertures 2444, each formed in respective optically non-transparent layers 2446a and 2446b. First and/or second apertures 2444 can be formed of void space defined by openings within layers 2446a and 2446b in some embodiments, while first and/or second apertures 2444 can be formed by optically transparent materials in some other embodiments. First and second optically non-transparent layers 2446a and 2446b can be supported by an optically transparent substrate 2445 sandwiched between first and second optically non-transparent layers 2446a and 2446b.

[0213] Receiver channel 2400 can also include an optical lens layer 2450 disposed below aperture layer 2440. Optical lens layer 2450 can include a collimating lens 2451 and an optically non-transparent spacer structure 2456. Collimating lens 2451 can be separated from aperture layer 2440 by optically non-transparent spacer structure 2456. In some embodiments, optically non-transparent spacer structure 2456 forms a tube having a circumference that surrounds collimating lens 2451 and extends toward aperture layer 2440. Optically non-transparent spacer structure 2456 can be formed of an optically reflective or absorptive material that prevents any light from traveling outside of receiver channel 2400 in the region between aperture layer 2440 and collimating lens 2451.

[0214] In addition to aperture layer 2440 and optical lens layer 2450, receiver channel 2400 can further include an optical filter layer 2460 positioned directly below optical lens layer 2450. Optical filter layer 2460 can include two optical filters 2461 sandwiching an optically transparent

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substrate 2465 that structurally supports optical filters 2461. Optical filter layer 2460 can contain any number and type of optical filters 2461 on any number of substrates 2065. For instance, one of optical filters 2461 can be a bandpass filter and be positioned on either on top of or directly below optically transparent substrate 2465 that blocks all of the incident light for a defined set of wavelengths (e.g. 900-945 nm and 950-995nm). The other optical filter 2461 placed on the opposite side of optically transparent substrate 2465 can be a different filter, such as a wide spectrum blocking filter (except for the region covered by the bandpass filter), for example covering 200-915nm and 980-1600nm. The bandpass filter and blocking filter are designed such that there is no leakage in the transition region between the two filters. However, the filters could be two edge pass filters designed to work in conjunction as a bandpass filter or any other type of filter.

[0215] Immediately below optical filter layer 2460 can be a photosensor layer 2470. In some embodiments, photosensor layer 2470 of embodiment 2400 can include an optically non-transparent spacer structure 2463 positioned between a converging lens set 2491 and a photosensor 2473. Photosensor 2473 can be formed of a set of discrete photodetectors 2471 (e.g., SPADs) positioned between a set of inactive regions 2172 (e.g., integrated logic) in an alternating arrangement, where each discrete photodetector is configured to detect incident photons. Converging lens set 2491 can be interposed between optical filter layer 2460 and photosensor 2473 with photodetectors 2471, and including one converging lens 2491 per discrete photodetector 2471 within photosensor 2173, where each lens of the converging lens set 2491 is configured to focus incident photons passed by optical filter layer 2460 onto a corresponding discrete photodetector 2471. Each converging lens can exhibit a common focal length, and converging lens set 2491 can be offset above the sensing plane of the photosensor by this common focal length (or by a distance substantially similar to this common focal length), and each converging lens can converge incident light – collimated in optical lens layer 2450 and passed by optical filter layer 2460 – onto one corresponding photodetector 2471 in photosensor 2473. Optically non-transparent spacer structure 2463 forms a tube of substantially similar or larger diameter to a collimating lens 2451 and prevents any light from traveling outside of receiver channel 2400 in the region between lens set 2491 and photosensor 2473. Optically non-transparent spacer structure 2163 could be made from optically non-transparent bulk media (e.g. silicon or polymer).

[0216] Another exemplary embodiment of a receiver channel is shown in FIG. 25. FIG. 25 is a simplified cross-sectional view diagram of an exemplary receiver channel 2500, according to some embodiments of the present disclosure. Receiver channel 2500 can include an aperture layer 2540, an optical lens layer 2550 disposed below aperture layer 2540, and an optical filter layer 2560 below both aperture layer 2540 and optical lens layer 2550. Aperture layer 2540, optical lens layer 2550, and optical filter layer 2560 can have the same construction and function as corresponding components in FIG. 24.

[0217] Receiver channel 2500 can also include a photosensor layer 2570 positioned immediately below optical filter layer 2560. In some embodiments, photosensor layer 2570 of embodiment 2400 can include an optically non-transparent spacer structure 2563, a converging lens set 2591, and a photosensor 2573. Unlike converging lens set 2491 of receiver channel 2400 in FIG 24, converging lens set 2591 of receiver channel 2500 can be positioned directly on at top surface of photosensor 2573 instead of directly on an underside of optical filter layer 2560. Furthermore, optically non-transparent spacer structure 2563 can be formed of an optically non-transparent material (e.g., black chrome) coated on an optically transparent layer, such as a silicon or glass substrate, instead of being a solid optically non-transparent structure, e.g., optically non-transparent spacer structure 2463 of receiver channel 2400 in FIG. 24. Lens set 2591 serves to focus light onto photodetectors 2571 of photosensor 2573, rather than inactive areas 2572.

[0218] By implementing a receiver channel according to any of embodiments 2400 and 2500, errant light can be prevented from exposing on adjacent receiver channels, thereby improving the accuracy of each photosensor's ability to capture photons for imaging.

VI. MICRO OPTICAL RECEIVER CHANNEL ARRAY VARIATIONS

[0219] According to some embodiments of the present disclosure, micro-optical receiver channels can be organized in an array. The array can have various dimensions according to design. For instance, an array of micro-optical receiver channels can be arranged in a M x N array where M and N are equal to or greater than 1. Accordingly, micro-optical receiver channels can be one- and two-dimensional arrays, as will be discussed furthered herein with respect to FIGS. 26-30, which illustrate different embodiments of micro-optical receiver channel

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arrays where each dot represents a micro-optical receiver channel. As aforementioned herein, each receiver channel can include a plurality of layers stacked upon each other. Thus, it can be appreciated that when arranged in an array, each micro-optic receiver channel is part of a monolithic layer composed of the individual elements reproduced many times in the M x N arrangement, e.g., an M x N aperture layer array, an M x N micro lens layer array, and an M x N photosensor layer array. When bonded together, these array layers create a monolithic multi-channel micro optical receiver array.

[0220] FIG. 26 is a simplified illustration of an exemplary micro-optical receiver array 2600, according to some embodiments of the present disclosure. Micro-optical receiver array 2600 is configured as a linear (M x 1) array, specifically a 16 x 1 array. This layout can achieve a high resolution (e.g. 16 x 1024) as the implementation is amenable to scanning the array in one dimension. As an example, for a receiver channel pitch of 500 microns the layout illustrated can be implemented in a chip of a size that is approximately 500 microns by 8000 microns.

[0221] FIG. 27 is a simplified illustration of an exemplary micro-optical receiver array 2700, according to some embodiments of the present disclosure. Micro-optical receiver array 2700 is configured as a rectangular (M x N) array, specifically a 16 x 32 array. Thus, for a receiver channel pitch of 500 microns the layout illustrated can be implemented in a chip of size 8,000 microns by 12000 microns.

[0222] FIG. 28 is a simplified illustration of an exemplary micro-optical receiver array 2800, according to some embodiments of the present disclosure. Micro-optical receiver array 2800 is configured as an M x N staggered array. In this illustration, receiver channels 2832 are laid out in a 16 x 4 staggered array. This layout can achieve a high resolution (e.g. 64 x 1024) as the implementation is amenable to sweeping. For a receiver channel pitch of 500 microns the layout illustrated in FIG. 28 can be implemented in a chip of a size that is approximately 2000 microns by 8375 microns.

[0223] FIG. 29 is a simplified illustration of an exemplary micro-optical receiver array 2900, according to some embodiments of the present disclosure. Micro-optical receiver array 2900 is configured as a warped linear (M × 1) array. In this embodiment, the spacing between receiver channels 2932 is uneven. Receiver channels near the center, shown as 2932-01, are placed close together (e.g. 400 microns apart), while the exterior channels, shown as 2932-02, are placed

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farther apart (e.g., greater than 400 microns apart), or vice versa. This layout has an advantage of being able to allow for correction of the distortion curve of a lens (i.e. the angles between the receiver channel fields of view are evenly spaced in the object space). The arrangement shown in FIG. 29 can be used to achieve a high resolution (e.g. 16 x 1024) as the implementation is amenable to sweeping. For an average receiver channel pitch of 500 microns the layout illustrated can be implemented in a chip of a size that is approximately 500 microns by 8000 microns.

[0224] In some embodiments, the receiver channels can be configured in a M x N warped array (where $N \geq 1$). In such embodiments, the receiver channels in the center are placed further from each other in both the x and y direction than the exterior receiver channels. This corrects for another possible form of lens distortion.

[0225] FIG. 29 is a simplified illustration of an exemplary micro-optical receiver array 2900, according to some embodiments of the present disclosure. Micro-optical receiver array 2900 is configured in an arbitrary pattern. This layout arrangement has the advantage of being able to accommodate lens distortion, to make adjustments to compensate for any timing or routing variations, and also to match an arbitrary pattern from an illumination source.

[0226] Although the present disclosure has been described with respect to specific embodiments, it will be appreciated that the present disclosure is intended to cover all modifications and equivalents within the scope of the following claims.

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WHAT IS CLAIMED IS:

1. An optical system for performing distance measurements, the optical system comprising:

a stationary housing having an optically transparent window;

a spinning light ranging device disposed within the housing, the light ranging device comprising:

a platform;

an optical transmitter coupled to the platform, the optical transmitter comprising a bulk transmitter optic and a plurality of transmitter channels, each transmitter channel including a light emitter configured to generate and transmit a narrowband light through the bulk transmitter optic into a field external to the optical system; and

an optical receiver coupled to the platform, the optical receiver comprising a bulk receiver optic and a plurality of micro-optic receiver channels, each micro-optic channel including an aperture coincident with a focal plane of the bulk receiver optic, an optical filter positioned along a path of light from the bulk receiver optic and axially aligned with the aperture, and a photosensor responsive to incident photons passed through the aperture and the optical filter;

a motor disposed within the housing and operatively coupled to spin the light ranging device including the platform, optical transmitter, and optical receiver within the housing; and

a system controller disposed within the housing, the system controller configured to control the motor and to start and stop light detection operations of the light ranging device.

2. The optical system set forth in claim 1 wherein the optical receiver further includes a collimating lens behind the aperture and directly coupled to the optical filter, the optical filter positioned behind the collimating lens.

3. The optical system set forth in claim 1 wherein the optical filter is a filter layer on a hemispherical lens positioned directly on a top or bottom side of the aperture.

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4. The optical system set forth in claim 1 wherein the stationary housing is cylindrical in shape and the optically transparent window extends fully around a periphery of the stationary housing.

5. The optical system set forth in claim 4 further comprising a corrective optical structure to correct for optical aberrations caused by the transparent window.

6. The optical system set forth in claim 5 wherein the corrective optical structure is constructed as a cylindrical lens included as part of the bulk receiver optic, a cylindrical lens included as part of the bulk transmitter optic, an array of cylindrical lenses included as part of the micro-optic receiver channels, or an array of biconical lenses included as part of the plurality of transmitter channels.

7. The optical system set forth in claim 1 wherein the optical transmitter and optical receiver are configured such that each transmitter channel is paired with a receiver channel and the centers of their fields-of-view are aligned to be non-overlapping at a certain distance from the optical system.

8. The optical system set forth in claim 1 wherein the plurality of micro-optic receiver channels are part of a monolithic ASIC constructed on a common substrate, within which the array of photosensors are fabricated, and the separate layers for the aperture layer, and the filter layer are formed on the monolithic ASIC such that they become part of the monolithic structure of the ASIC.

9. An optical system for performing distance measurements, the optical system comprising:

a stationary housing having a base, a top and an optically transparent window disposed between the base and the top;

a spinning light ranging device disposed within the housing and aligned with the optically transparent window, the light ranging device comprising:

a platform;

an optical transmitter coupled to the platform, the optical transmitter comprising an image-space telecentric bulk transmitter optic and a plurality of transmitter

channels, each channel including a light emitter configured to generate and transmit a narrowband light through the bulk transmitter optic into a field external to the optical system; and

an optical receiver coupled to the platform, the optical receiver comprising an image-space telecentric bulk receiver optic and a plurality of micro-optic receiver channels, each micro-optic channel including an aperture coincident with a focal plane of the bulk receiver optic, a collimating lens behind the aperture, an optical filter behind the collimating lens and a photosensor responsive to incident photons passed through the aperture into the collimating lens and through the filter;

a motor disposed within the housing and operatively coupled to spin the light ranging device including the platform, optical transmitter and optical receiver within the housing;

a system controller disposed within the housing, the system controller configured to control the motor and to start and stop light detection operations of the light ranging device.

10. The optical system set forth in claim 9 wherein the stationary housing is cylindrical in shape and the optically transparent window extends fully around a periphery of the stationary housing.

11. The optical system set forth in claim 9 wherein the optical transmitter and optical receiver are configured such that each transmitter channel is paired with a receiver channel and the centers of their fields-of-view are aligned to be non-overlapping at a certain distance from the optical system.

12. The optical system set forth in claim 9 wherein the plurality of micro-optic receiver channels are part of a monolithic ASIC constructed on a common substrate, within which the array of photosensors are fabricated, and the separate layers for the aperture layer, and the filter layer are formed on the monolithic ASIC such that they become part of the monolithic structure of the ASIC.

13. The optical system set forth in claim 9 wherein each of the separate layers for the apertures, the filter layer, and the photosensors is bonded to its adjacent layer.

14. An optical system for performing distance measurements, the optical system comprising:

a stationary housing having a base, a top and an optically transparent window disposed between the base and the top;

a light ranging device disposed within the housing and aligned with the optically transparent window, the light ranging device comprising:

a platform;

a plurality of vertical-cavity surface emitting lasers (VCSELs) arranged in an array, each VCSEL in the plurality of VCSELs being configured to generate and transmit discrete pulses of light into a field external to the optical system; and

an optical receiver coupled to the platform, the optical receiver comprising a bulk receiver optic, a plurality of photosensors, each photosensor comprising a plurality of single-photon avalanche diodes (SPADs) responsive to incident photons, and an optical filter disposed between the bulk receiver optic and the plurality of photosensors and configured to allow a band of light to pass through the filter to the plurality of photosensors while blocking light outside the band from reaching the plurality of photosensors;

a motor disposed within the housing and operatively coupled to spin the light ranging device within the housing; and

a system controller disposed within the housing, the system controller configured to control the motor and to start and stop light detection operations of the light ranging device.

15. The optical system set forth in claim 14 wherein the stationary housing is cylindrical in shape and the optically transparent window extends fully around a periphery of the stationary housing.

16. The optical system set forth in claim 14 wherein the optical transmitter and optical receiver are configured such that each transmitter channel is paired with a receiver channel and the centers of their fields-of-view are aligned to be non-overlapping at a certain distance from the optical system.

17. The optical system set forth in claim 14 wherein the plurality of photosensors are fabricated within, and form part of, a monolithic ASIC constructed on a common substrate, and wherein the separate layers for the aperture layer, and the filter layer are formed on the monolithic ASIC such that they become part of the monolithic structure of the ASIC.

18. The optical system set forth in claim 14 wherein the plurality of micro-optic receiver channels are part of a monolithic ASIC constructed on a common substrate, within which the array of photosensors are fabricated, and the separate layers for the aperture layer, and the filter layer are formed on the monolithic ASIC such that they become part of the monolithic structure of the ASIC.

19. The optical system set forth in claim 14 wherein each of the separate layers for the apertures, the filter layer, and the photosensors is bonded to its adjacent layer.

20. The optical system set forth in claim 14 wherein the discrete pulses of light are each coded with an embedded positive-value pulse-code formed by an intensity of its respective pulse of light.

ABSTRACT OF THE DISCLOSURE

Embodiments describe optical imagers that include one or more micro-optic components. Some imagers can be passive imagers that include a light detection system for receiving ambient light from a field. Some imagers can be active imagers that include a light emission system in addition to the light detection system. The light emission system can be configured to emit light into the field such that emitted light is reflected off surfaces of an object in the field and received by the light detection system. In some embodiments, the light detection system and/or the light emission system includes micro-optic components for improving operational performance.

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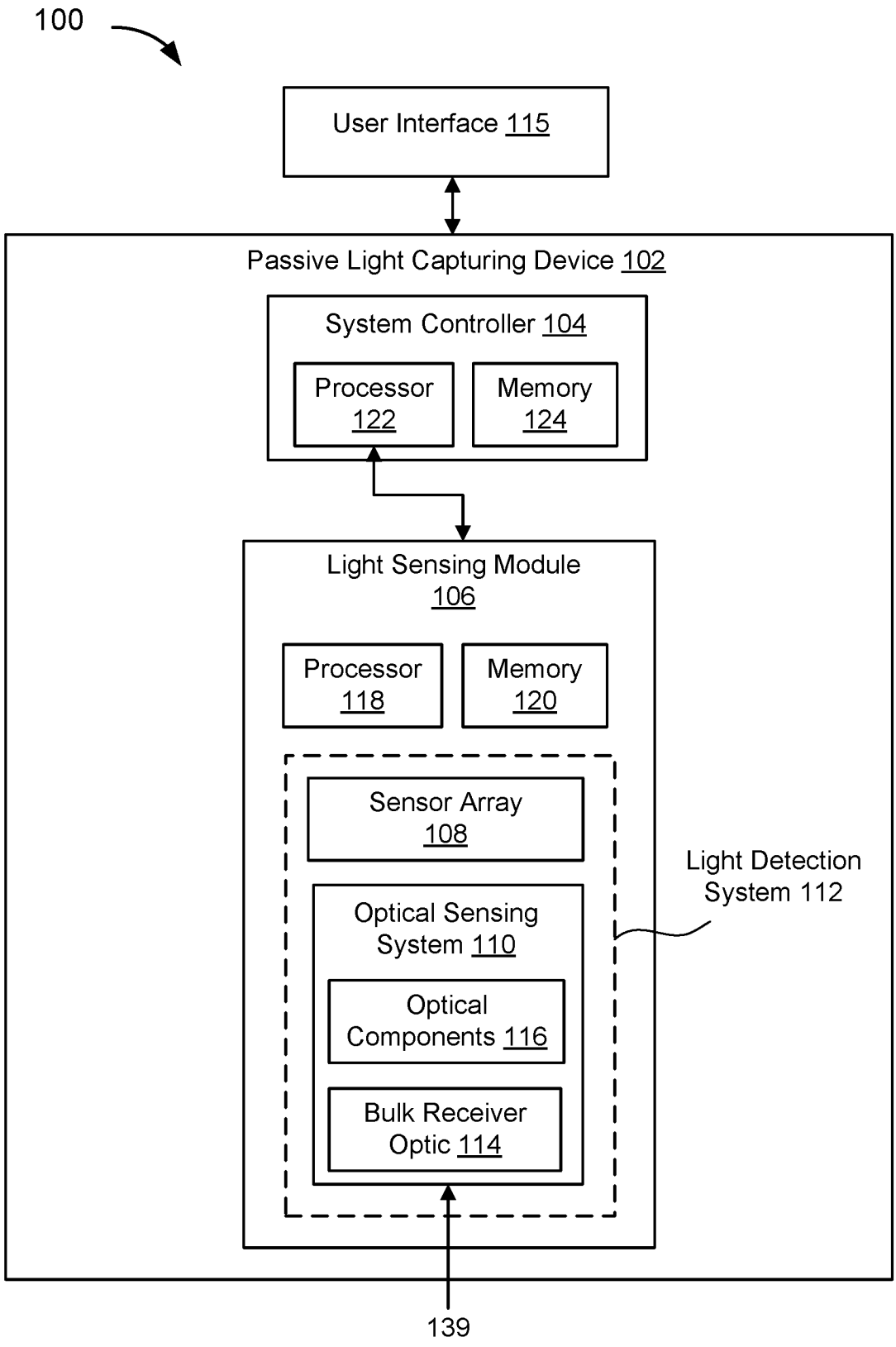

100
User Interface 115
Passive Light Capturing Device 102
System Controller 104
Processor 122
Memory 124
Light Sensing Module 106
Processor 118
Memory 120
Sensor Array 108
Optical Sensing System 110
Optical Components 116
Bulk Receiver Optic 114
Light Detection System 112
139

FIG. 1

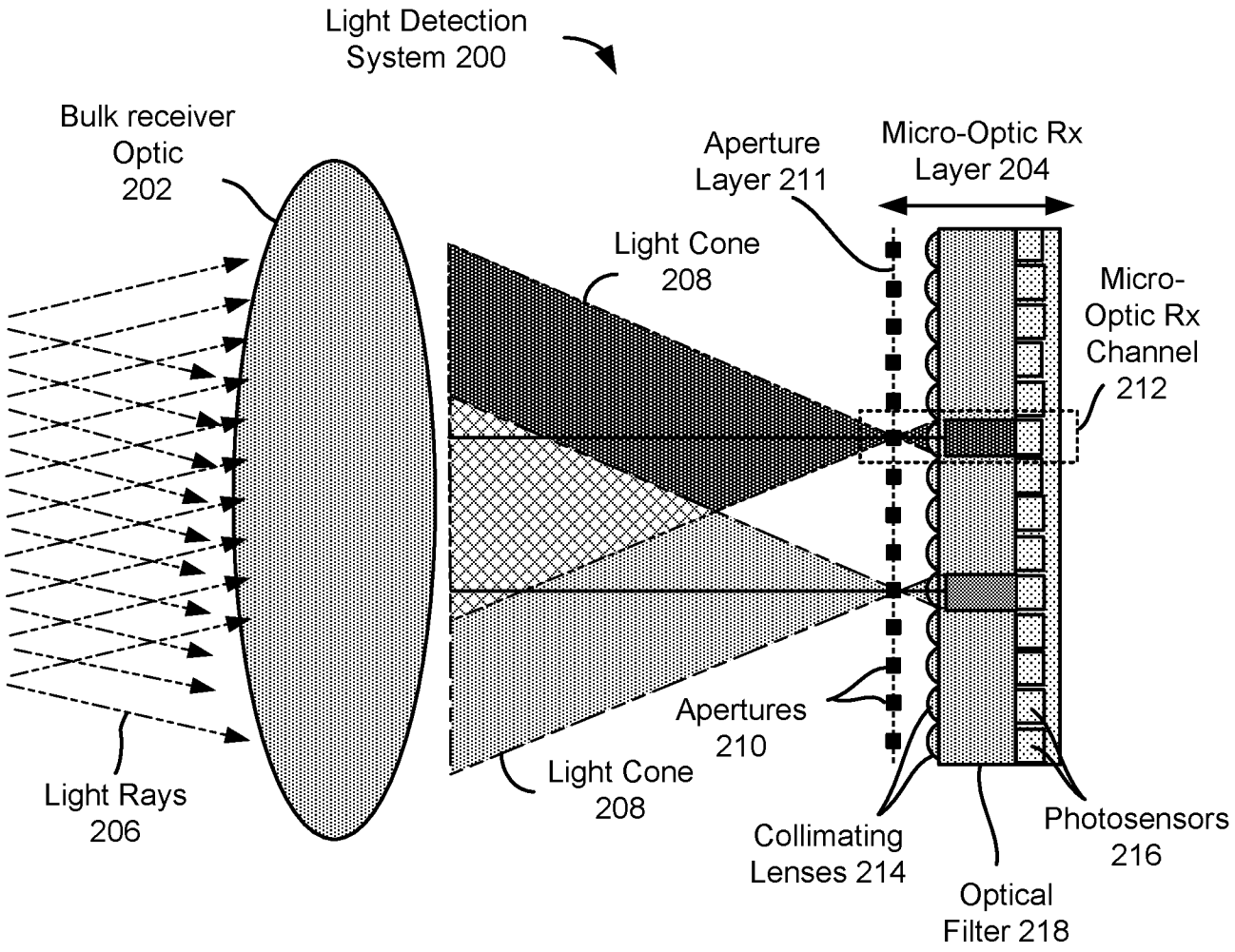

Light Detection System 200
Bulk receiver Optic 202
Aperture Layer 211
Micro-Optic Rx Layer 204
Light Cone 208
Micro-Optic Rx Channel 212
Apertures 210
Light Cone 208
Light Rays 206
Collimating Lenses 214
Photosensors 216
Optical Filter 218

