

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

Samsung Electronics Co., Ltd.,
Petitioner,

v.

SiOnyx, LLC,
Patent Owner.

Case No. IPR2025-00161
Patent No. 11,721,714

**DECLARATION OF MICHAEL LEBBY IN SUPPORT OF PETITION FOR
INTER PARTES REVIEW OF U.S. PATENT NO. 11,721,714**

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I. INTRODUCTION

1. I, Michael Lebby, declare as follows.

2. I have been retained as a technical consultant on behalf of Samsung Electronics Co., Ltd., (“Samsung” or “Petitioner”), which I understand to be the petitioner in the present proceeding. I have been asked to consider whether the references listed as Exhibits 1005-1013 below disclose or render obvious the limitations recited in claims 1-18 of U.S. Patent No. 11,721,714 (Ex-1001, “’714 patent”). I have also been asked to consider the state of the art and the “prior art,” i.e., references, available before the time of the alleged invention of the ’714 patent. My opinions are provided in this declaration.

3. I am being compensated at my standard consulting rate for my time. My compensation is in no way contingent on the results of these or any other proceedings relating to the ’714 patent.

II. BACKGROUND AND QUALIFICATIONS

4. A description of my professional background and qualifications is provided below. An additional account of my work experience and qualifications is included in my *curriculum vitae*, which is Ex-1004 (“CV”).

5. I am currently the CEO and CTO at GenusTechnik Inc., which provides consulting services in areas that include image sensors, photonics, optoelectronics, semiconductors as used in image sensors and other optical applications.

6. In addition, I am currently the Chairman, CEO, and Director of the Board of Directors for Lightwave Logic. As CEO, I successfully guided Lightwave Logic to up-list to NASDAQ in September 2021 organically (i.e., without the raising of financing), and I led the company to acceptance in the Russell 3000 index in 2022.

7. I have led and run optoelectronics start-ups, and I have commercialized optoelectronic and photonics technologies into volume manufacturing. I have also worked as a Corporate Venture Capitalist specializing in optical communications, photonics, sensing, electronics, and semiconductors, and I am currently a technical expert advising the European Commission regarding evaluation of numerous photonic technology proposals, including image sensor proposals. I am a Fellow Member of the National Academy of Inventors (NAI), the IEEE, and Optica (OSA), and I was voted Photonic Integrated Circuit (PIC) business leader of the year by the PIC International Conference in 2018.

8. In particular, my technical expertise has included the design of components for photonics technology that can source light as well as receive and detect light. These components include LEDs, ICs, lasers, photodetectors, diodes, image sensors, etc. In many of my industrial and commercial roles in the photonics industry I have used, designed, optimized, and improved photonic materials, components, and packages both through solutions of engineering problems as well as patents and publications.

9. Over the course of my career in photonics, optoelectronics, and optical technology in general, I have worked in nearly every aspect of the field, including optical assembly, laser diodes, photodetectors, image sensors, LEDs, integrated circuits (e.g. drivers, and other basic electronic digital and analog functions), as well as fiber optics. In particular, I have designed optoelectronic devices such as LEDs, laser diodes (VCSELs – vertical cavity surface emitting lasers), photodiodes, image sensors, and solar cells with a focus on efficient optical device design that maximizes device performance. For example, I have worked on improving light extraction efficiency in laser diodes as well as LEDs, where these devices are utilized in modules. I have also worked on arrays of detectors for sensing applications.

10. I started my career in 1977 at the Ministry of Defense (United Kingdom), in the Royal Electrical and Mechanical Engineers as a telecommunications apprentice. At the Ministry of Defense, I studied material and characterization issues relating to Gallium Arsenide (GaAs) and Indium Phosphide (InP) optoelectronic devices, as well as semiconductor device design, fabrication, and characterization, particularly with materials using III-V semiconductors. I also worked with silicon for integrated circuits, silicon photonics, and ceramic-based radio-frequency (RF) electronic packaging that included low-temperature co-fired ceramic. These devices and materials were utilized in photonic-based transceiver packages and modules. I also worked on electronics, motors, sensors, and other technologies that combined photonics with electronics.