FIG. 2

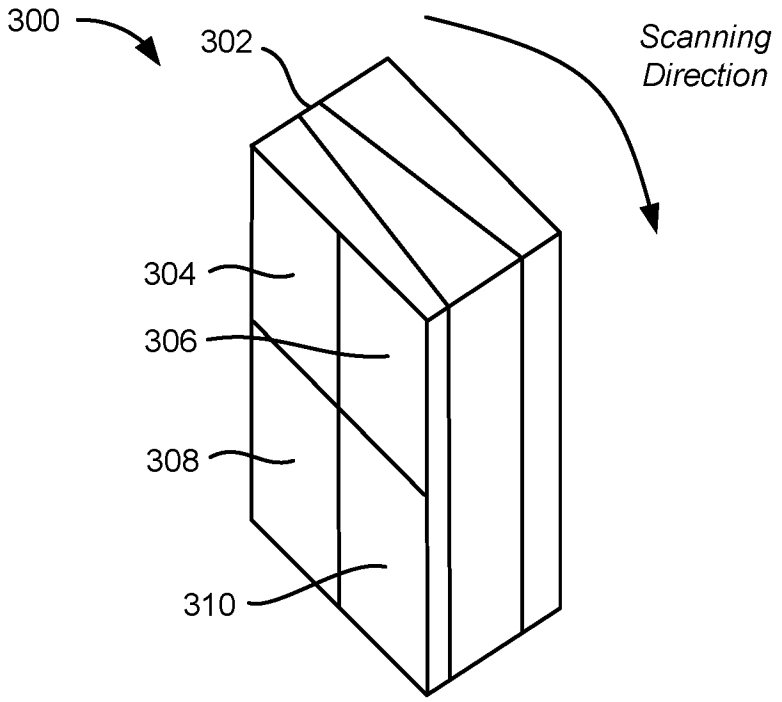

300
302
Scanning Direction
304
306
308
310

FIG. 3A

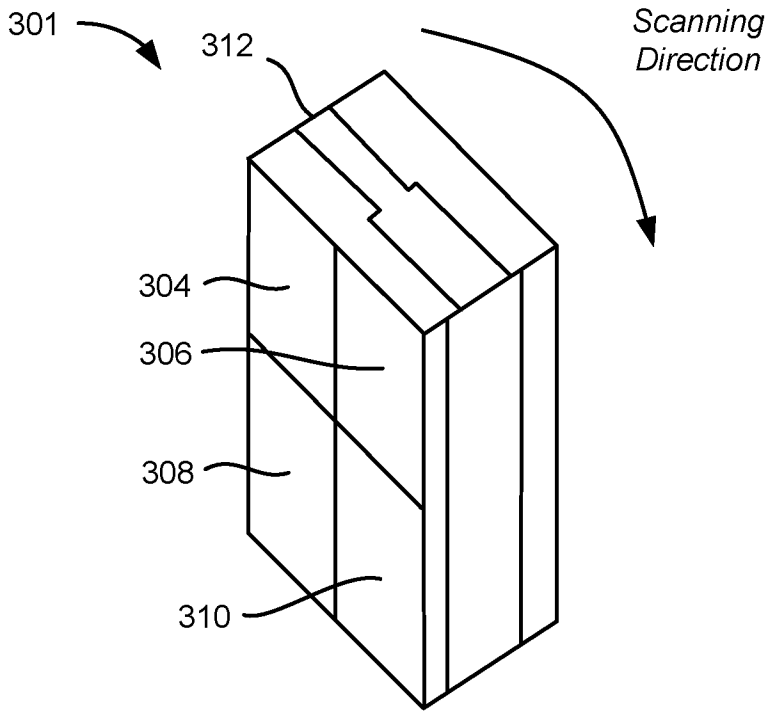

301
312
Scanning Direction
304
306
308
310

FIG. 3B

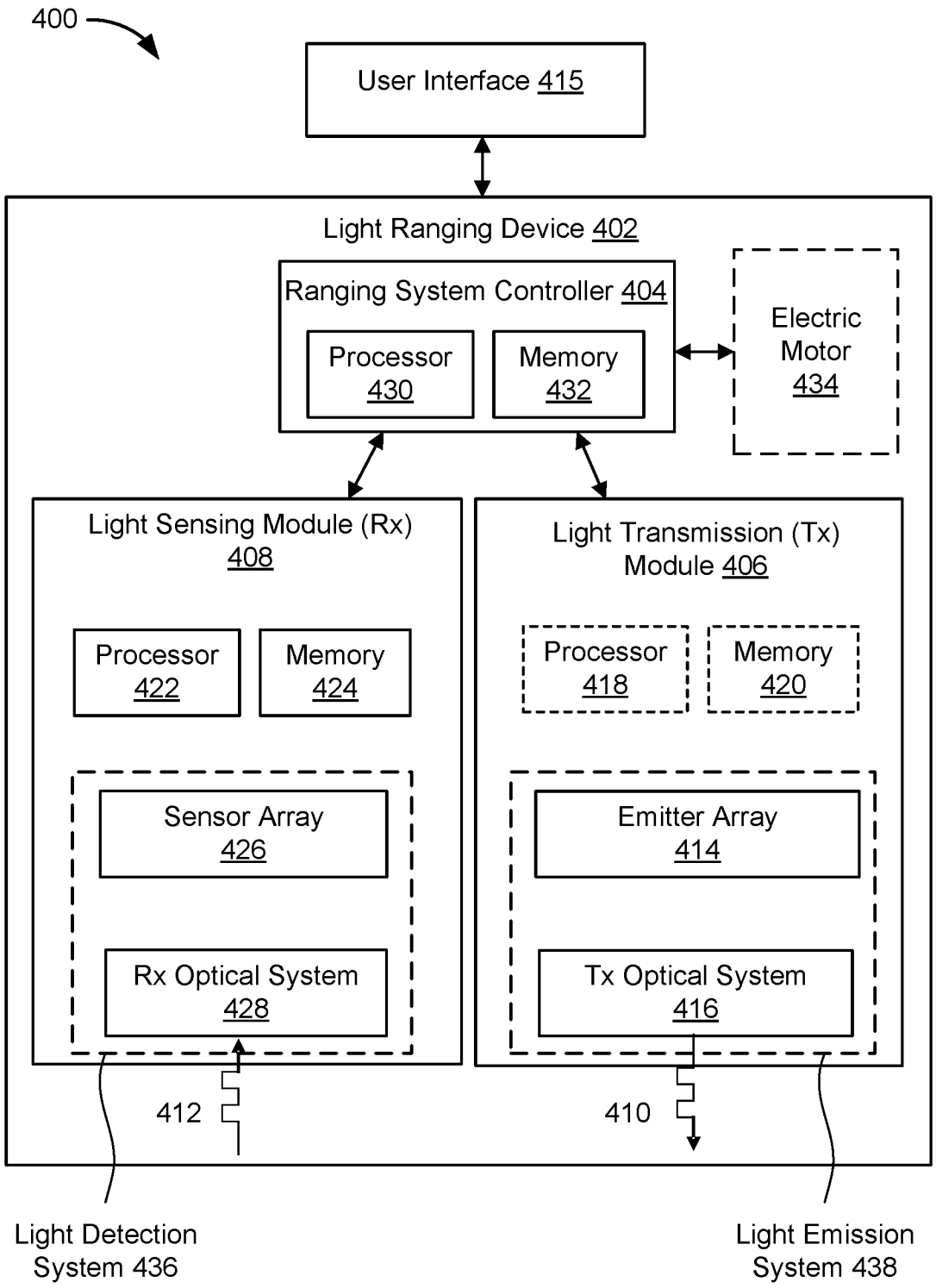

400
User Interface 415
Light Ranging Device 402
Ranging System Controller 404
Processor 430
Memory 432
Electric Motor 434
Light Sensing Module (Rx) 408
Processor 422
Memory 424
Sensor Array 426
Rx Optical System 428
Light Transmission (Tx) Module 406
Processor 418
Memory 420
Emitter Array 414
Tx Optical System 416
412
410
Light Detection System 436
Light Emission System 438

FIG. 4

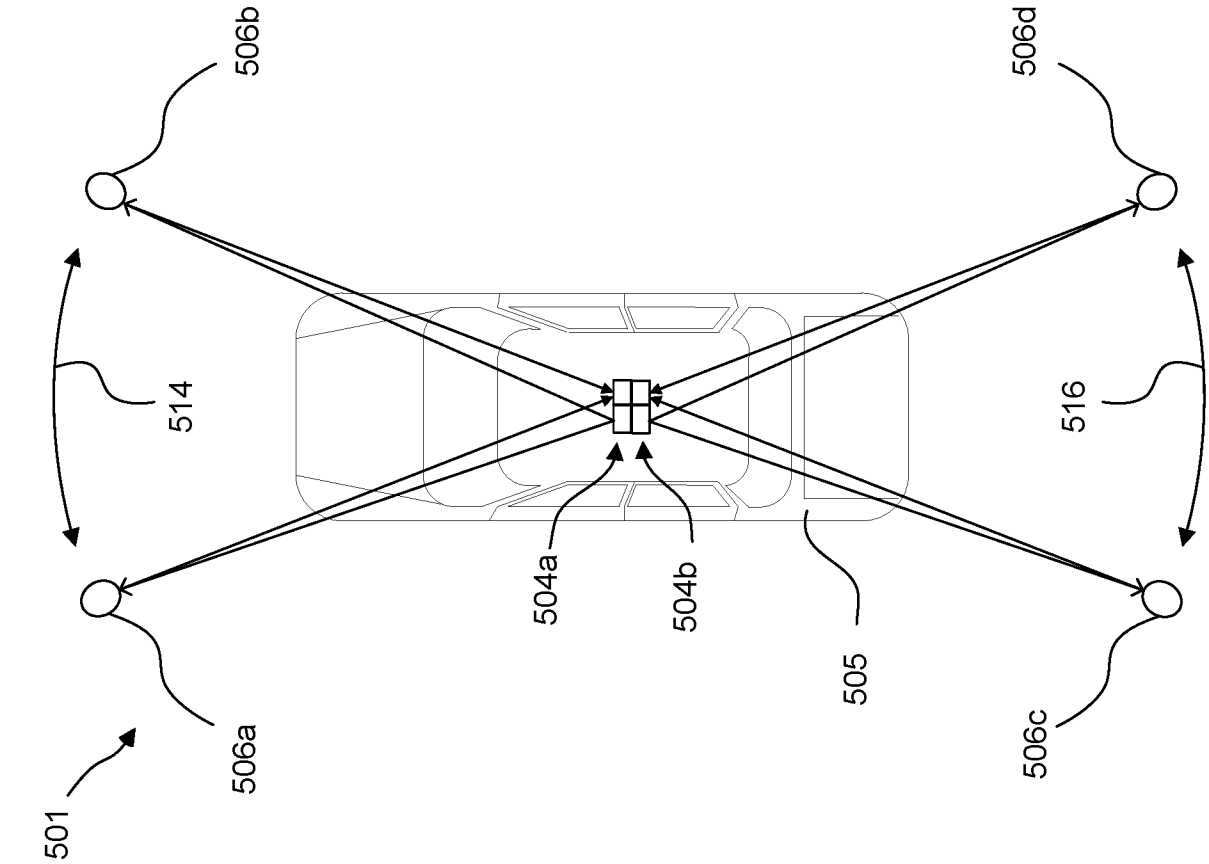

506b
506d
514
516
504a
504b
505
501
506a
506c

FIG. 5B

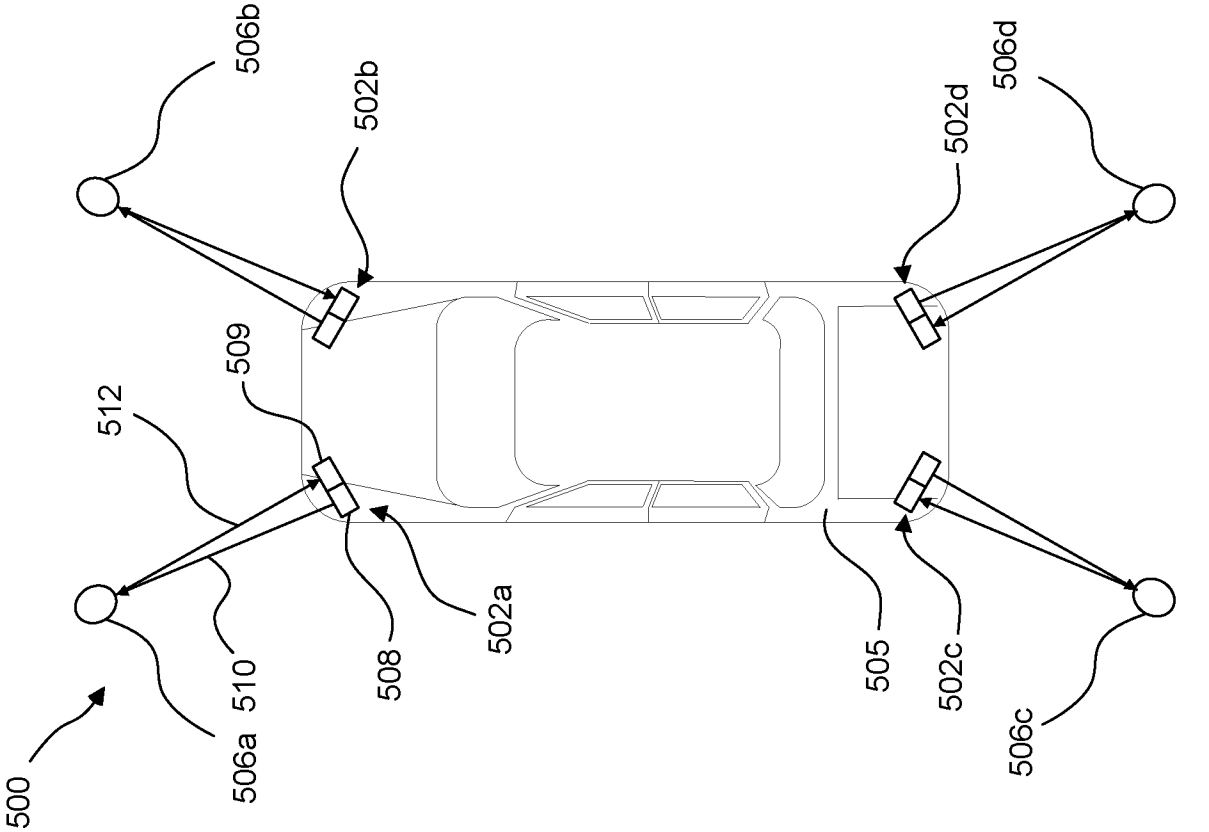

506b
502b
502d
506d
509
512
500
506a
510
508
502a
505
502c
506c

FIG. 5A

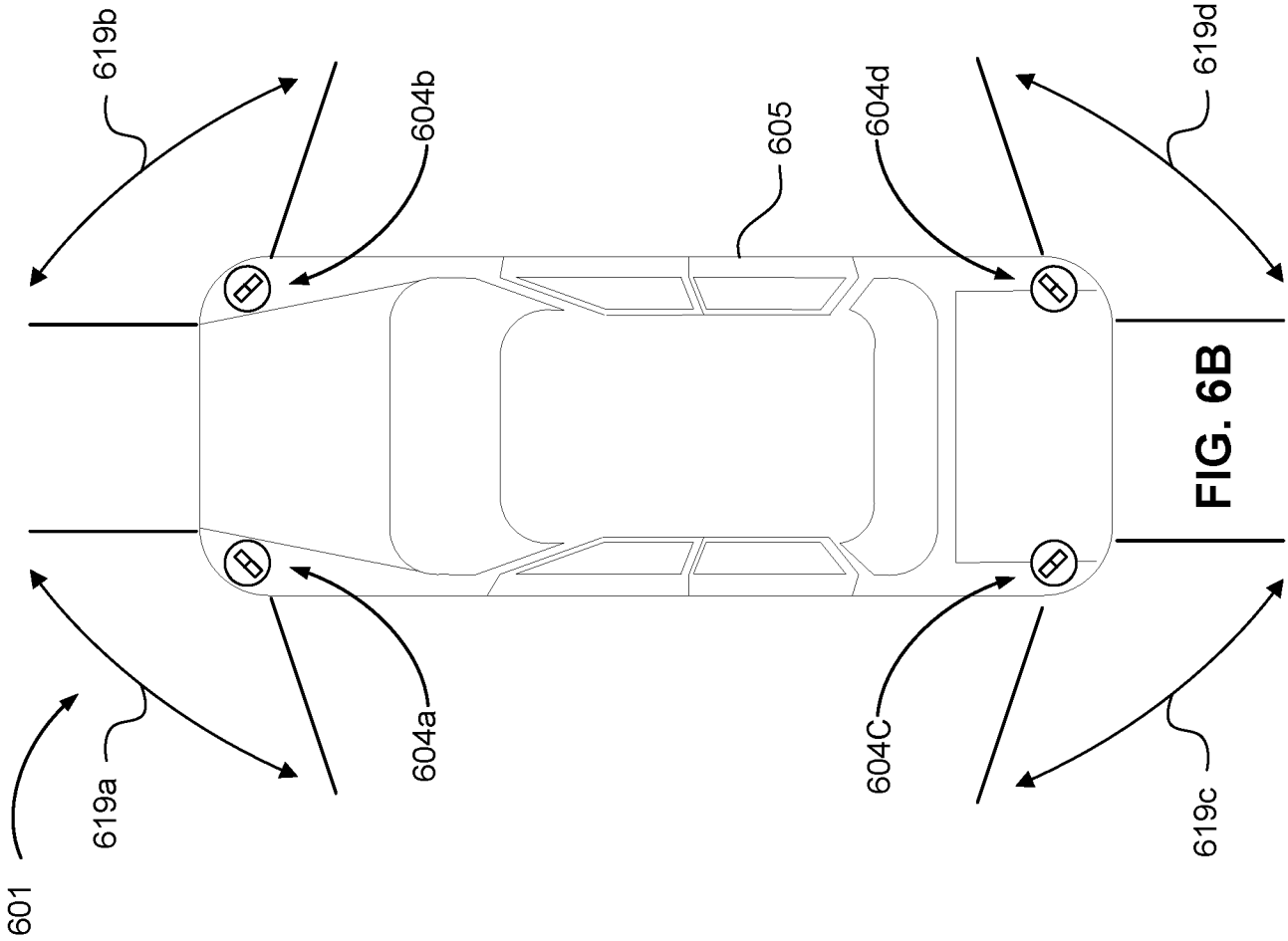

619b
604b
605
604d
619d
601
619a
604a
604C
619c

FIG. 6B

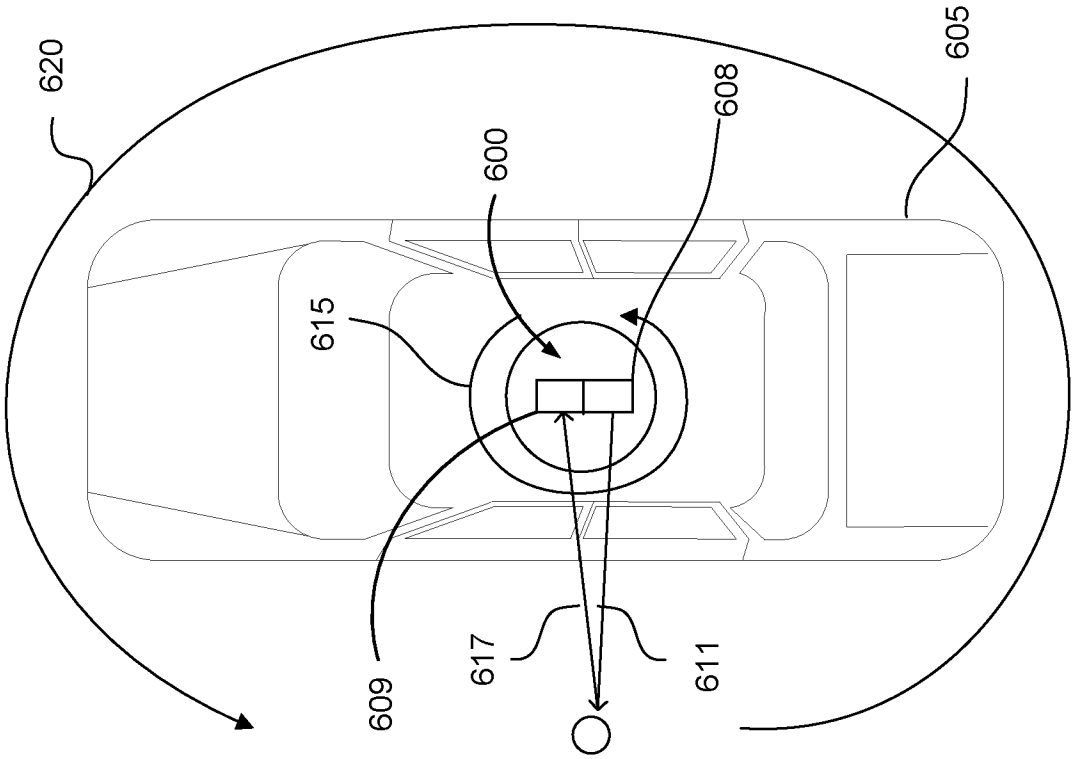

620
605
608
600
615
609
617
611

FIG. 6A

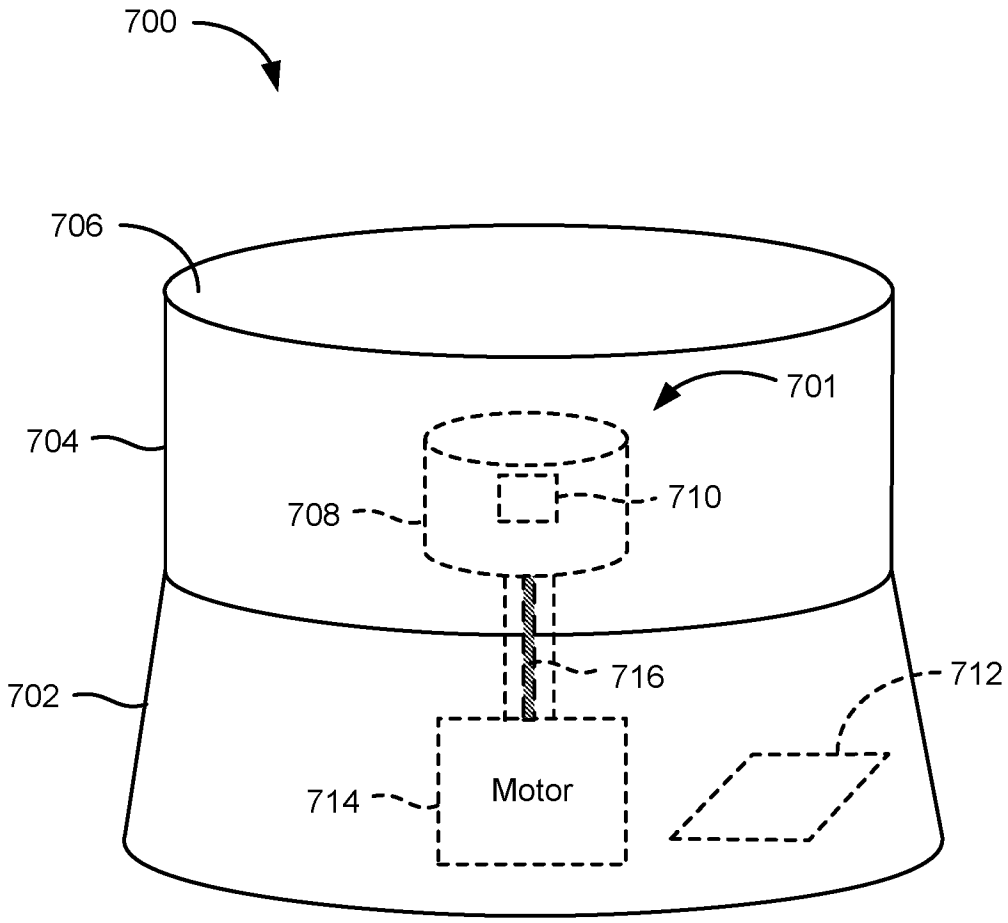


FIG. 7

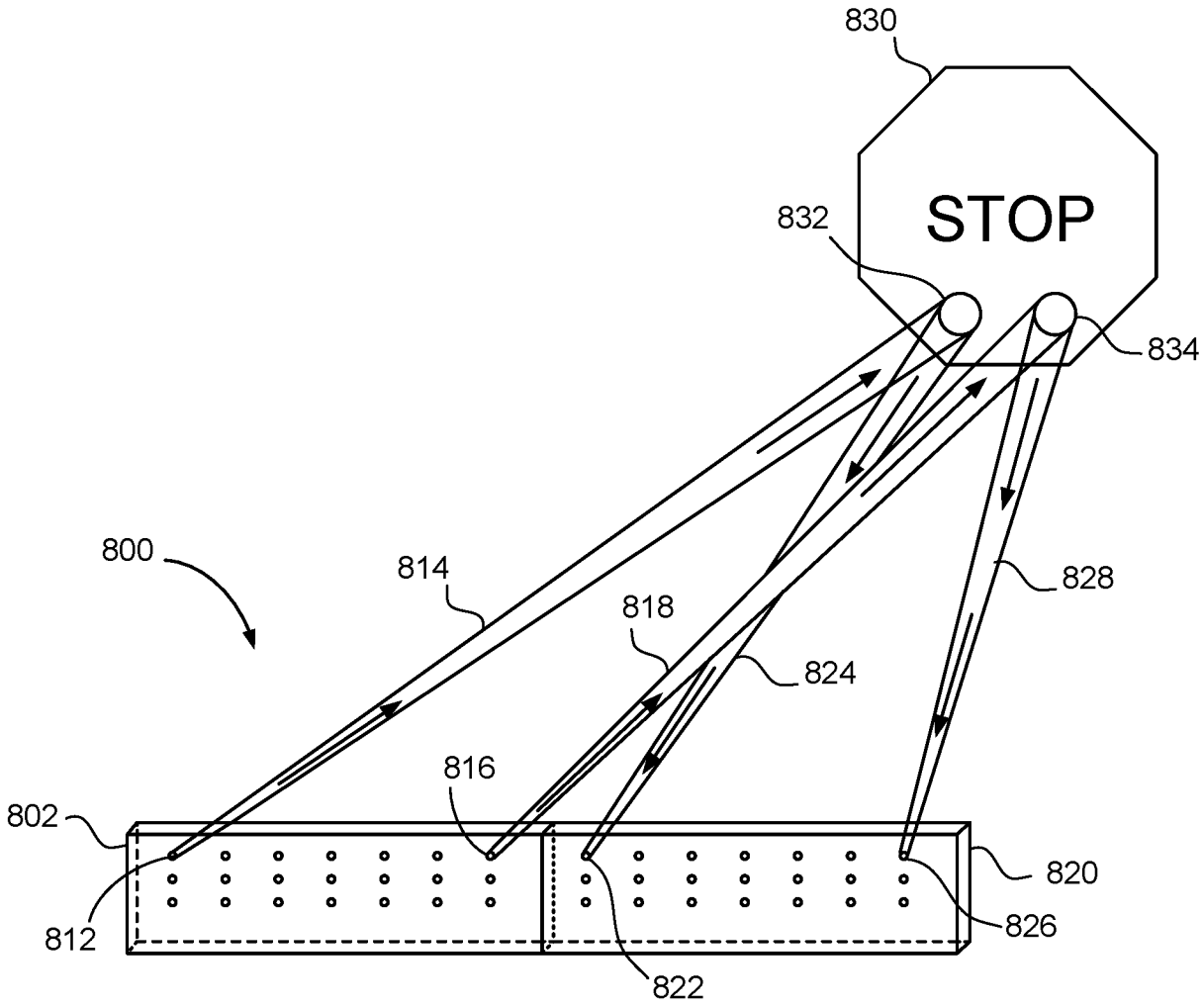


FIG. 8

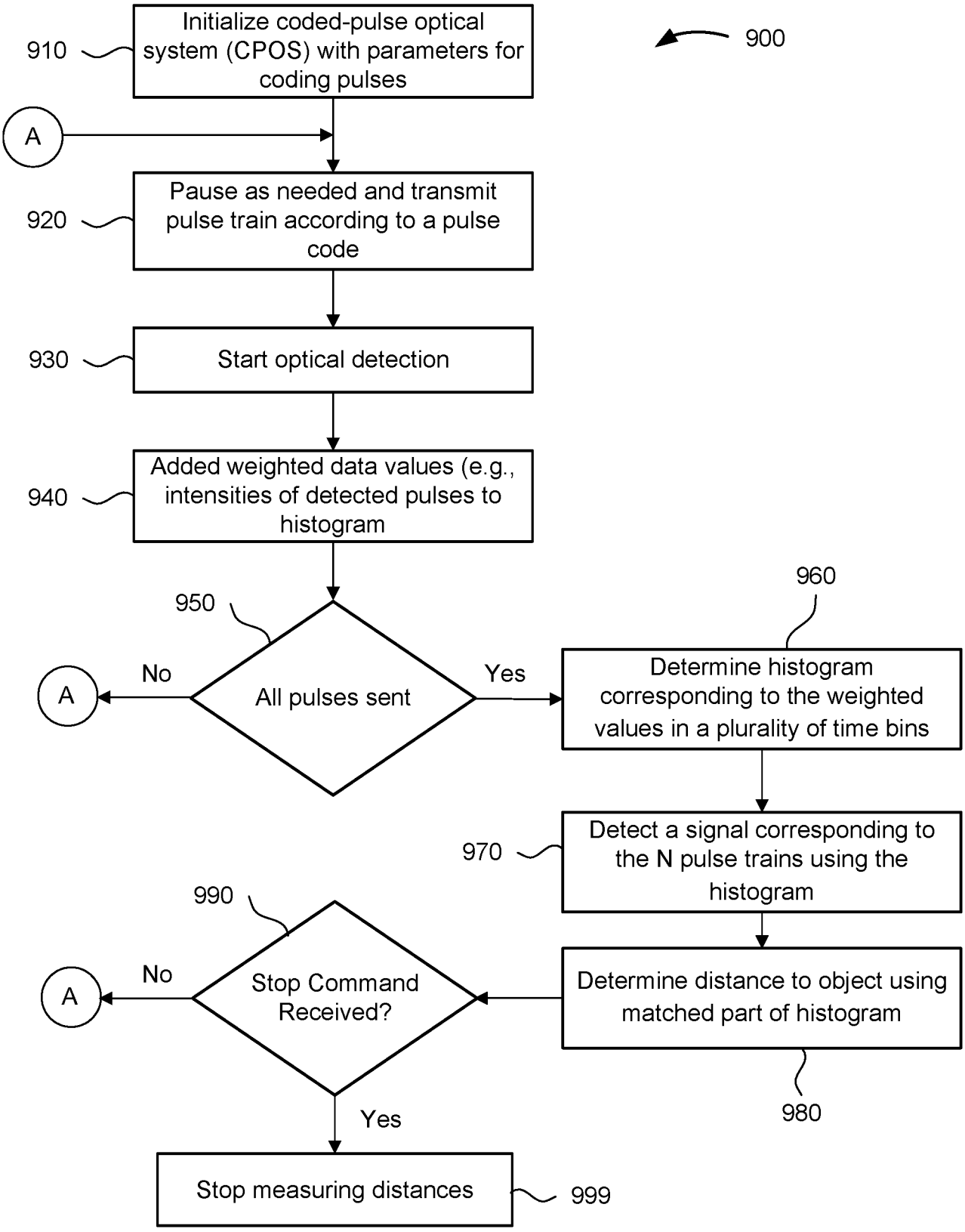

900
910
Initialize coded-pulse optical system (CPOS) with parameters for coding pulses
A
920
Pause as needed and transmit pulse train according to a pulse code
930
Start optical detection
940
Added weighted data values (e.g., intensities of detected pulses to histogram
950
All pulses sent
No
A
Yes
960
Determine histogram corresponding to the weighted values in a plurality of time bins
970
Detect a signal corresponding to the N pulse trains using the histogram
Determine distance to object using matched part of histogram
980
990
Stop Command Received?
No
A
Yes
Stop measuring distances
999

FIG. 9

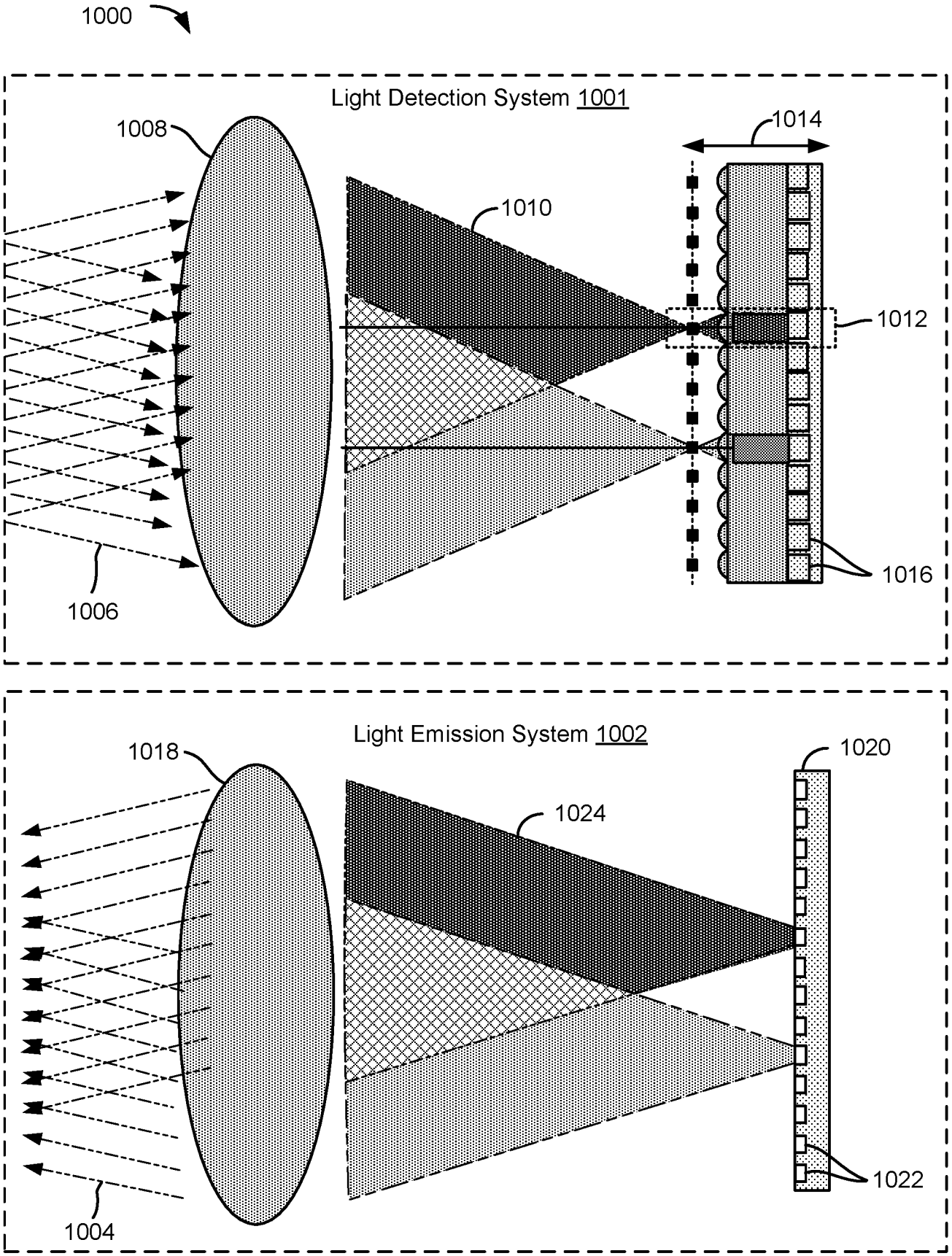

1000
Light Detection System 1001
1008
1014
1010
1012
1016
1006
Light Emission System 1002
1018
1020
1024
1022
1004

FIG. 10

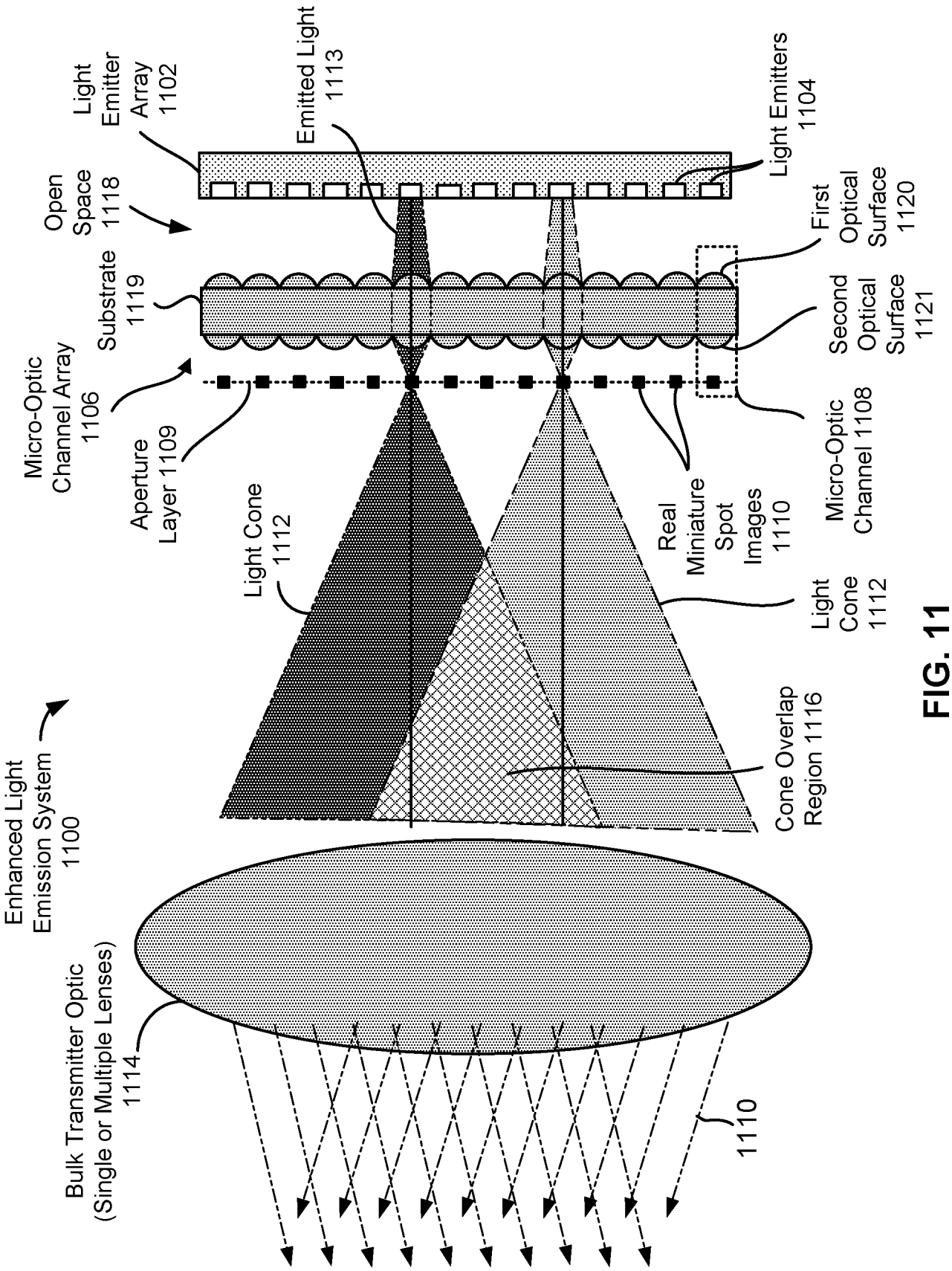

Enhanced Light Emission System 1100
Bulk Transmitter Optic (Single or Multiple Lenses) 1114
Light Emitter Array 1102
Emitted Light 1113
Light Emitters 1104
Open Space 1118
Substrate 1119
First Optical Surface 1120
Second Optical Surface 1121
Micro-Optic Channel Array 1106
Aperture Layer 1109
Micro-Optic Channel 1108
Real Miniature Spot Images 1110
Light Cone 1112
Light Cone 1112
Cone Overlap Region 1116
1110

FIG. 11

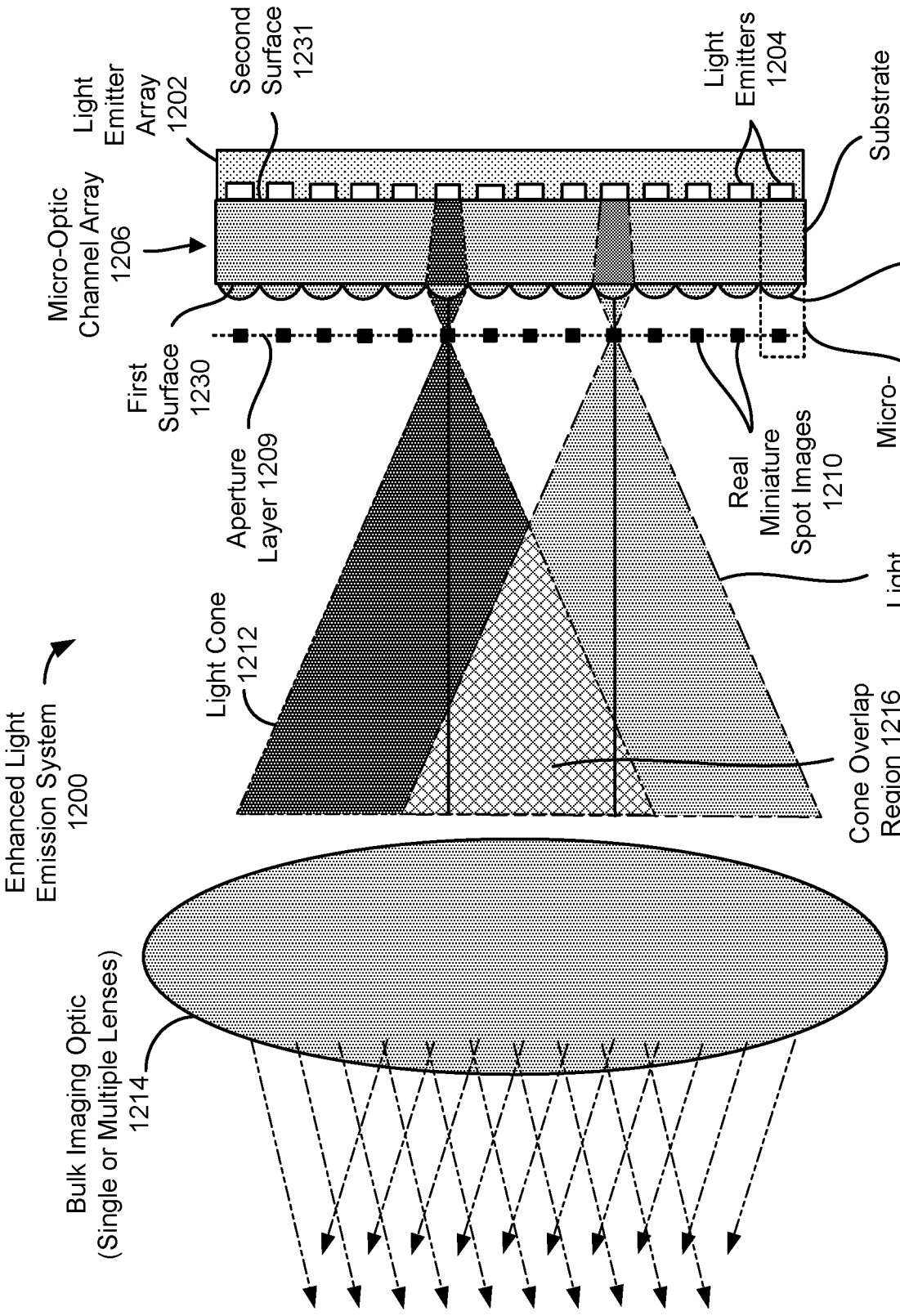

Enhanced Light Emission System 1200
Bulk Imaging Optic (Single or Multiple Lenses) 1214
Light Cone 1212
Cone Overlap Region 1216
Light Cone 1212
Aperture Layer 1209
First Surface 1230
Micro-Optic Channel Array 1206
Light Emitter Array 1202
Second Surface 1231
Real Miniature Spot Images 1210
Micro-Optic Channel 1208
Optical Surface 1220
Substrate 1219
Light Emitters 1204

FIG. 12

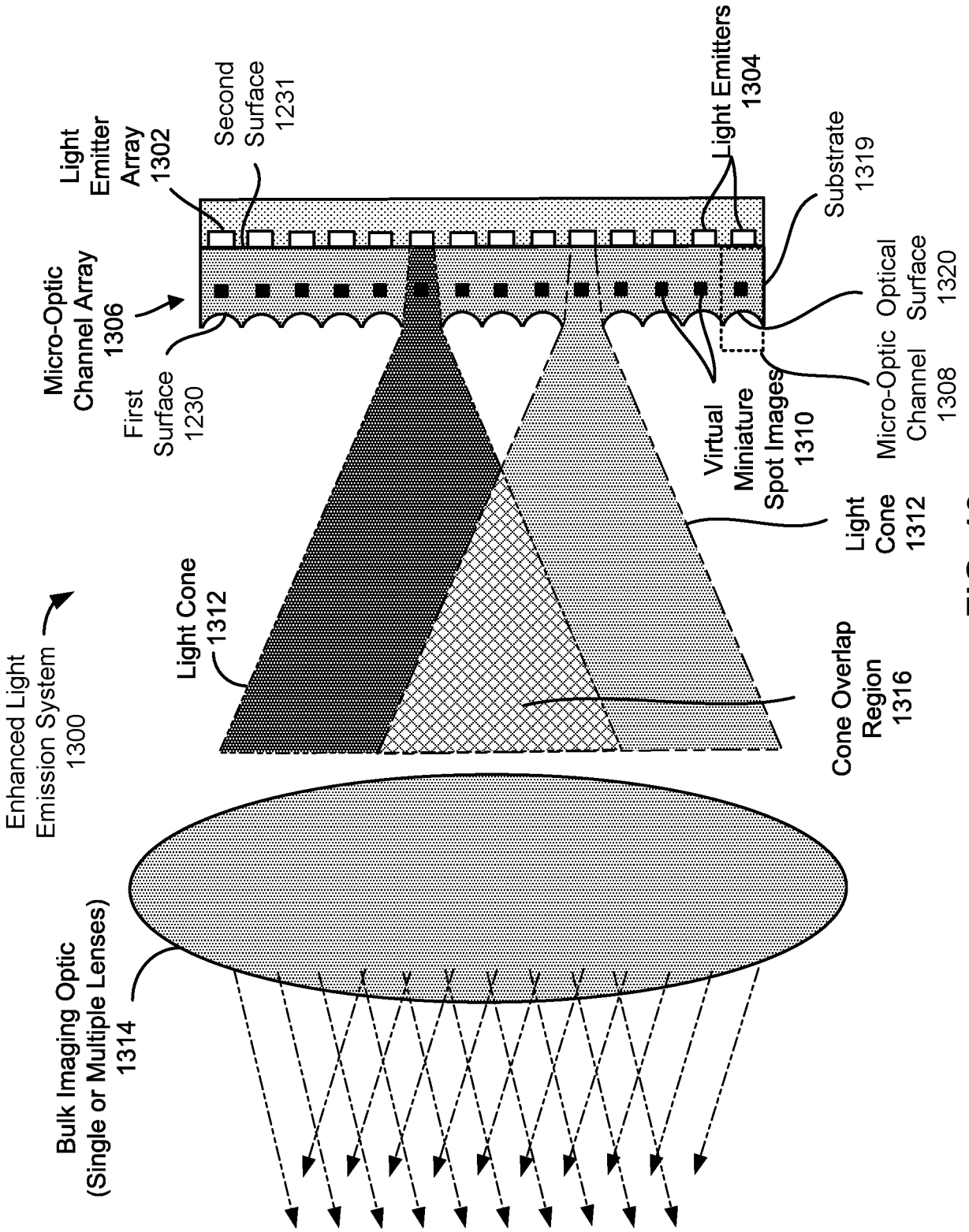

Enhanced Light Emission System 1300
Bulk Imaging Optic (Single or Multiple Lenses) 1314
Micro-Optic Channel Array 1306
Light Emitter Array 1302
First Surface 1230
Second Surface 1231
Light Emitters 1304
Substrate 1319
Micro-Optic Optical Surface 1320
Micro-Optic Channel 1308
Virtual Miniature Spot Images 1310
Light Cone 1312
Light Cone 1312
Cone Overlap Region 1316