11. I attended the University of Bradford, where I obtained a Bachelor's of Engineering (Electrical Engineering), with honors, in 1984, an MBA in 1985 and a Ph.D. (Electrical Engineering) in 1987. My Ph.D. thesis related to the characterization and fabrication of both optoelectronic and electronic semiconductor devices that included the detection of light. In 2004, I was awarded a Doctor of Engineering (a Doctorate degree higher than a Ph.D.) from the University of Bradford for my "Technical Contributions to Optoelectronics." This was only the second time in the University of Bradford's history that a Doctor of Engineering was granted based on industry experience.

12. While attending the University of Bradford and for a few years thereafter, i.e., from 1985 to 1989, I worked as a researcher in the Photonics Research Department of AT&T Bell Labs ("Bell Labs"). At Bell Labs, I focused my research on novel device designs using III-V semiconductor material systems including FETs, bipolar transistors, LEDs, laser diodes, and photodetectors. My research at Bell Labs became the subject of my Ph.D. thesis.

13. After completing my Ph.D. at the University of Bradford and my work at Bell Labs, I became a Research and Development Manager ("R&D Manager") in the photonics division of Motorola's Corporate R&D Labs ("Motorola"). I worked at Motorola from 1989 to 1998, where my responsibilities included research and development in optical interconnects, electrical and fiber optic connectors,

optical/electrical engines, electronic ICs, displays, laser devices, LEDs, optical lenses, image sensors, and optical waveguides, as well as the packaging and reliability of mobile product prototypes. Some of the prototypes on which I worked included moving parts with motors (both standard as well as semiconductor MEMs based), and phased array optical beams that could direct and re-direct optical beams. While at Motorola, I was the inventor or co-inventor on over 150 utility patents, and I received a special award from the Chairman of Motorola in 1998 for exemplary patent accomplishments. At that time, I had the highest number of issued utility patents in the history of Motorola.

14. As an R&D Manager at Motorola, I initiated Motorola's work in optical interconnect technology (known at Motorola as "Optobus"™) and associated optical connectors, electronics, and photonics components, and I was also involved in research and development on the IC chip designs that this parallel interconnect module utilized. In this project, transparent plastics were developed and molded onto standard metallic lead frames for both light-emitting devices (e.g., LEDs, VCSELs) and photodetectors, which collect light and convert it into an electronic signal. These transparent lead frame packages were developed in volume production at Motorola. I also worked on various techniques to improve both photonics based detectors such as photodetectors, image sensors as well as photonics based emitters such as lasers and LEDs, both as individual components as well as in arrays of multiple components.

15. In 1998, I left Motorola to join TE Connectivity (previously Tyco Electronics) as Director of Technology and Business Development. In that role, I helped develop technology strategy for optical communications, optoelectronic transceivers, and fiber optic connector and adapter products for the Global Optoelectronics Division. My work included designing and characterizing photodetectors, sensors, LEDs, laser-based photonic packages and modules for product manufacturing.

16. In 1999, I joined Intel Capital (“Intel”) as Director of Business Development and as a corporate investor. My work at Intel included sourcing, negotiating, and closing private placement equity deals in the optical networking, photonic component, interconnect, optical lens, image sensor, and semiconductor industries. My work at Intel also included investigating the investment of Intel Capital equity in photonic devices, optical beams, and other technologies to support the physical movement of optical signals. I also was one of the founders of Intel’s silicon photonics division, which worked to establish a fabrication facility in South San Jose to investigate silicon based image sensors and the integration of silicon FET electronics with optoelectronics into the same silicon semiconductor wafer.

17. From 2005 to 2010, I served as the Executive Director, President, and CEO of the Optoelectronic Industry Development Association (OIDA) – a trade association that represented photonics manufacturers in the fields of photonic sensing,

fiber optics, display, defense, aerospace, LED lighting and automotive/motor vehicles. I was responsible for organizing technical conferences, workshops and forecasts using industry roadmaps, all of which featured a portfolio of photonics technology that included: optical sensors, free-space optics, optical interconnects, fiber optics, optical communications, automotive photonic technologies, wavelength division multiplexing, LEDs, displays and their associated packaging.