FIG. 13

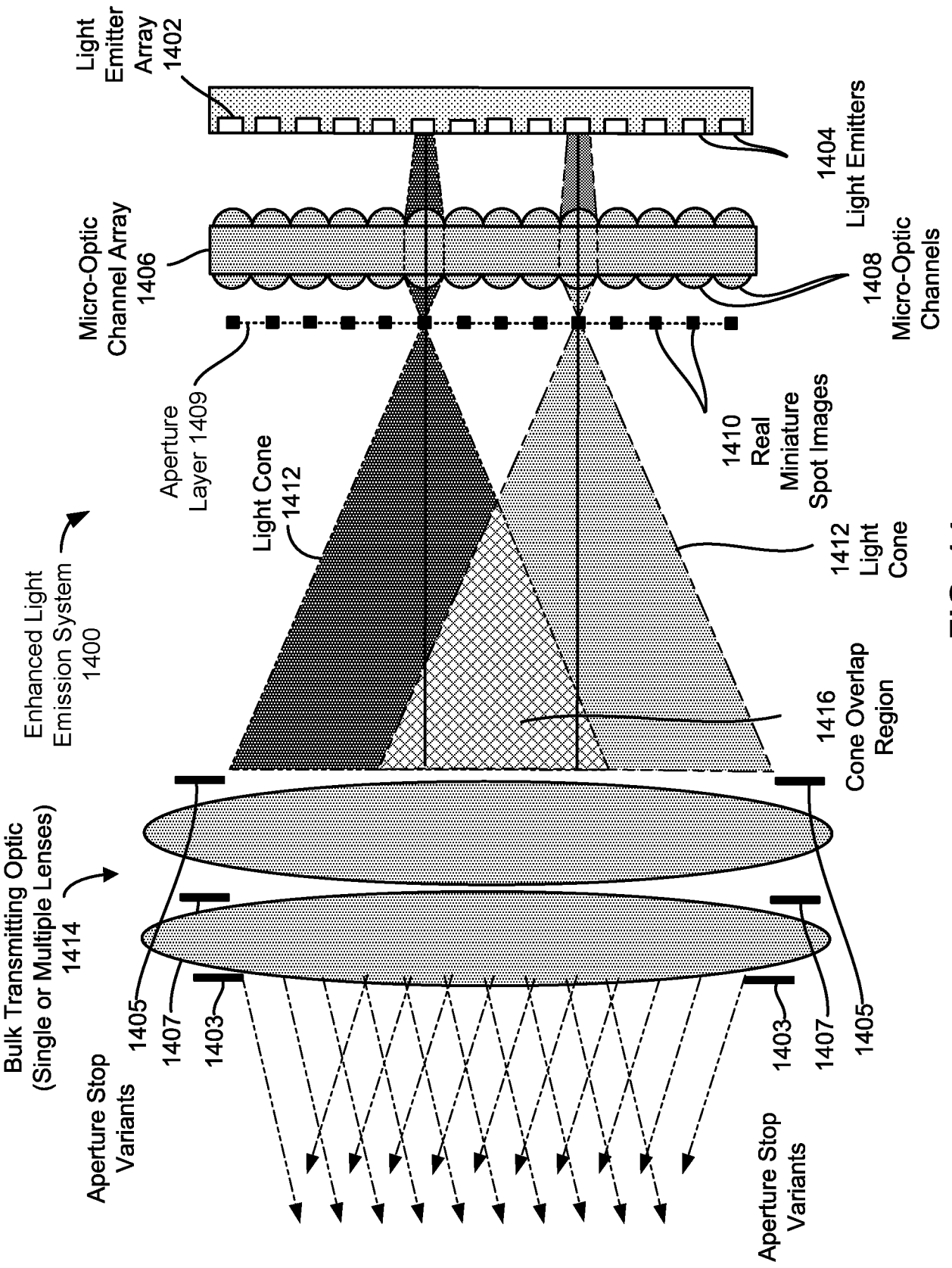

Light Emitter Array 1402
1404 Light Emitters
Micro-Optic Channel Array 1406
1408 Micro-Optic Channels
Aperture Layer 1409
1410 Real Miniature Spot Images
Light Cone 1412
1412 Light Cone
Enhanced Light Emission System 1400
1416 Cone Overlap Region
Bulk Transmitting Optic (Single or Multiple Lenses) 1414
Aperture Stop Variants
1405
1407
1403
1403
1407
1405
Aperture Stop Variants

FIG. 14

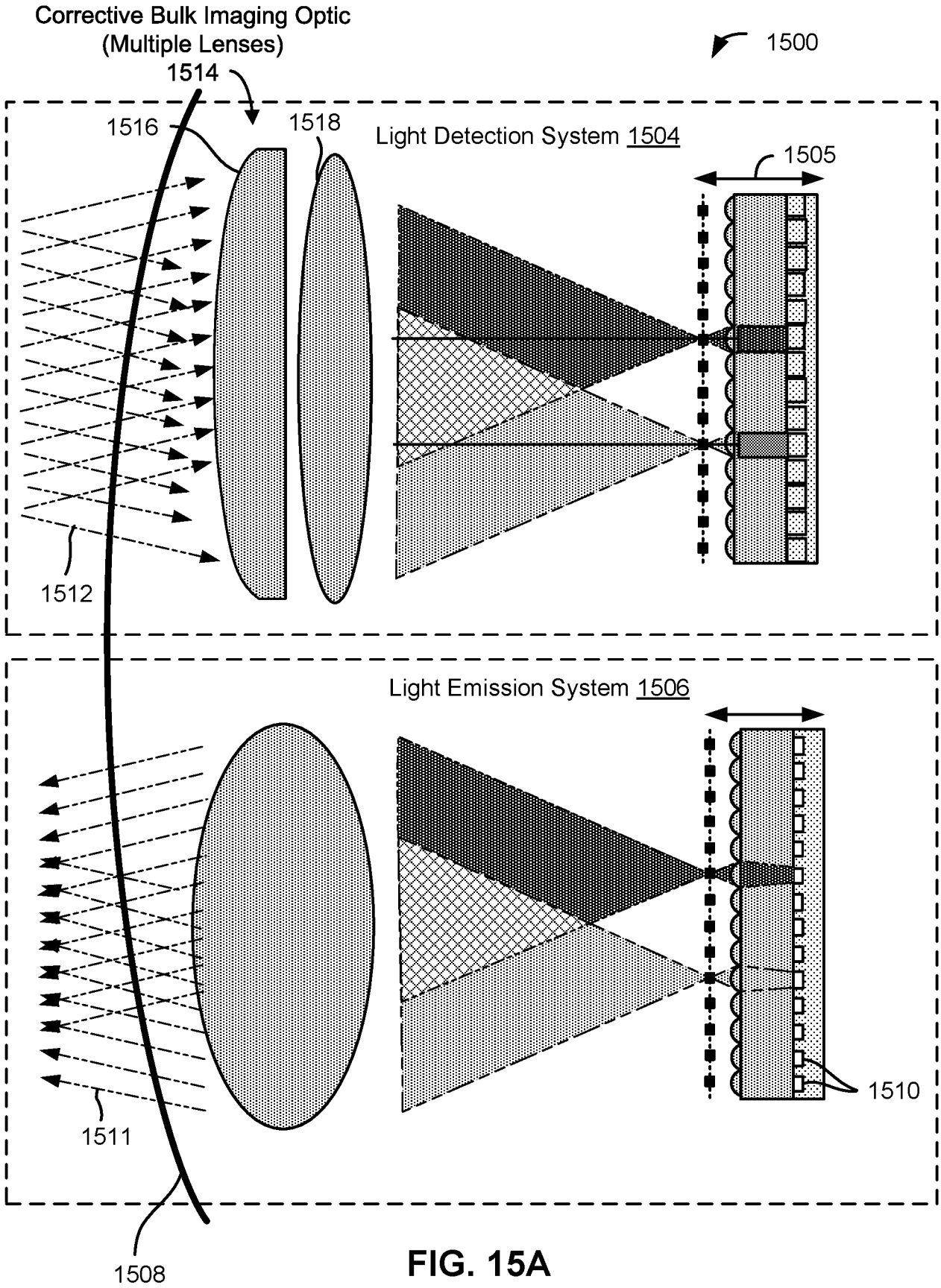

Corrective Bulk Imaging Optic
(Multiple Lenses)
1514
1500
1516
1518
Light Detection System 1504
1505
1512
Light Emission System 1506
1510
1511
1508

FIG. 15A

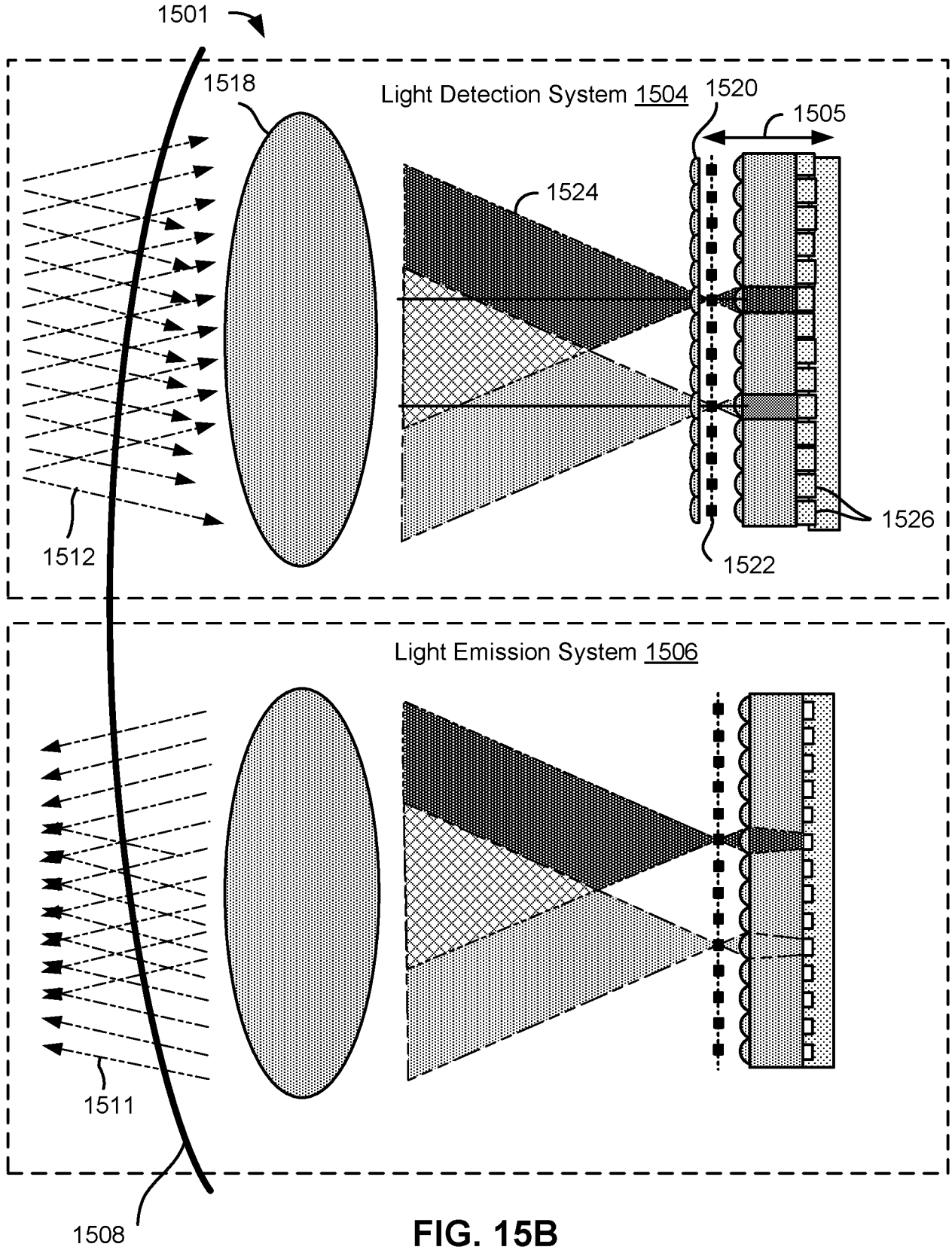

1501
1518
Light Detection System 1504
1520
1505
1524
1526
1512
1522
Light Emission System 1506
1511
1508

FIG. 15B

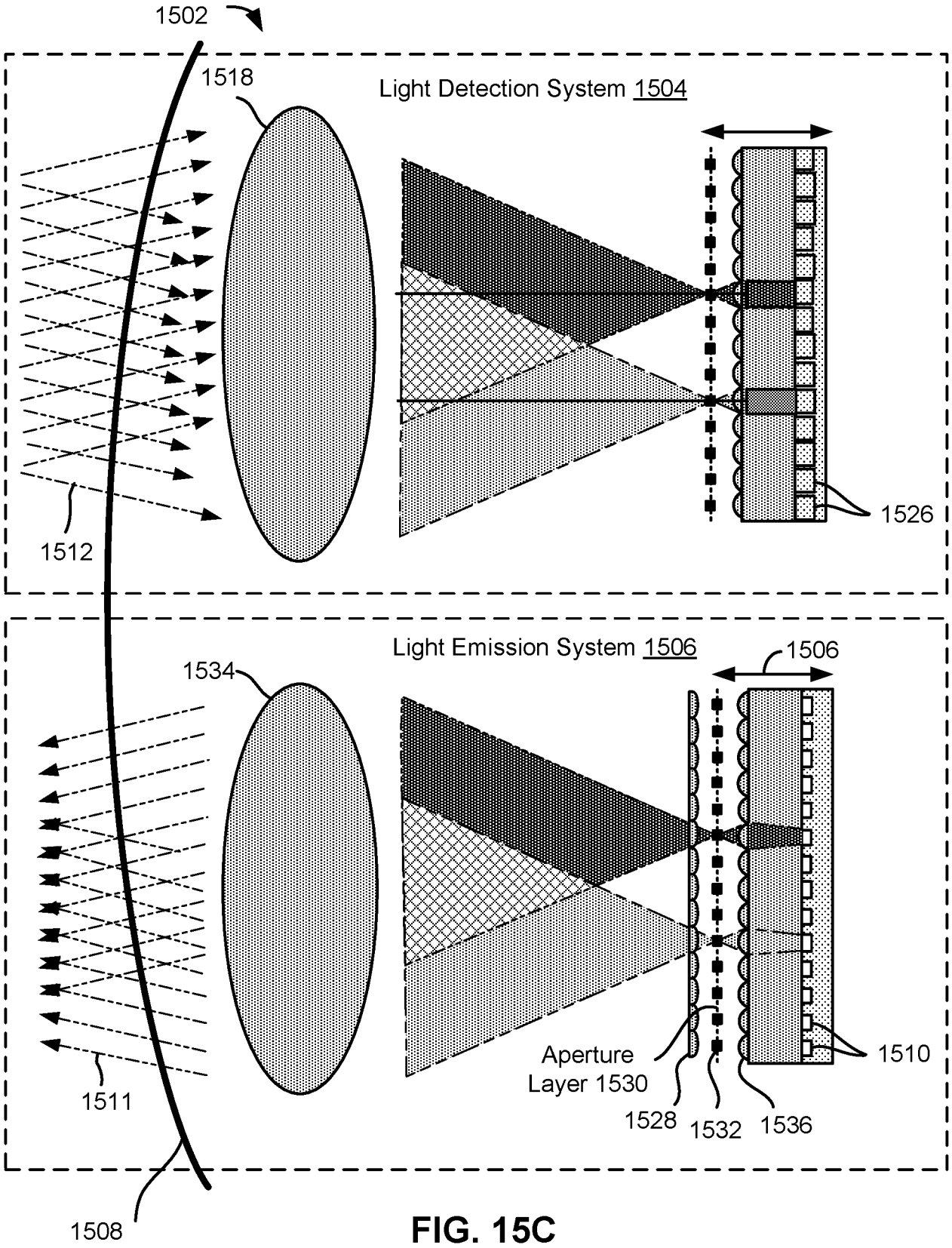

1502
1518
Light Detection System 1504
1526
1512
Light Emission System 1506
1506
1534
1510
Aperture
Layer 1530
1528
1532
1536
1511
1508

FIG. 15C

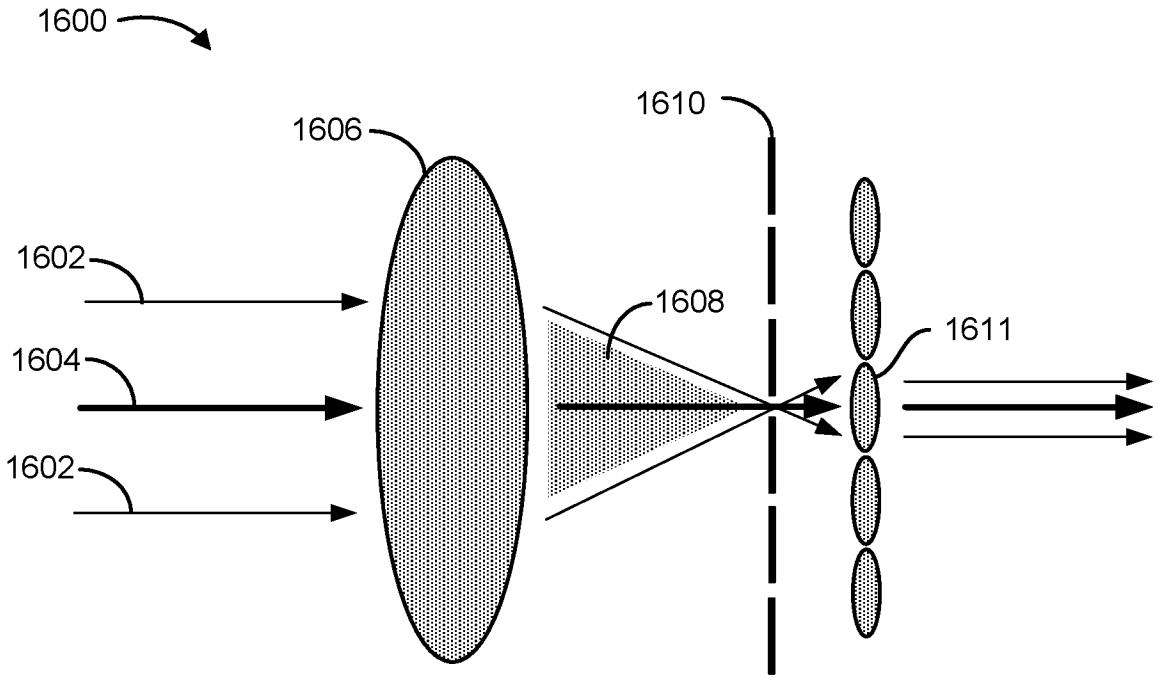


FIG. 16A

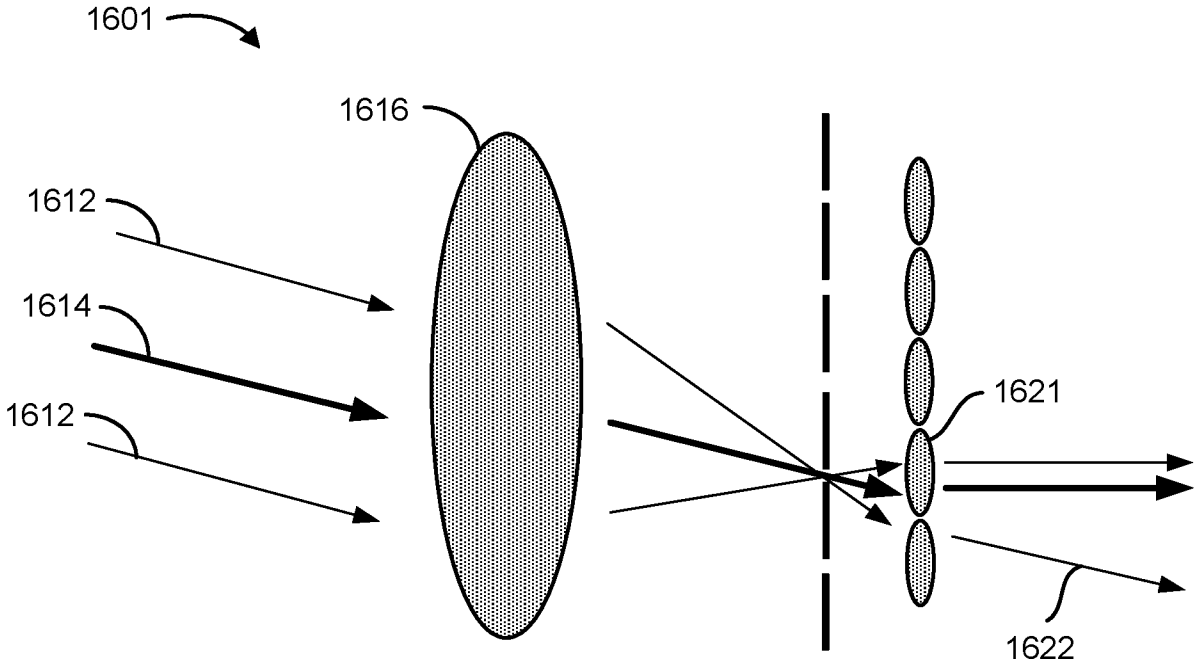


FIG. 16B

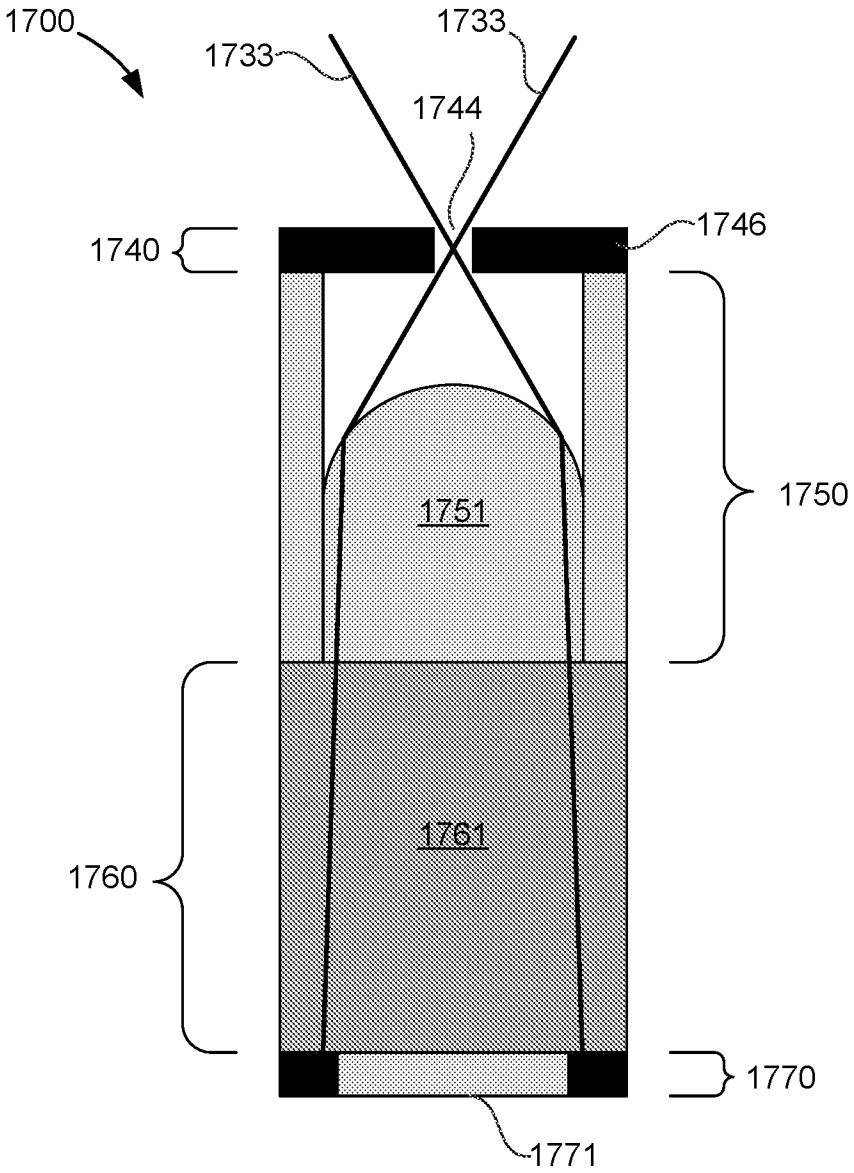


FIG. 17

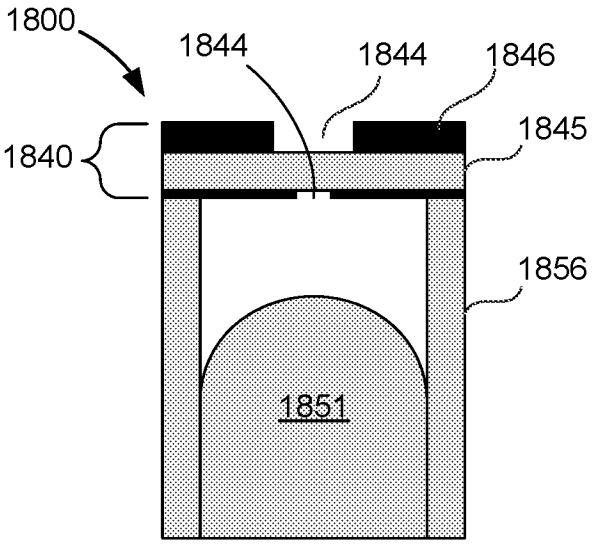


FIG. 18A

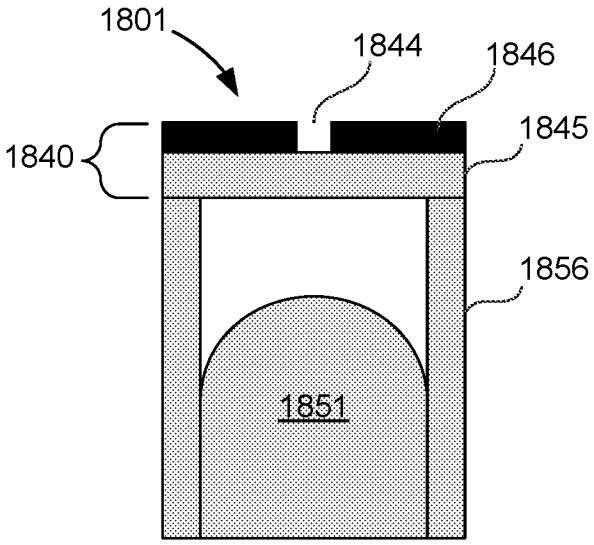


FIG. 18B

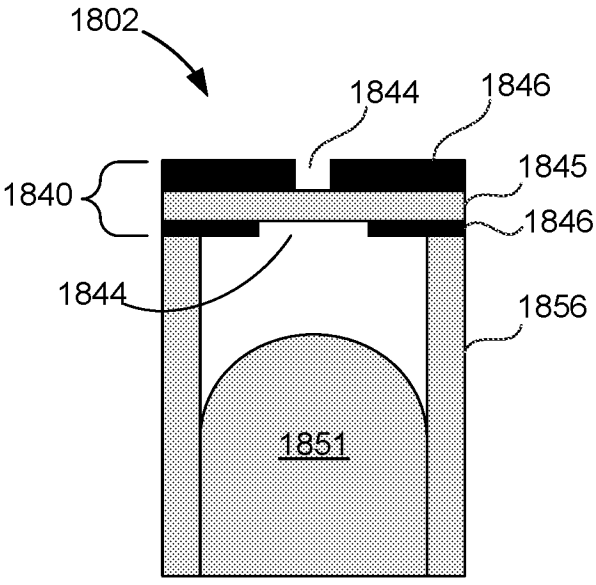


FIG. 18C

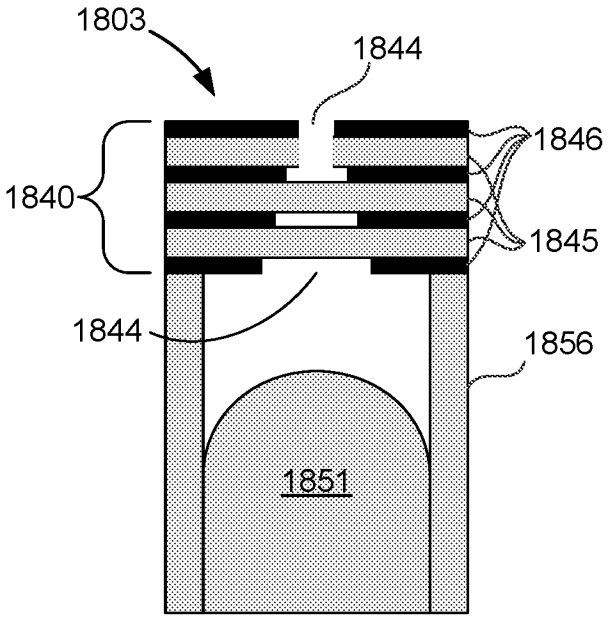


FIG. 18D

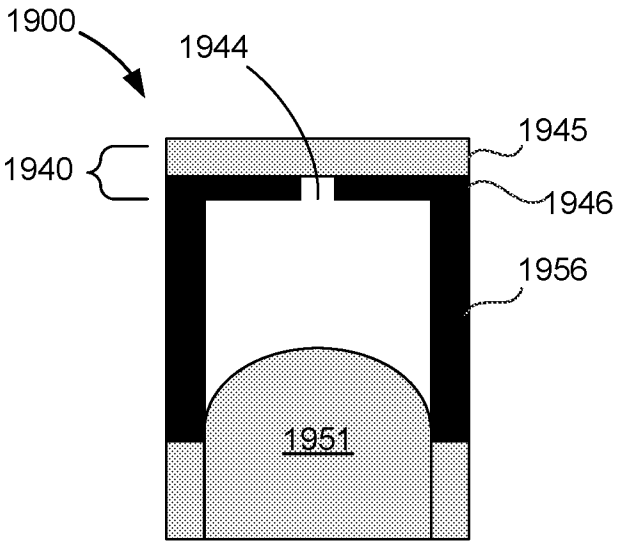


FIG. 19A

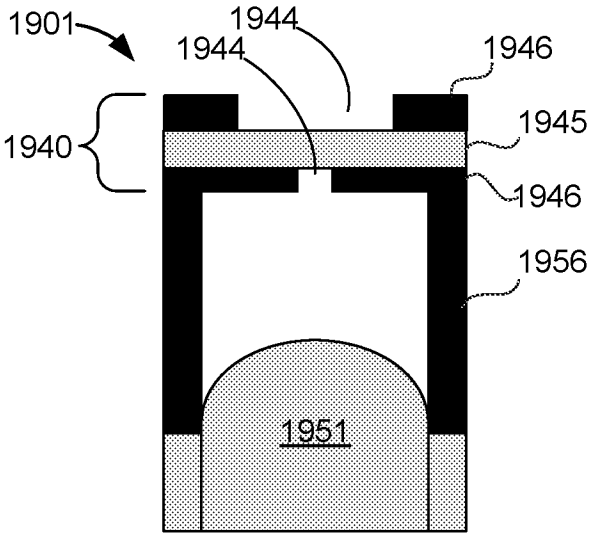


FIG. 19B

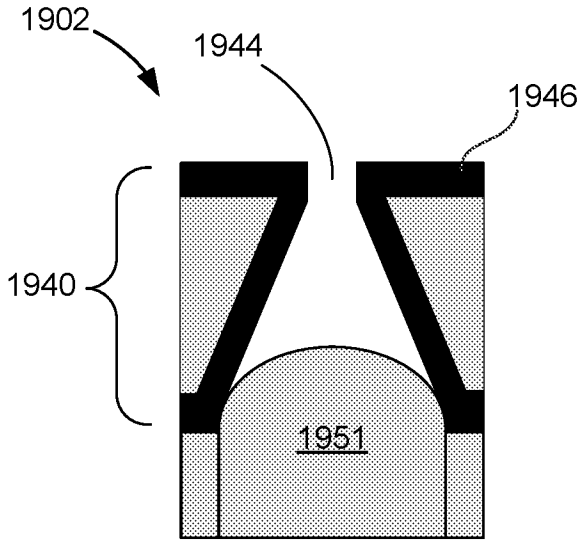


FIG. 19C

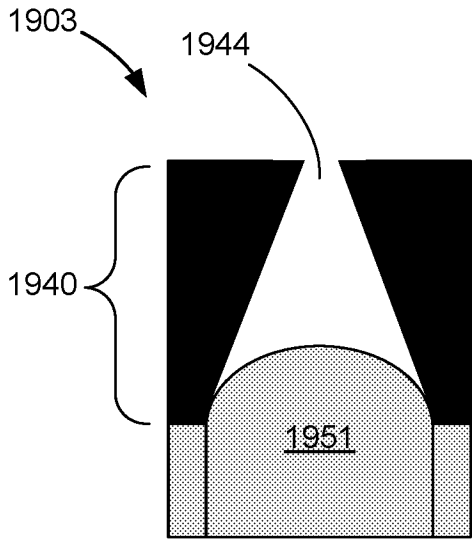


FIG. 19D

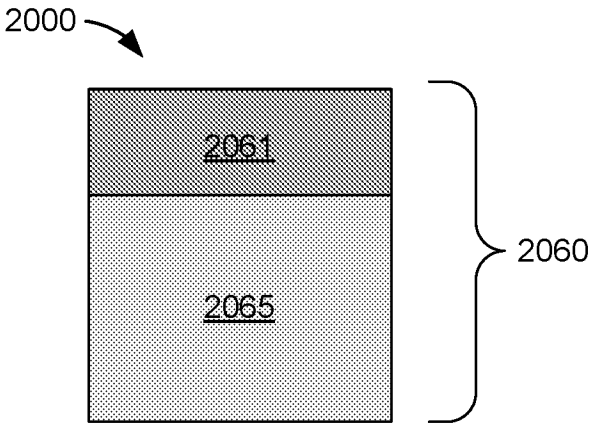


FIG. 20A

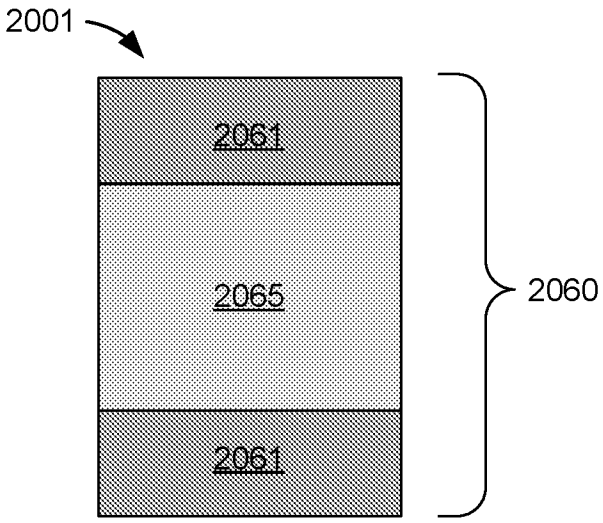


FIG. 20B

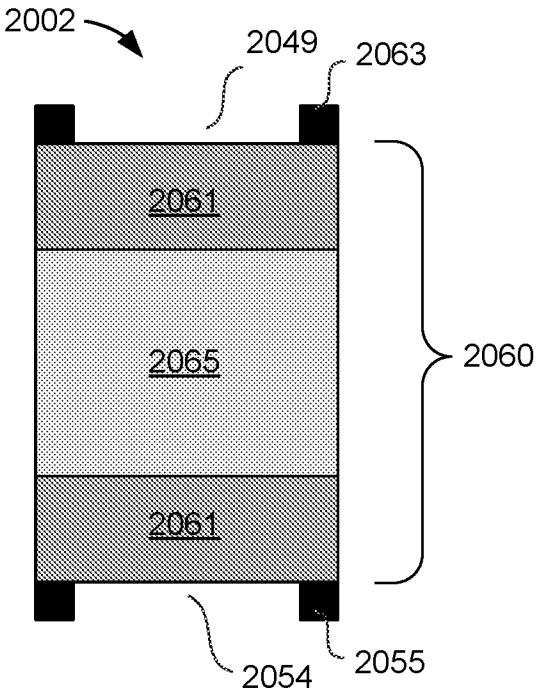


FIG. 20C

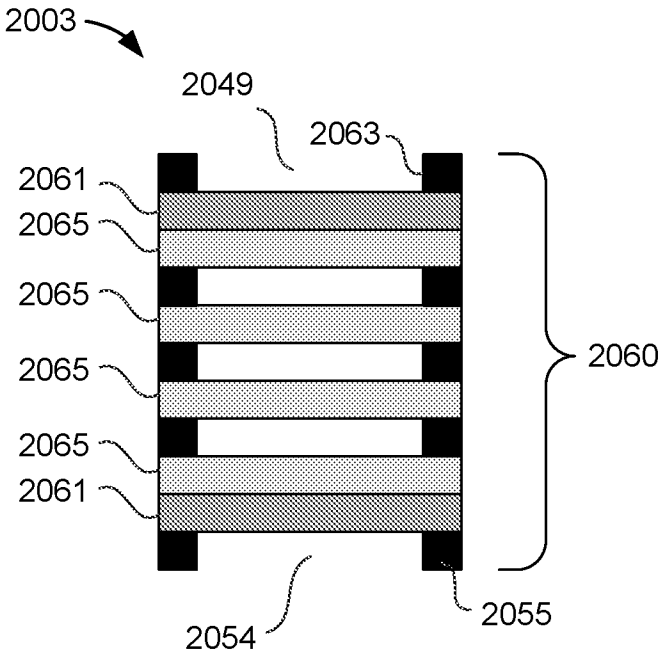


FIG. 20D

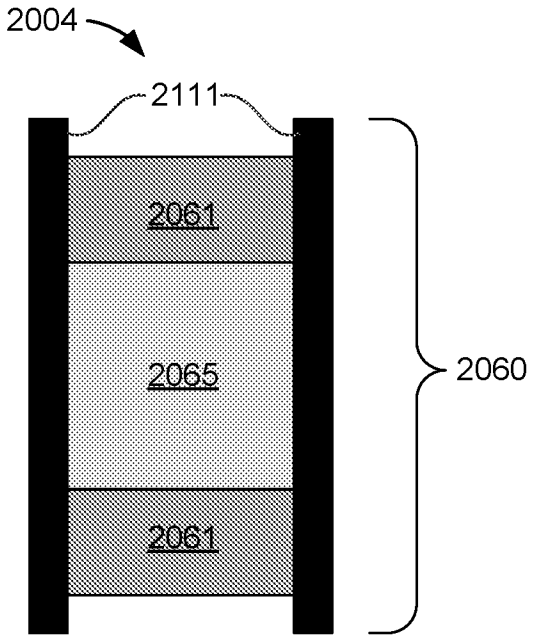


FIG. 20E

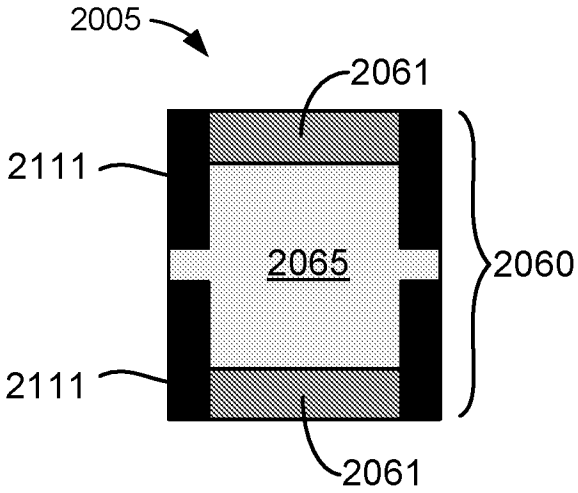


FIG. 20F

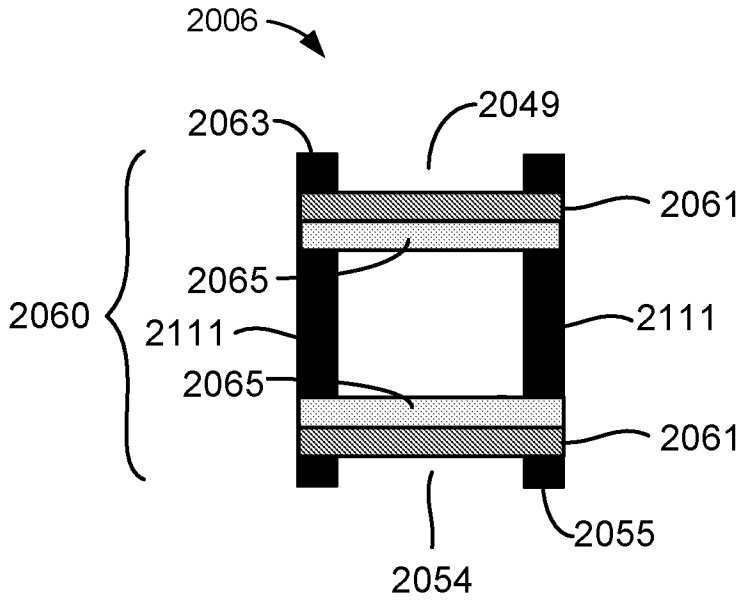


FIG. 20G

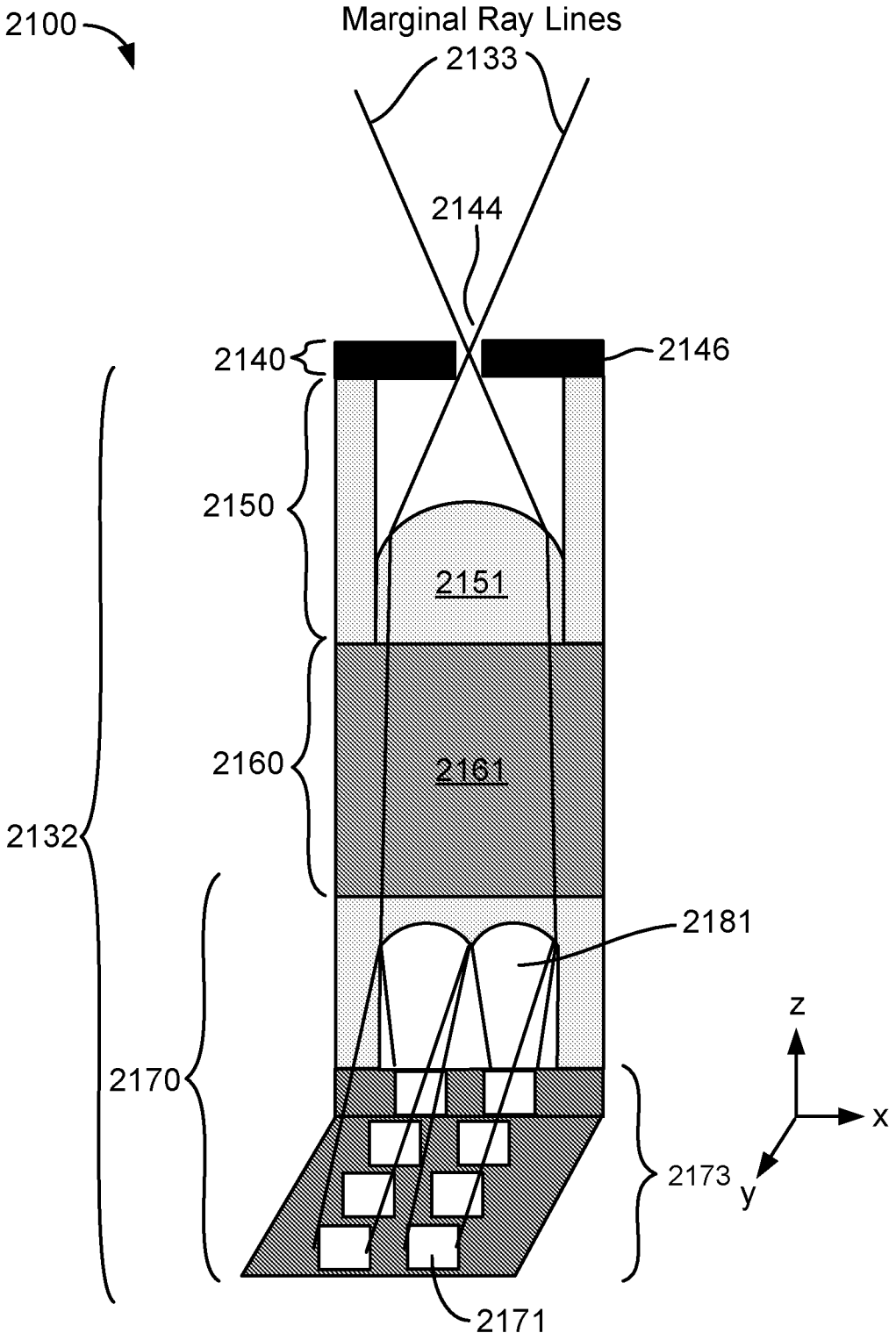

2100
Marginal Ray Lines
2133
2144
2140
2146
2150
2151
2160
2161
2132
2181
2170
2173
2171
z
x
y

FIG. 21A

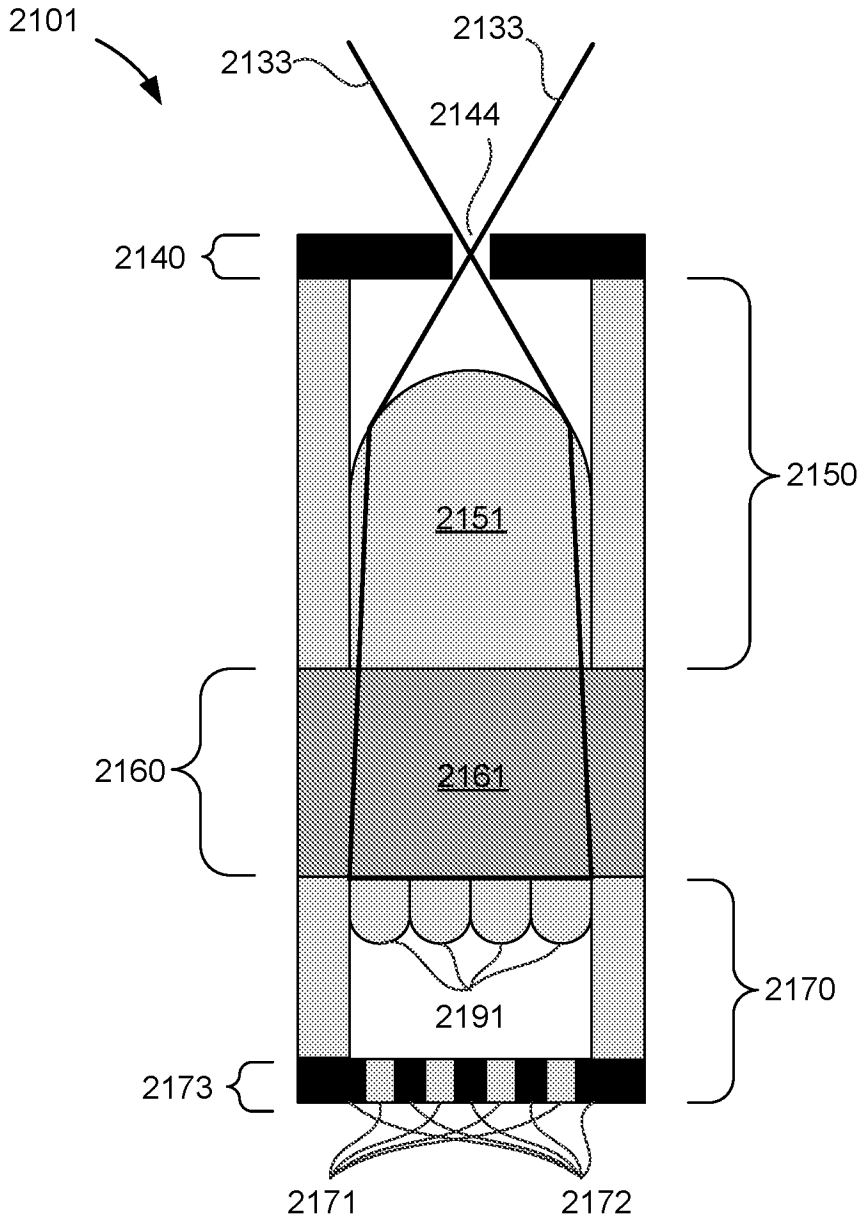

2101
2133
2133
2144
2140
2150
2151
2160
2161
2170
2191
2173
2171
2172

FIG. 21B

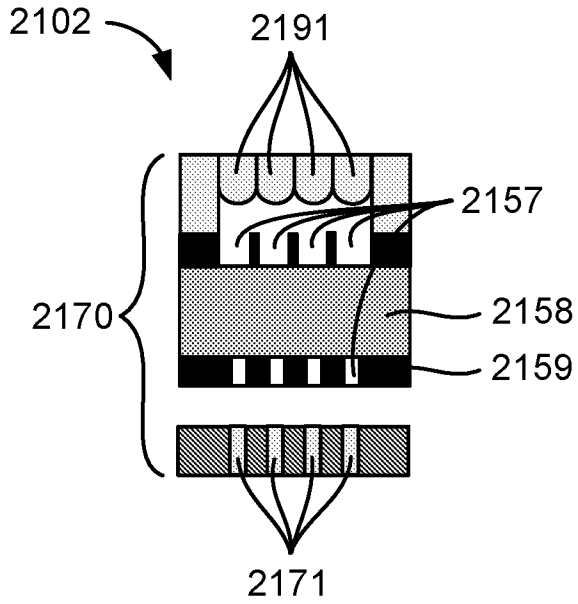


FIG. 21C

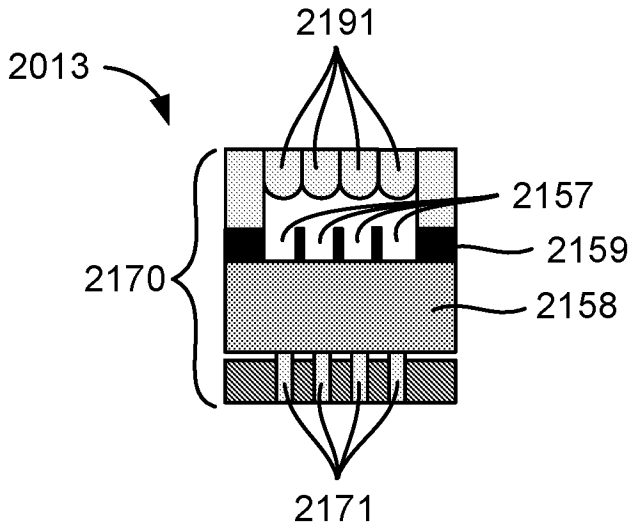


FIG. 21D

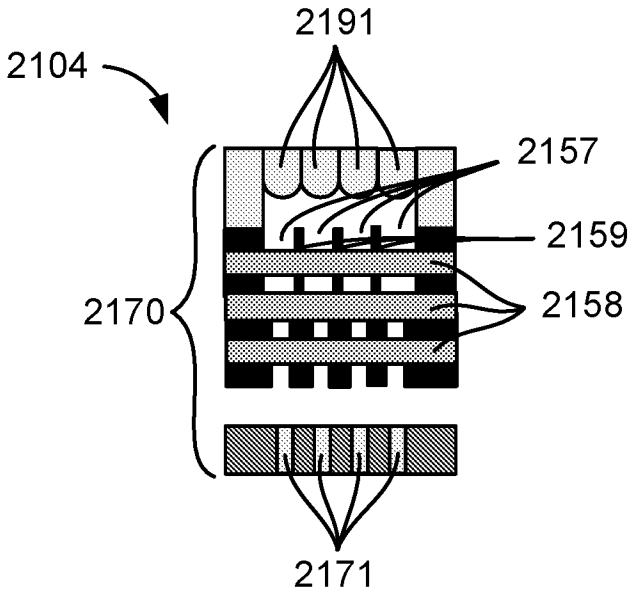


FIG. 21E

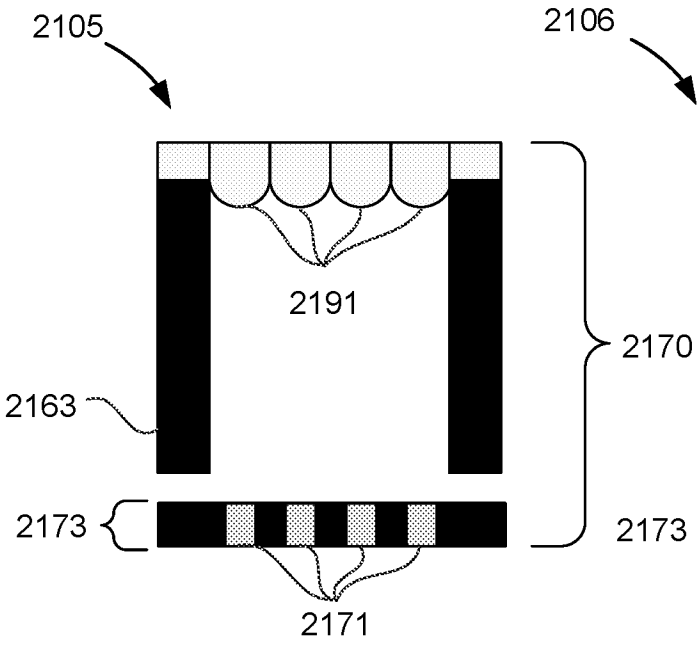


FIG. 21F

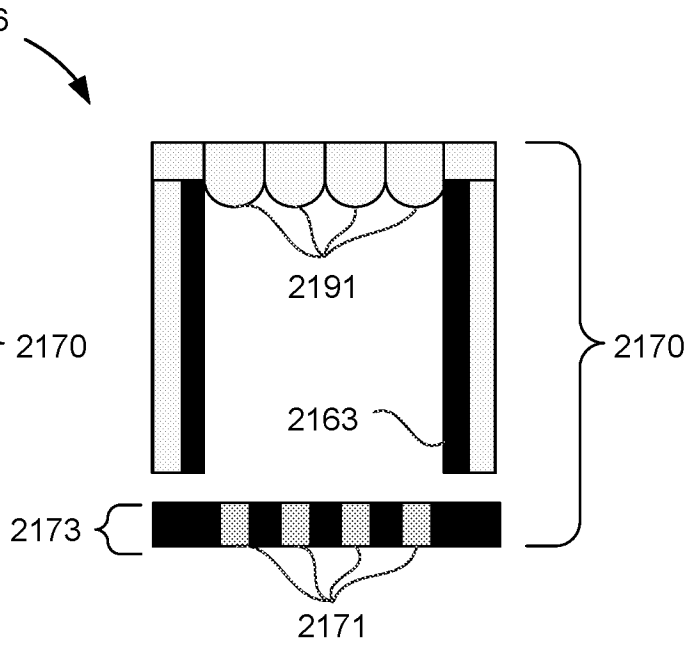


FIG. 21G

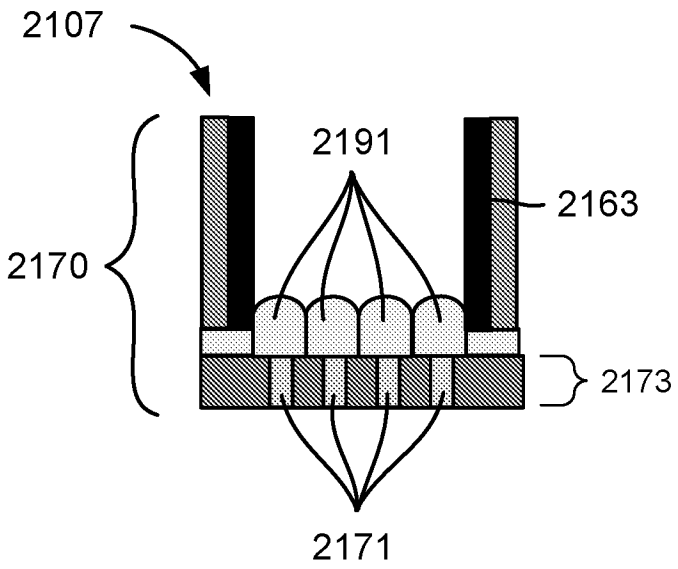


FIG. 21H

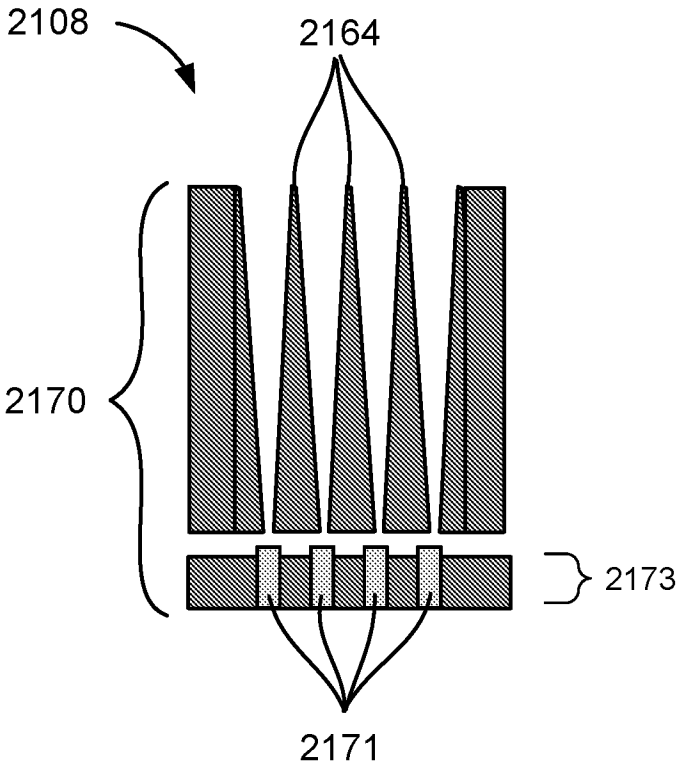


FIG. 21I

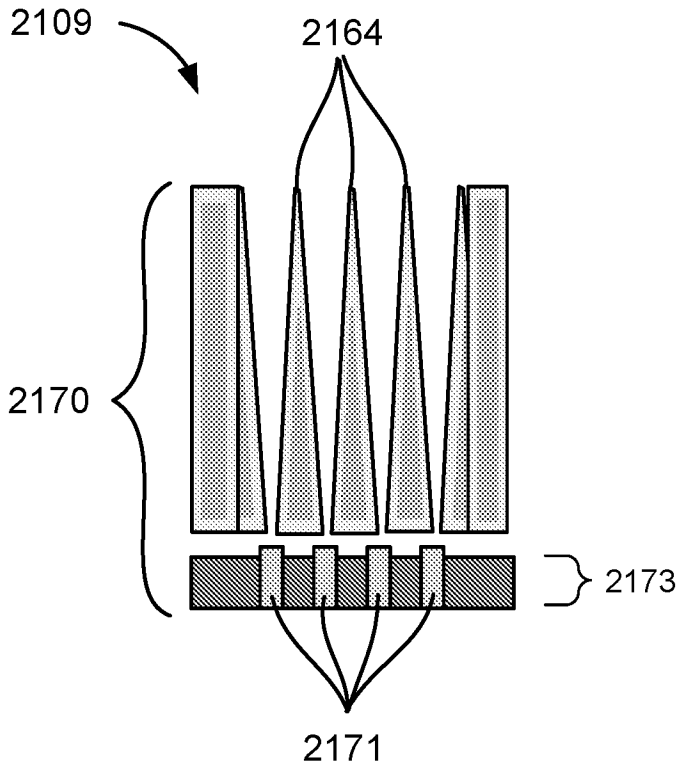


FIG. 21J

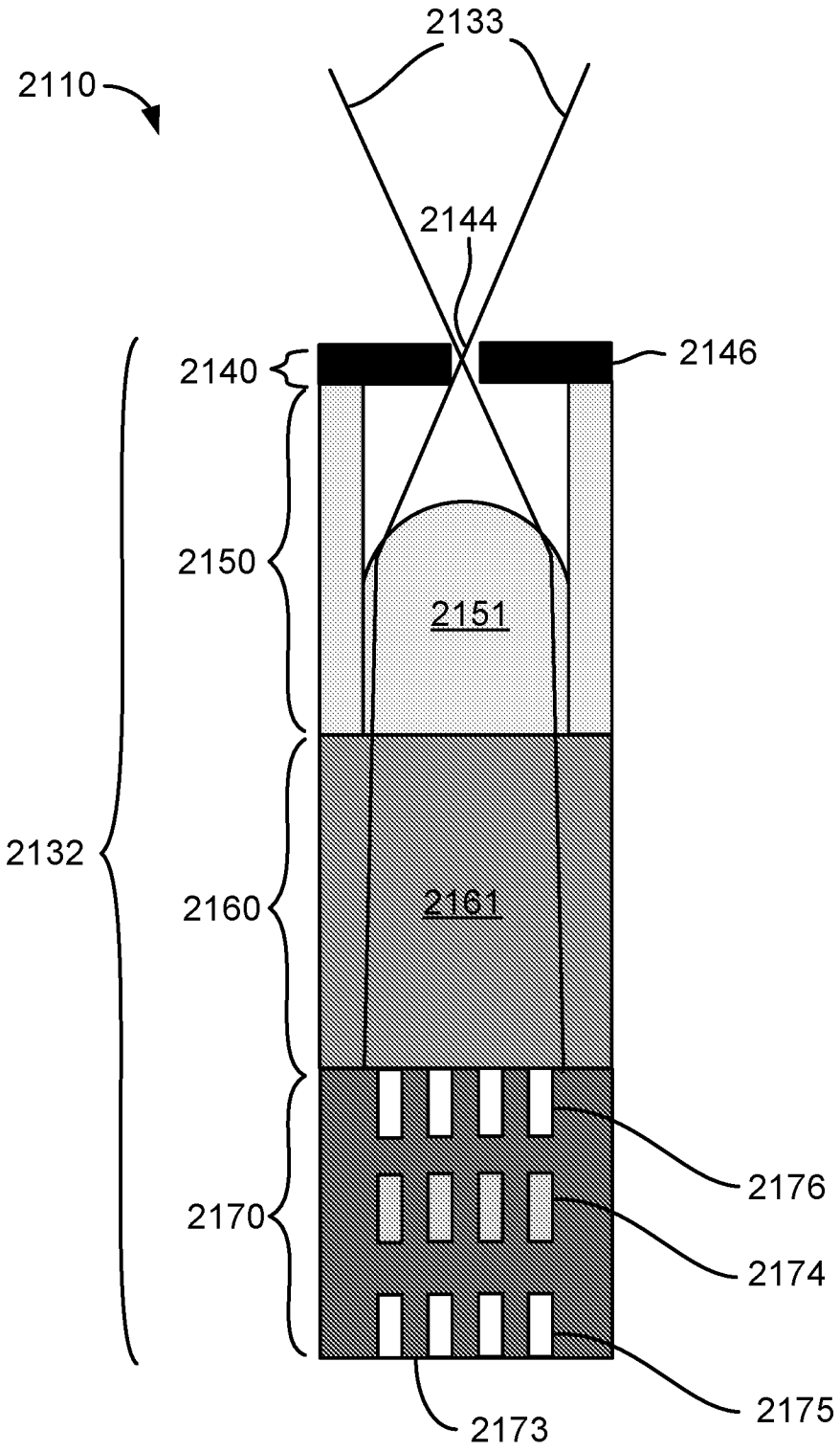

2133
2110
2144
2140
2146
2150
2151
2132
2160
2161
2176
2170
2174
2175
2173

FIG. 21K

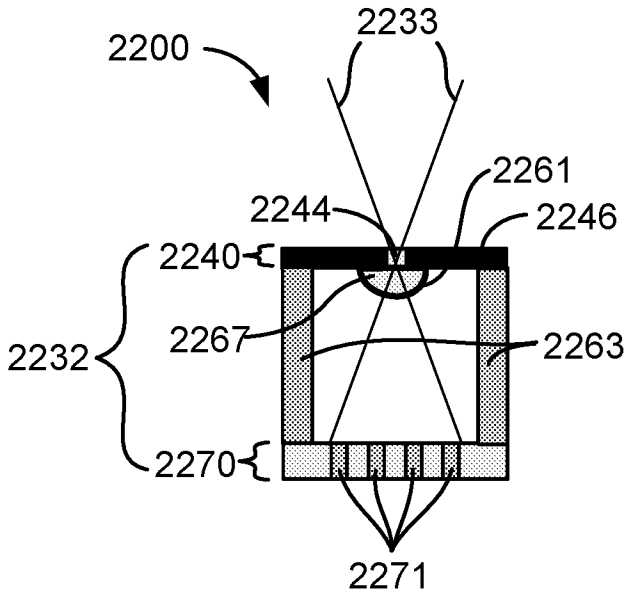


FIG. 22A

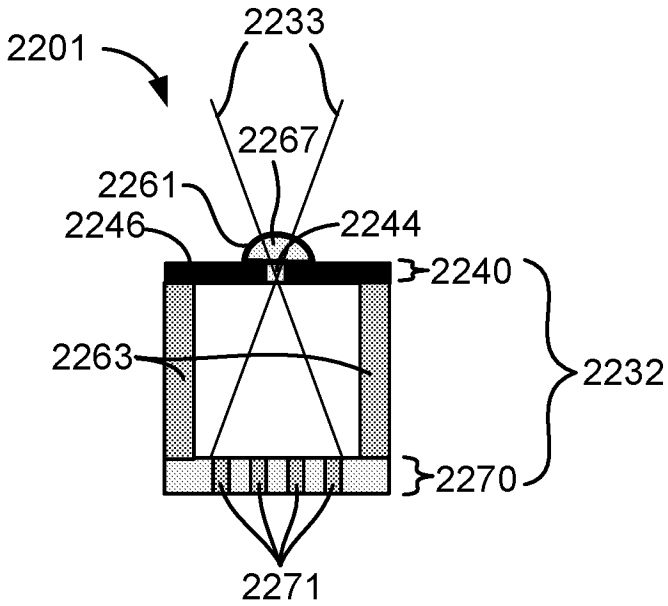


FIG. 22B

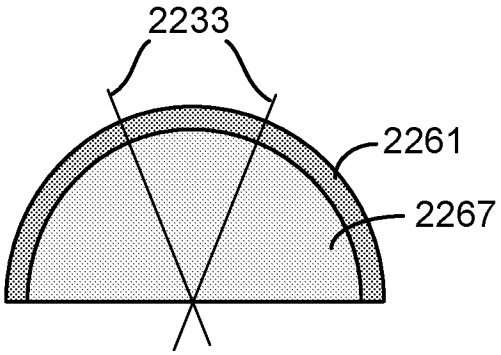


FIG. 22C

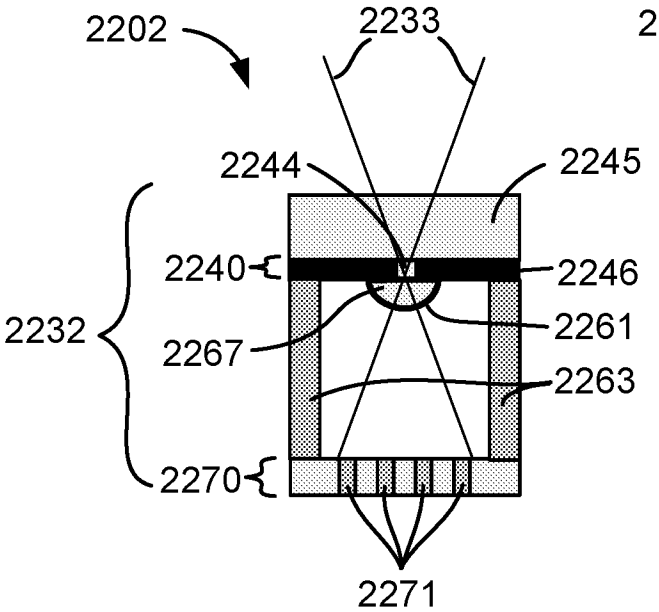


FIG. 22D

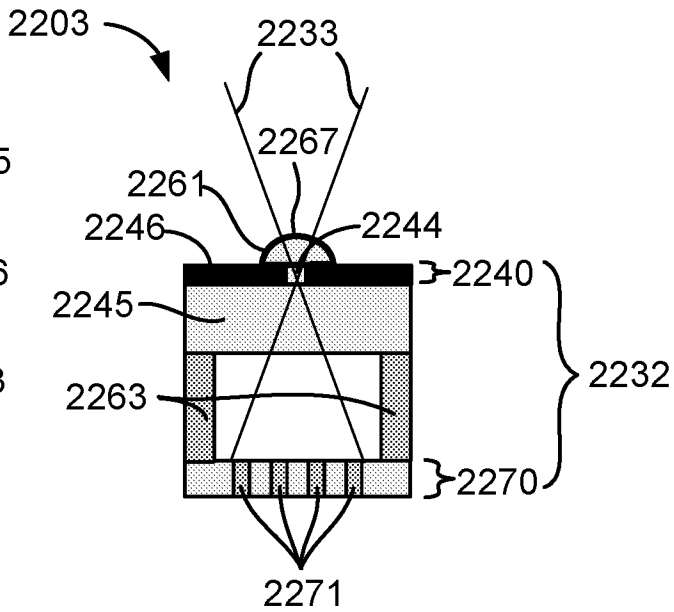


FIG. 22E

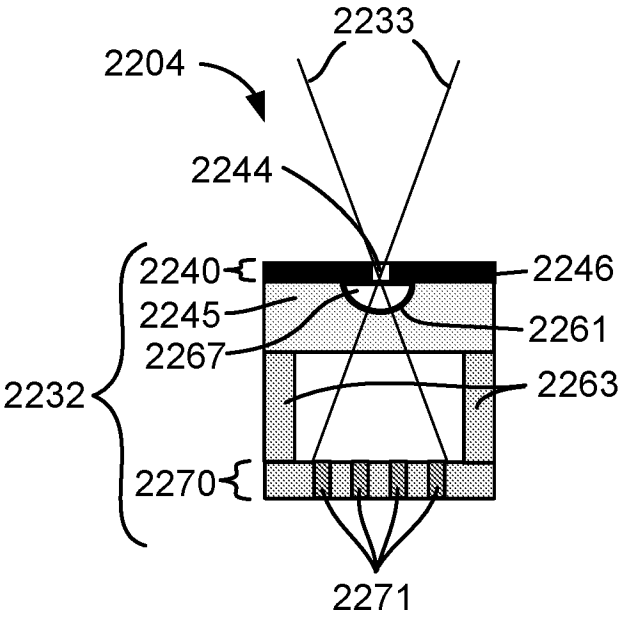


FIG. 22F

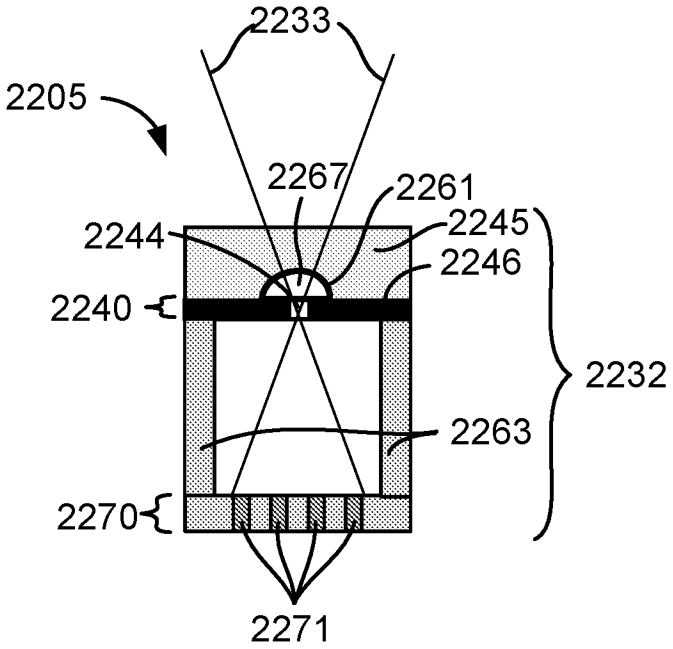


FIG. 22G

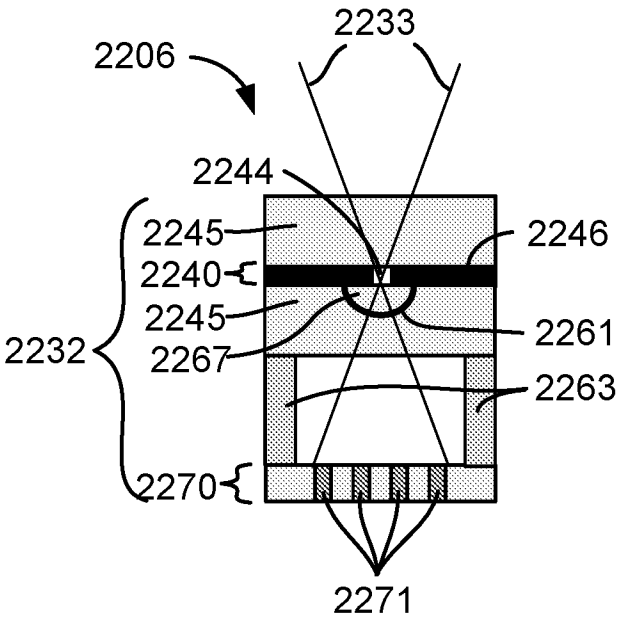


FIG. 22H

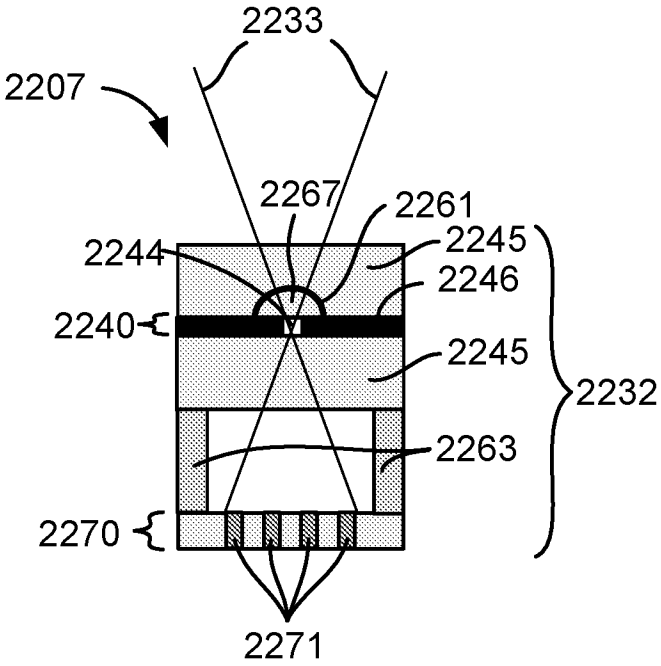


FIG. 22I

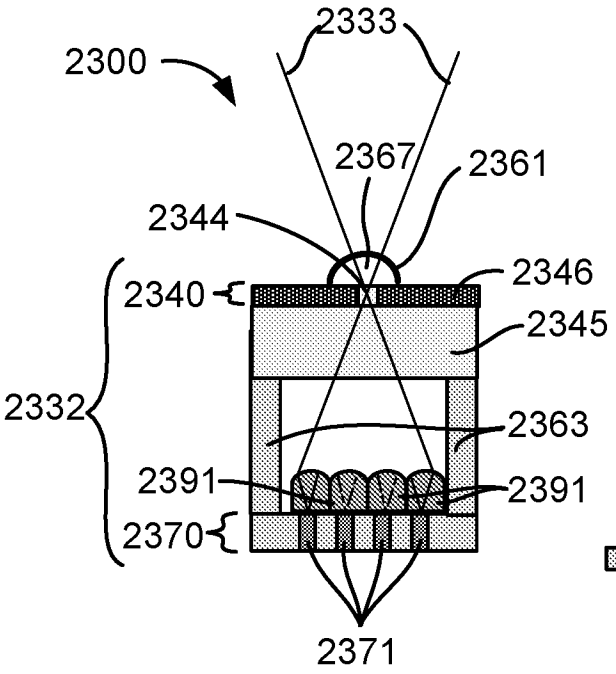


FIG. 23A

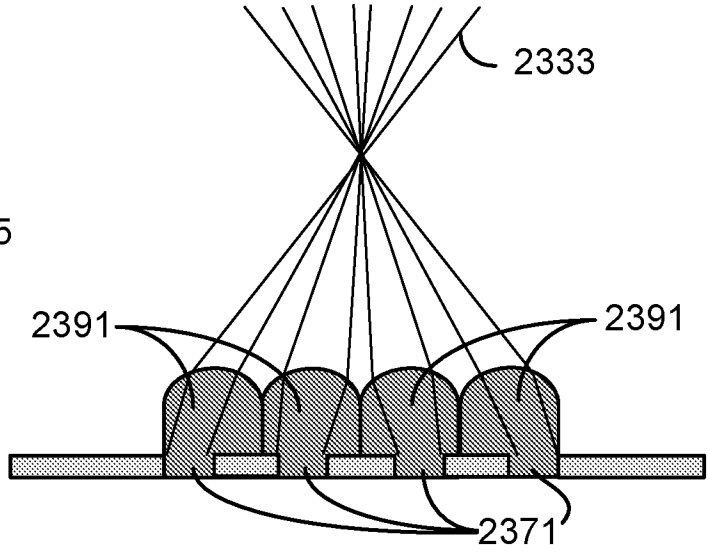


FIG. 23B

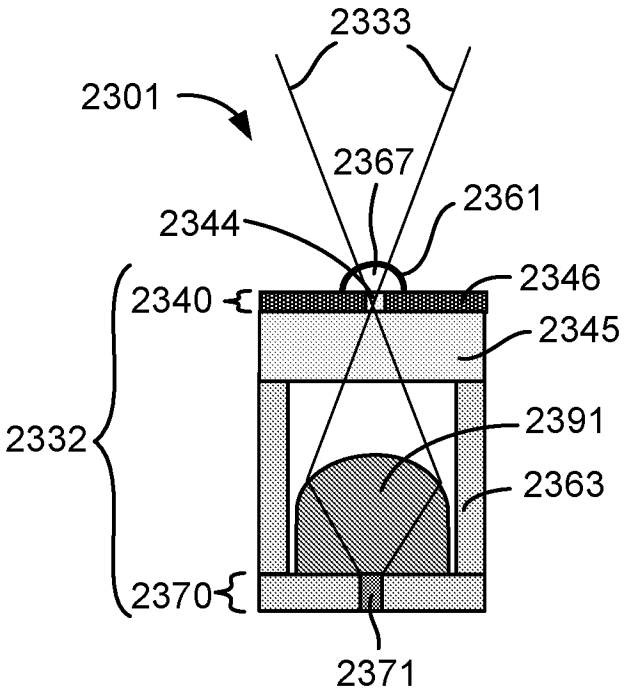


FIG. 23C

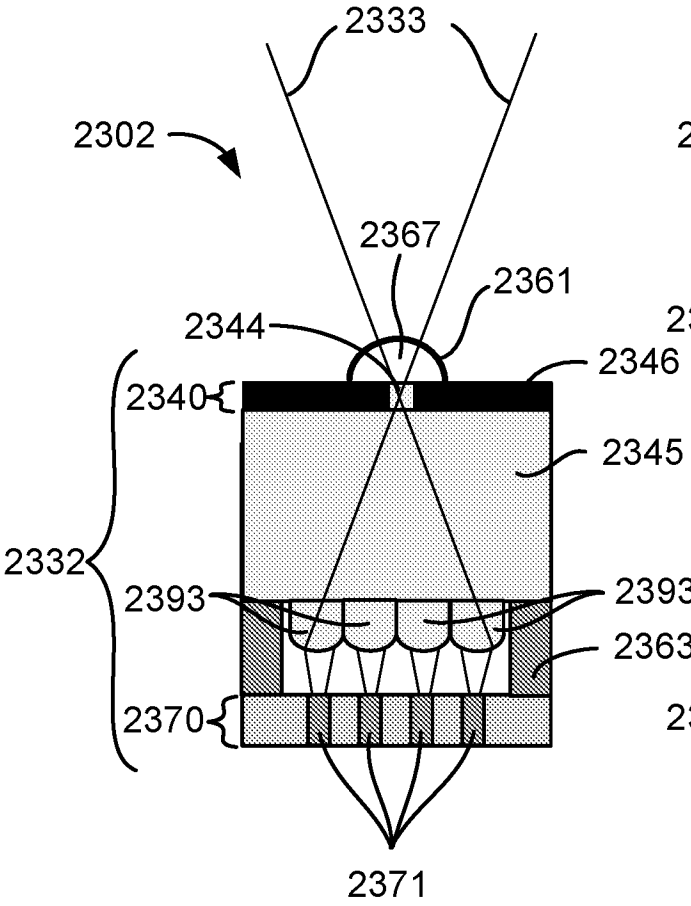


FIG. 23D

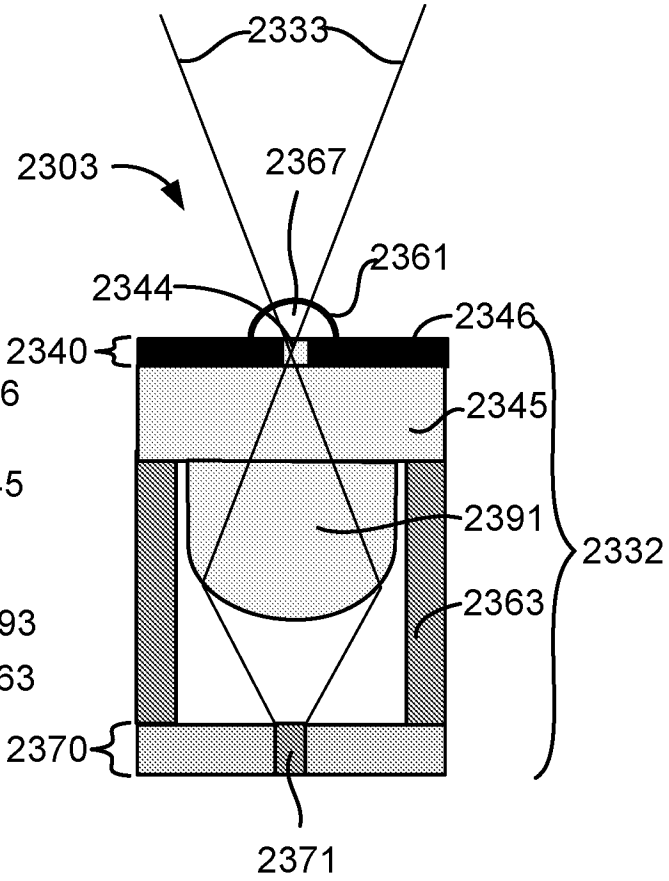


FIG. 23E

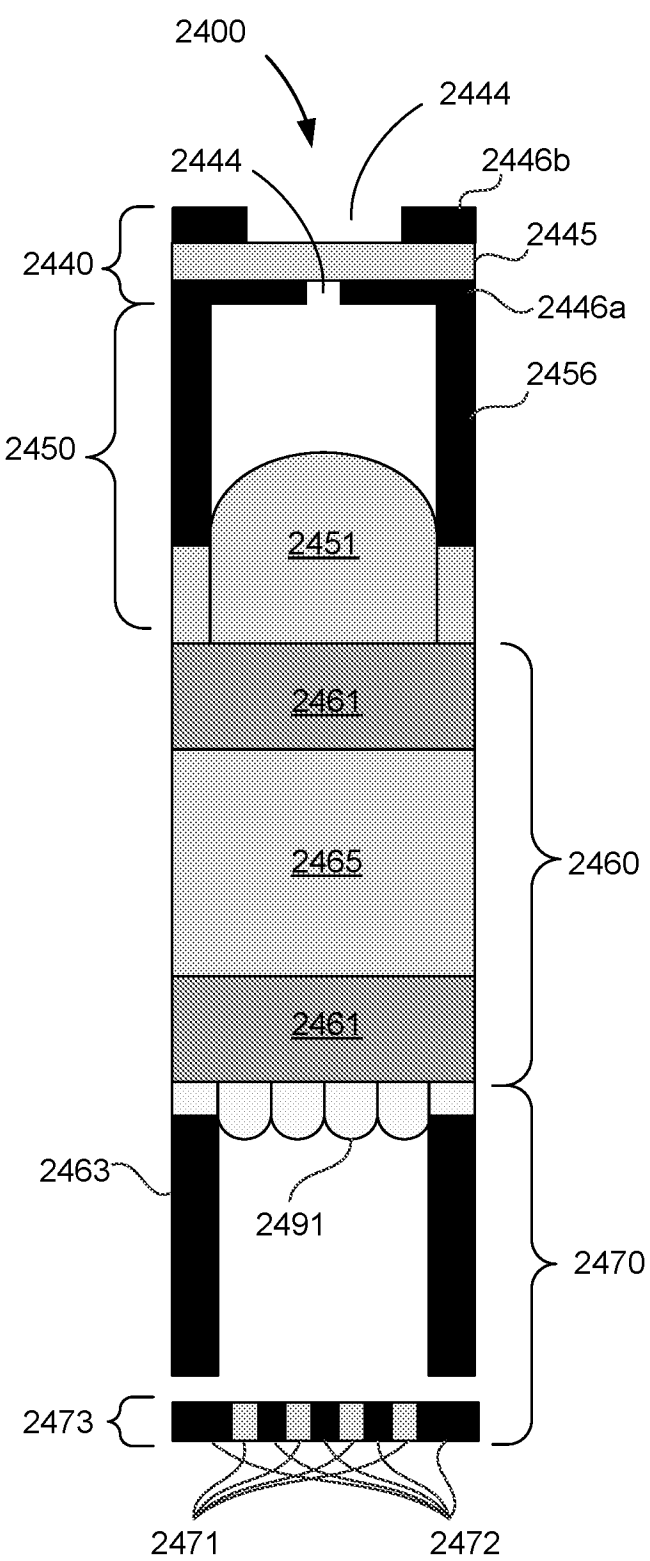

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2444
2446b
2445
2440
2446a
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2461
2465
2460
2461
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2473
2471
2472

FIG. 24

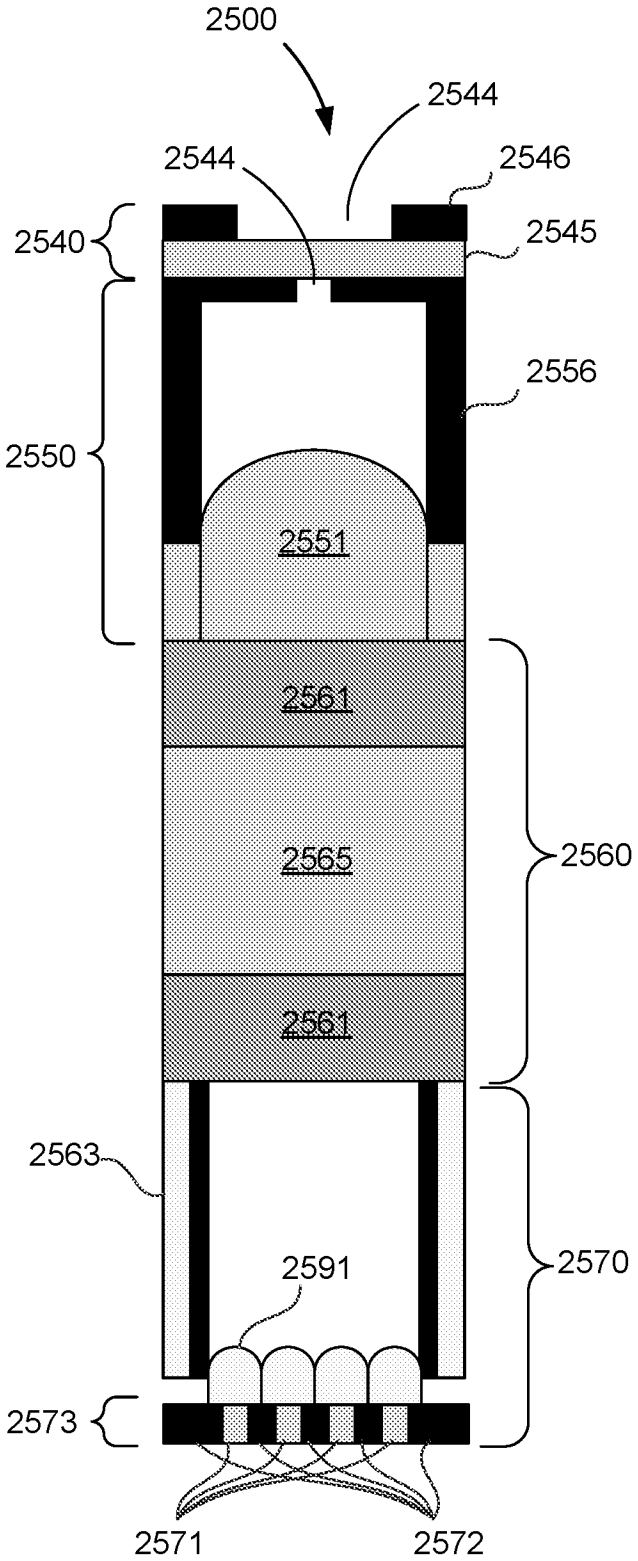

2500
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2540
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2551
2561
2565
2560
2561
2563
2591
2570
2573
2571
2572

FIG. 25

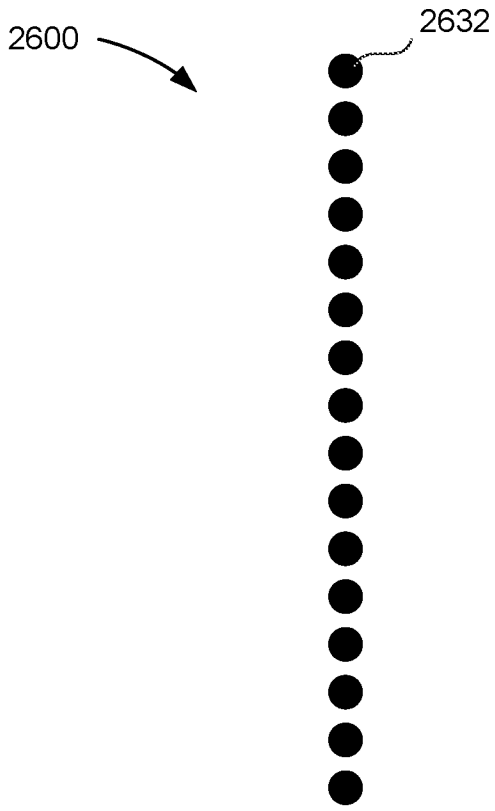


FIG. 26

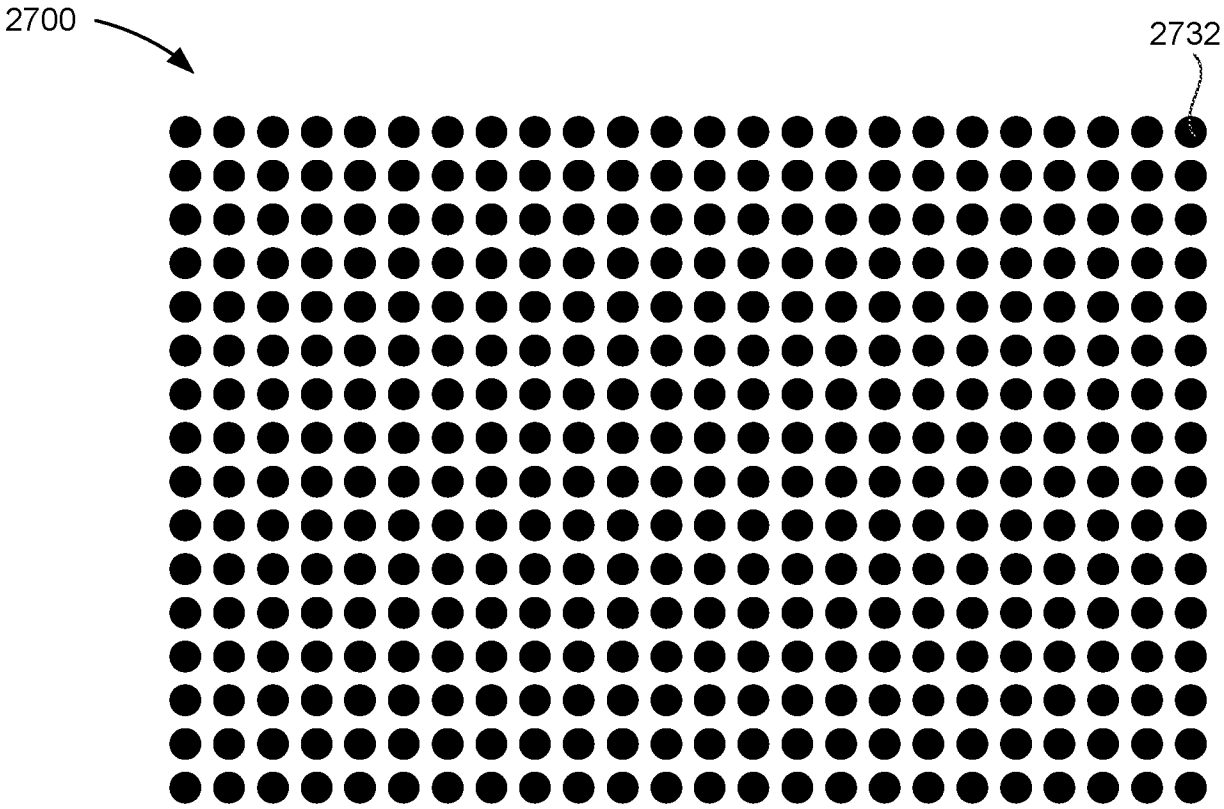


FIG. 27

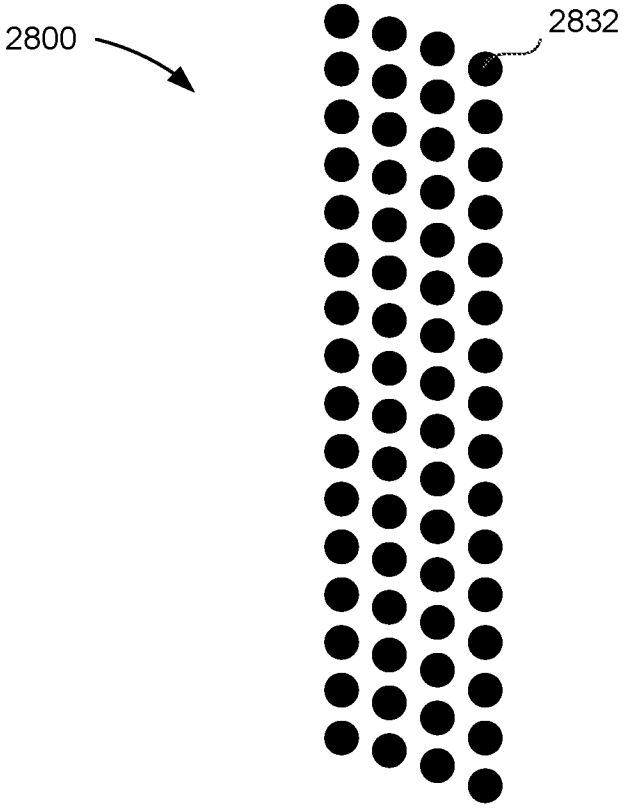


FIG. 28

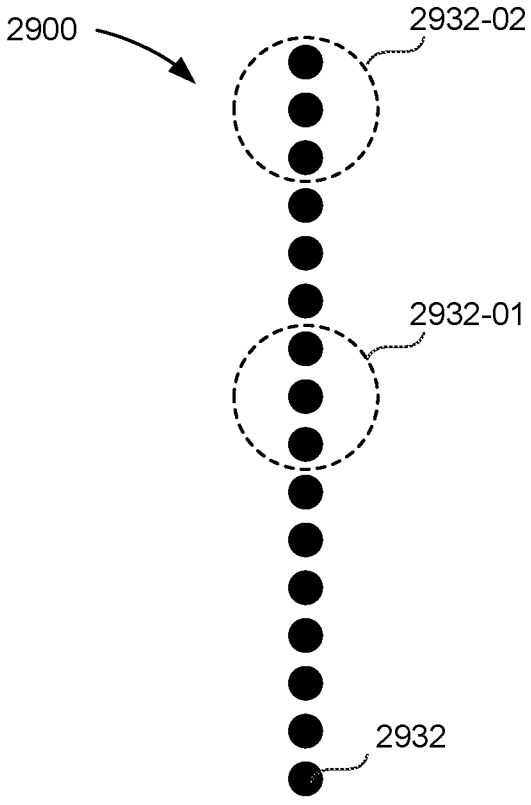


FIG. 29

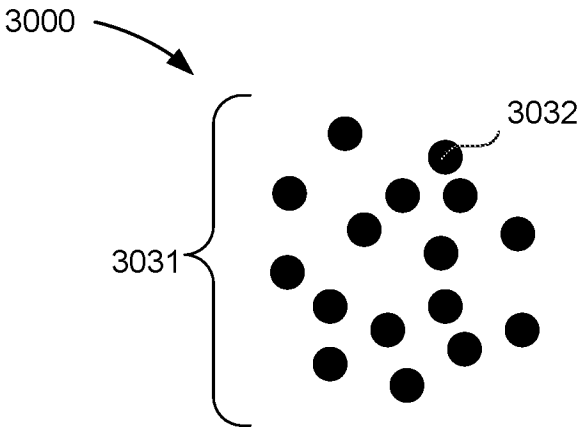


FIG. 30

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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	103033-P006US3-1086284
	Application Number	
Title of Invention	SPINNING LIDAR UNIT WITH MICRO-OPTICS ALIGNED BEHIND STATIONARY WINDOW	

The application data sheet is part of the provisional or nonprovisional application for which it is being submitted. The following form contains the bibliographic data arranged in a format specified by the United States Patent and Trademark Office as outlined in 37 CFR 1.76.
This document may be completed electronically and submitted to the Office in electronic format using the Electronic Filing System (EFS) or the document may be printed and included in a paper filed application.

Secrecy Order 37 CFR 5.2:

☐ Portions or all of the application associated with this Application Data Sheet may fall under a Secrecy Order pursuant to 37 CFR 5.2 (Paper filers only. Applications that fall under Secrecy Order may not be filed electronically.)

Inventor Information:

Inventor 1 Remove

Legal Name

Prefix	Given Name	Middle Name	Family Name	Suffix
	Angus		PACALA	

Residence Information (Select One) ● US Residency Non US Residency Active US Military Service

City	State/Province	Country of Residence
San Francisco	CA	US

Mailing Address of Inventor:

Address 1	2741 16th St
Address 2	

City	State/Province	Postal Code	Country
San Francisco	CA	94103	US

Inventor 2 Remove

Legal Name

Prefix	Given Name	Middle Name	Family Name	Suffix
	Mark		FRICHTL	

Residence Information (Select One) ◉ US Residency Non US Residency Active US Military Service

City	State/Province	Country of Residence
San Francisco	CA	US

Mailing Address of Inventor:

Address 1	2741 16th St
Address 2	

City	State/Province	Postal Code	Country
San Francisco	CA	94103	US

Inventor 3 Remove

Legal Name

Prefix	Given Name	Middle Name	Family Name	Suffix
	Marvin		SHU	

Residence Information (Select One) ◉ US Residency Non US Residency Active US Military Service

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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	103033-P006US3-1086284
	Application Number	
Title of Invention	SPINNING LIDAR UNIT WITH MICRO-OPTICS ALIGNED BEHIND STATIONARY WINDOW	

City	San Francisco	State/Province	CA	Country of Residence	US

Mailing Address of Inventor:

Address 1	2741 16th St		
Address 2			
City	San Francisco	**State/Province**	CA
Postal Code	94103	**Country**	US

All Inventors Must Be Listed - Additional Inventor Information blocks may be generated within this form by selecting the **Add** button. Add

Correspondence Information:

Enter either Customer Number or complete the Correspondence Information section below.
For further information see 37 CFR 1.33(a).

☐ **An Address is being provided for the correspondence Information of this application.**

Customer Number	20350		
Email Address	ipefiling@kilpatricktownsend.com	Add Email	Remove Email

Application Information:

Title of the Invention	SPINNING LIDAR UNIT WITH MICRO-OPTICS ALIGNED BEHIND STATIONARY WINDOW		
Attorney Docket Number	103033-P006US3-1086284	**Small Entity Status Claimed**	☒
Application Type	Nonprovisional		
Subject Matter	Utility		
Total Number of Drawing Sheets (if any)	36	**Suggested Figure for Publication (if any)**	

Filing By Reference:

Only complete this section when filing an application by reference under 35 U.S.C. 111(c) and 37 CFR 1.57(a). Do not complete this section if application papers including a specification and any drawings are being filed. Any domestic benefit or foreign priority information must be provided in the appropriate section(s) below (i.e., "Domestic Benefit/National Stage Information" and "Foreign Priority Information").

For the purposes of a filing date under 37 CFR 1.53(b), the description and any drawings of the present application are replaced by this reference to the previously filed application, subject to conditions and requirements of 37 CFR 1.57(a).

Application number of the previously filed application	Filing date (YYYY-MM-DD)	Intellectual Property Authority or Country

Publication Information:

☐ Request Early Publication (Fee required at time of Request 37 CFR 1.219)

☐ **Request Not to Publish.** I hereby request that the attached application not be published under 35 U.S.C. 122(b) and certify that the invention disclosed in the attached application **has not and will not** be the subject of an application filed in another country, or under a multilateral international agreement, that requires publication at eighteen months after filing.

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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	103033-P006US3-1086284
	Application Number	
Title of Invention	SPINNING LIDAR UNIT WITH MICRO-OPTICS ALIGNED BEHIND STATIONARY WINDOW	

Representative Information:

Representative information should be provided for all practitioners having a power of attorney in the application. Providing this information in the Application Data Sheet does not constitute a power of attorney in the application (see 37 CFR 1.32).
Either enter Customer Number or complete the Representative Name section below. If both sections are completed the customer Number will be used for the Representative Information during processing.

Please Select One:	● Customer Number	US Patent Practitioner	◯ Limited Recognition (37 CFR 11.9)
Customer Number	20350		

Domestic Benefit/National Stage Information:

This section allows for the applicant to either claim benefit under 35 U.S.C. 119(e), 120, 121, 365(c), or 386(c) or indicate National Stage entry from a PCT application. Providing benefit claim information in the Application Data Sheet constitutes the specific reference required by 35 U.S.C. 119(e) or 120, and 37 CFR 1.78.
When referring to the current application, please leave the "Application Number" field blank.

Prior Application Status	Pending		Remove
Application Number	Continuity Type	Prior Application Number	Filing or 371(c) Date (YYYY-MM-DD)
	Claims benefit of provisional	62506449	2017-05-15
Prior Application Status	Pending		Remove
Application Number	Continuity Type	Prior Application Number	Filing or 371(c) Date (YYYY-MM-DD)
	Claims benefit of provisional	62506437	2017-05-15
Prior Application Status	Pending		Remove
Application Number	Continuity Type	Prior Application Number	Filing or 371(c) Date (YYYY-MM-DD)
	Claims benefit of provisional	62506445	2017-05-15
Prior Application Status			Remove
Application Number	Continuity Type	Prior Application Number	Filing or 371(c) Date (YYYY-MM-DD)
	Claims benefit of provisional	62515291	2017-06-05

Additional Domestic Benefit/National Stage Data may be generated within this form by selecting the **Add** button. Add

Foreign Priority Information:

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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	103033-P006US3-1086284
	Application Number	
Title of Invention	SPINNING LIDAR UNIT WITH MICRO-OPTICS ALIGNED BEHIND STATIONARY WINDOW	

This section allows for the applicant to claim priority to a foreign application. Providing this information in the application data sheet constitutes the claim for priority as required by 35 U.S.C. 119(b) and 37 CFR 1.55. When priority is claimed to a foreign application that is eligible for retrieval under the priority document exchange program (PDX)[i] the information will be used by the Office to automatically attempt retrieval pursuant to 37 CFR 1.55(i)(1) and (2). Under the PDX program, applicant bears the ultimate responsibility for ensuring that a copy of the foreign application is received by the Office from the participating foreign intellectual property office, or a certified copy of the foreign priority application is filed, within the time period specified in 37 CFR 1.55(g)(1).

Remove

Application Number	Country[i]	Filing Date (YYYY-MM-DD)	Access Code[i] (if applicable)

Additional Foreign Priority Data may be generated within this form by selecting the **Add** button. Add

Statement under 37 CFR 1.55 or 1.78 for AIA (First Inventor to File) Transition Applications

☐ This application (1) claims priority to or the benefit of an application filed before March 16, 2013 and (2) also contains, or contained at any time, a claim to a claimed invention that has an effective filing date on or after March 16, 2013.
NOTE: By providing this statement under 37 CFR 1.55 or 1.78, this application, with a filing date on or after March 16, 2013, will be examined under the first inventor to file provisions of the AIA.

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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	103033-P006US3-1086284
	Application Number	
Title of Invention	SPINNING LIDAR UNIT WITH MICRO-OPTICS ALIGNED BEHIND STATIONARY WINDOW	

Authorization or Opt-Out of Authorization to Permit Access:

When this Application Data Sheet is properly signed and filed with the application, applicant has provided written authority to permit a participating foreign intellectual property (IP) office access to the instant application-as-filed (see paragraph A in subsection 1 below) and the European Patent Office (EPO) access to any search results from the instant application (see paragraph B in subsection 1 below).

Should applicant choose not to provide an authorization identified in subsection 1 below, applicant **must opt-out** of the authorization by checking the corresponding box A or B or both in subsection 2 below.

NOTE: This section of the Application Data Sheet is **ONLY** reviewed and processed with the **INITIAL** filing of an application. After the initial filing of an application, an Application Data Sheet cannot be used to provide or rescind authorization for access by a foreign IP office(s). Instead, Form PTO/SB/39 or PTO/SB/69 must be used as appropriate.

1. Authorization to Permit Access by a Foreign Intellectual Property Office(s)

A. Priority Document Exchange (PDX) - Unless box A in subsection 2 (opt-out of authorization) is checked, the undersigned hereby **grants the USPTO authority** to provide the European Patent Office (EPO), the Japan Patent Office (JPO), the Korean Intellectual Property Office (KIPO), the State Intellectual Property Office of the People's Republic of China (SIPO), the World Intellectual Property Organization (WIPO), and any other foreign intellectual property office participating with the USPTO in a bilateral or multilateral priority document exchange agreement in which a foreign application claiming priority to the instant patent application is filed, access to: (1) the instant patent application-as-filed and its related bibliographic data, (2) any foreign or domestic application to which priority or benefit is claimed by the instant application and its related bibliographic data, and (3) the date of filing of this Authorization. See 37 CFR 1.14(h)(1).

B. Search Results from U.S. Application to EPO - Unless box B in subsection 2 (opt-out of authorization) is checked, the undersigned hereby **grants the USPTO authority** to provide the EPO access to the bibliographic data and search results from the instant patent application when a European patent application claiming priority to the instant patent application is filed. See 37 CFR 1.14(h)(2).

The applicant is reminded that the EPO's Rule 141(1) EPC (European Patent Convention) requires applicants to submit a copy of search results from the instant application without delay in a European patent application that claims priority to the instant application.

2. Opt-Out of Authorizations to Permit Access by a Foreign Intellectual Property Office(s)

☐ A. Applicant **DOES NOT** authorize the USPTO to permit a participating foreign IP office access to the instant application-as-filed. If this box is checked, the USPTO will not be providing a participating foreign IP office with any documents and information identified in subsection 1A above.

☐ B. Applicant **DOES NOT** authorize the USPTO to transmit to the EPO any search results from the instant patent application. If this box is checked, the USPTO will not be providing the EPO with search results from the instant application.

NOTE: Once the application has published or is otherwise publicly available, the USPTO may provide access to the application in accordance with 37 CFR 1.14.

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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	103033-P006US3-1086284
	Application Number	
Title of Invention	SPINNING LIDAR UNIT WITH MICRO-OPTICS ALIGNED BEHIND STATIONARY WINDOW	

Applicant Information:

Providing assignment information in this section does not substitute for compliance with any requirement of part 3 of Title 37 of CFR to have an assignment recorded by the Office.

Applicant 1 — Remove

If the applicant is the inventor (or the remaining joint inventor or inventors under 37 CFR 1.45), this section should not be completed. The information to be provided in this section is the name and address of the legal representative who is the applicant under 37 CFR 1.43; or the name and address of the assignee, person to whom the inventor is under an obligation to assign the invention, or person who otherwise shows sufficient proprietary interest in the matter who is the applicant under 37 CFR 1.46. If the applicant is an applicant under 37 CFR 1.46 (assignee, person to whom the inventor is obligated to assign, or person who otherwise shows sufficient proprietary interest) together with one or more joint inventors, then the joint inventor or inventors who are also the applicant should be identified in this section.

Clear

● Assignee	Legal Representative under 35 U.S.C. 117	Joint Inventor
Person to whom the inventor is obligated to assign.	Person who shows sufficient proprietary interest	

If applicant is the legal representative, indicate the authority to file the patent application, the inventor is:

Name of the Deceased or Legally Incapacitated Inventor:

If the Applicant is an Organization check here. ☒

Organization Name	Ouster, Inc.		
Mailing Address Information For Applicant:			
Address 1	2741 16th Street		
Address 2			
City	San Francisco	**State/Province**	CA
Country	US	Postal Code	94103
Phone Number		Fax Number	
Email Address			

Additional Applicant Data may be generated within this form by selecting the Add button. Add

Assignee Information including Non-Applicant Assignee Information:

Providing assignment information in this section does not substitute for compliance with any requirement of part 3 of Title 37 of CFR to have an assignment recorded by the Office.

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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	103033-P006US3-1086284
	Application Number	
Title of Invention	SPINNING LIDAR UNIT WITH MICRO-OPTICS ALIGNED BEHIND STATIONARY WINDOW	

Assignee 1

Complete this section if assignee information, including non-applicant assignee information, is desired to be included on the patent application publication. An assignee-applicant identified in the "Applicant Information" section will appear on the patent application publication as an applicant. For an assignee-applicant, complete this section only if identification as an assignee is also desired on the patent application publication.

Remove

If the Assignee or Non-Applicant Assignee is an Organization check here. ☒

Organization Name	Ouster, Inc.

Mailing Address Information For Assignee including Non-Applicant Assignee:

Address 1	2741 16th Street		
Address 2			
City	San Francisco	**State/Province**	CA
Country i	US	Postal Code	94103
Phone Number		Fax Number	
Email Address			

Additional Assignee or Non-Applicant Assignee Data may be generated within this form by selecting the Add button. Add

Signature:

Remove

NOTE: This Application Data Sheet must be signed in accordance with 37 CFR 1.33(b). **However, if this Application Data Sheet is submitted with the INITIAL filing of the application and either box A or B is not checked in subsection 2 of the "Authorization or Opt-Out of Authorization to Permit Access" section, then this form must also be signed in accordance with 37 CFR 1.14(c).**

This Application Data Sheet **must** be signed by a patent practitioner if one or more of the applicants is a **juristic entity** (e.g., corporation or association). If the applicant is two or more joint inventors, this form must be signed by a patent practitioner, **all** joint inventors who are the applicant, or one or more joint inventor-applicants who have been given power of attorney (e.g., see USPTO Form PTO/AIA/81) on behalf of **all** joint inventor-applicants.

See 37 CFR 1.4(d) for the manner of making signatures and certifications.

Signature	/Stephen A. Mao/			Date (YYYY-MM-DD)	2018-05-14
First Name	Stephen	Last Name	Mao	Registration Number	73418

Additional Signature may be generated within this form by selecting the Add button. Add

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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	103033-P006US3-1086284
	Application Number	
Title of Invention	SPINNING LIDAR UNIT WITH MICRO-OPTICS ALIGNED BEHIND STATIONARY WINDOW	

This collection of information is required by 37 CFR 1.76. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 23 minutes to complete, including gathering, preparing, and submitting the completed application data sheet form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

Privacy Act Statement

The Privacy Act of 1974 (P.L. 93-579) requires that you be given certain information in connection with your submission of the attached form related to a patent application or patent. Accordingly, pursuant to the requirements of the Act, please be advised that: (1) the general authority for the collection of this information is 35 U.S.C. 2(b)(2); (2) furnishing of the information solicited is voluntary; and (3) the principal purpose for which the information is used by the U.S. Patent and Trademark Office is to process and/or examine your submission related to a patent application or patent. If you do not furnish the requested information, the U.S. Patent and Trademark Office may not be able to process and/or examine your submission, which may result in termination of proceedings or abandonment of the application or expiration of the patent.

The information provided by you in this form will be subject to the following routine uses:

1 The information on this form will be treated confidentially to the extent allowed under the Freedom of Information Act (5 U.S.C. 552) and the Privacy Act (5 U.S.C. 552a). Records from this system of records may be disclosed to the Department of Justice to determine whether the Freedom of Information Act requires disclosure of these records.

2. A record from this system of records may be disclosed, as a routine use, in the course of presenting evidence to a court, magistrate, or administrative tribunal, including disclosures to opposing counsel in the course of settlement negotiations.

3 A record in this system of records may be disclosed, as a routine use, to a Member of Congress submitting a request involving an individual, to whom the record pertains, when the individual has requested assistance from the Member with respect to the subject matter of the record.

4. A record in this system of records may be disclosed, as a routine use, to a contractor of the Agency having need for the information in order to perform a contract. Recipients of information shall be required to comply with the requirements of the Privacy Act of 1974, as amended, pursuant to 5 U.S.C. 552a(m).

5. A record related to an International Application filed under the Patent Cooperation Treaty in this system of records may be disclosed, as a routine use, to the International Bureau of the World Intellectual Property Organization, pursuant to the Patent CooperationTreaty.

6. A record in this system of records may be disclosed, as a routine use, to another federal agency for purposes of National Security review (35 U.S.C. 181) and for review pursuant to the Atomic Energy Act (42 U.S.C. 218(c)).

7. A record from this system of records may be disclosed, as a routine use, to the Administrator, General Services, or his/her designee, during an inspection of records conducted by GSA as part of that agency's responsibility to recommend improvements in records management practices and programs, under authority of 44 U.S.C. 2904 and 2906. Such disclosure shall be made in accordance with the GSA regulations governing inspection of records for this purpose, and any other relevant (i.e., GSA or Commerce) directive. Such disclosure shall not be used to make determinations about individuals.

8. A record from this system of records may be disclosed, as a routine use, to the public after either publication of the application pursuant to 35 U.S.C. 122(b) or issuance of a patent pursuant to 35 U.S.C. 151. Further, a record may be disclosed, subject to the limitations of 37 CFR 1.14, as a routine use, to the public if the record was filed in an application which became abandoned or in which the proceedings were terminated and which application is referenced by either a published application, an application open to public inspections or an issued patent.

9. A record from this system of records may be disclosed, as a routine use, to a Federal, State, or local law enforcement agency, if the USPTO becomes aware of a violation or potential violation of law or regulation.

Electronic Patent Application Fee Transmittal

Application Number:	
Filing Date:	
Title of Invention:	SPINNING LIDAR UNIT WITH MICRO-OPTICS ALIGNED BEHIND STATIONARY WINDOW
First Named Inventor/Applicant Name:	ANGUS PACALA
Filer:	Stephen A. Mao/Larenda Meyer
Attorney Docket Number:	103033-P006US3-1086284

Filed as Small Entity

Filing Fees for Utility under 35 USC 111(a)

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Basic Filing:				
UTILITY FILING FEE (ELECTRONIC FILING)	4011	1	75	75
UTILITY SEARCH FEE	2111	1	330	330
UTILITY EXAMINATION FEE	2311	1	380	380
Pages:				
Claims:				
Miscellaneous-Filing:				
LATE FILING FEE FOR OATH OR DECLARATION	2051	1	80	80
Petition:				

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Patent-Appeals-and-Interference:				
Post-Allowance-and-Post-Issuance:				
Extension-of-Time:				
Miscellaneous:				
		Total in USD ($)		**865**

Electronic Acknowledgement Receipt

EFS ID:	32620821
Application Number:	15979266
International Application Number:	
Confirmation Number:	9761
Title of Invention:	SPINNING LIDAR UNIT WITH MICRO-OPTICS ALIGNED BEHIND STATIONARY WINDOW
First Named Inventor/Applicant Name:	ANGUS PACALA
Customer Number:	20350
Filer:	Stephen A. Mao/Larenda Meyer
Filer Authorized By:	Stephen A. Mao
Attorney Docket Number:	103033-P006US3-1086284
Receipt Date:	14-MAY-2018
Filing Date:	
Time Stamp:	19:17:17
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	yes
Payment Type	CARD
Payment was successfully received in RAM	$865
RAM confirmation Number	051518INTEFSW19174800
Deposit Account	201430
Authorized User	IP eFiling

The Director of the USPTO is hereby authorized to charge indicated fees and credit any overpayment as follows:

37 CFR 1.16 (National application filing, search, and examination fees)

37 CFR 1.17 (Patent application and reexamination processing fees)

37 CFR 1.19 (Document supply fees)

37 CFR 1.20 (Post Issuance fees)

37 CFR 1.21 (Miscellaneous fees and charges)

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1		Nonprovisional_App_P006US3-1086284.pdf	390730 52fa28b488b72aefb09d082d593fdf478578a6e2	yes	84

Multipart Description/PDF files in .zip description		
Document Description	**Start**	**End**
Specification	1	78
Claims	79	83
Abstract	84	84

Warnings:					
Information:					
2	Drawings-only black and white line drawings	Drawings_1086284.pdf	384076 09f93c10bf2eefcf15f0ff6e782ade7975a94055	no	36
Warnings:					
Information:					
3	Application Data Sheet	ADS_P006US3-1086284.pdf	1792620 deb9751671cbca9ba05ee1ee2cb745bbe1f81b29	no	9
Warnings:					
Information:					
4	Fee Worksheet (SB06)	fee-info.pdf	36828 58b292d7b8dac1d98effc1df8f8a52a5748547c1	no	2
Warnings:					
Information:					
		Total Files Size (in bytes):	2604254		

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New Applications Under 35 U.S.C. 111

If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

National Stage of an International Application under 35 U.S.C. 371

If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office

If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

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