18. In 2010, I became the General Manager and CTO of Translucent, Inc., a start-up company that developed and manufactured silicon and rare earth oxide-based epitaxial semiconductor wafers.

19. I was employed by Glyndŵr University from 2013 to 2015 as a Professor of Optoelectronics, where I focused on the design, simulation, and testing of high-speed, low-power photonic integrated circuits, optoelectronic integrated circuits, laser diodes, optics, and solar cells for applications that included communications, automotive, displays, sensing, and energy.

20. From 2013 to 2015, I was also employed as the President and CEO of OneChip Photonics Corporation, where I additionally served as an elected independent board member. In these roles, I focused on technical, business, and operational strategy for fiber optic communications based on InP photonic integrated circuits, as well as optoelectronic integrated circuits for fiber optic transceivers that incorporated electrical and optical multiplexing schemes using fiber optic connectors.

21. Over the course of my career, I have also led panels and given numerous keynote and invited presentations, speeches, and talks at workshops and conferences, including on photonic and optoelectronic materials, devices, components, packages as well as photonics technology in general.

22. Due to my passion for optics, I have been elected to the London Guild of Spectacle Makers. A more detailed description of my education, as well as my training and experience in the relevant technology, is included in my CV.

23. I hold over 340 combined issued USPTO patents and USPTO published patent applications that have been derived from over 230 issued U.S. utility patents, mostly in the field of optoelectronics, photonics, electronics, and semiconductors. I have been cited by the USPTO to be in the most prolific seventy-five inventors in the United States from 1988 to 1997.

24. I have authored approximately sixty-five (65) publications, and have achieved over 400 media events that include: technical articles, books, chapters, invited speaker events at conferences as well as for interviews that included TV, video, radio, and social, industrial, professional media in general. This includes technical, business-related, and financial conferences as a contributed, invited, and keynote speaker. Details can be found in my CV. Over the past decade, I have been a project reviewer and technical expert for the European Commission on numerous occasions.

25. I have also served as an expert witness on numerous patent matters, including 50 IPR proceedings and 5 PGR proceedings. I have also served on over 60 oral depositions that include ITC and District court proceedings.

26. A complete listing of these patents, publications, articles, lectures, and other public media is included with my CV.

27. On the basis of my education and the experience described above, I believe I am qualified to give the opinions set out herein.

III. MATERIALS REVIEWED

28. I am not an attorney and offer no legal opinions, but in my work, I have had experience studying and analyzing patents and patent claims from the perspective of a person skilled in the art. *See* Section VI.B below for the level of ordinary skill in the art for this declaration.

29. In preparing this declaration, I reviewed the '714 patent, including the claims of the patent in view of the specification, and I have reviewed the prosecution history of the '714 patent and numerous publications and technical references from and preceding the time of the alleged invention. More specifically, I have reviewed each of the following:

Exhibit	Description
1001	U.S. Patent No. 11,721,714 (the "'714 patent")
1002	File History for U.S. Patent No. 11,721,714
1005	U.S. Patent No. 7,675,099 (Hwang)
1006	Japanese Patent Application Publication No. 2011-119558 (Mori)

Exhibit	Description
1007	Certified English Translation of Japanese Patent Application Publication No. 2011-119558 (Mori)
1008	U.S. Patent No. 7,285,808 (Kasuga)
1009	U.S. Patent Application Publication No. 2009/0160000 (Kim)
1010	U.S. Patent No. 7,709,775 (Konno)
1011	Japanese Patent Application Publication No. 2009-188316 (Yamada)
1012	Certified English Translation of Japanese Patent Application Publication No. 2009-188316 (Yamada)
1013	E. Fred Schubert, <i>Light-Emitting Diodes</i> (2nd ed. 2006)
1014	Samsung's Proposed Constructions, Inv. No. 337-TA-1403 (Aug. 27, 2024)
1015	SiOnyx's Proposed Constructions, Inv. No. 337-TA-1403 (Aug. 27, 2024)
1016	Email from N. Subhedar re: Claim Construction M&C Follow-Up (Sept. 8, 2024)
1017	Joint Proposed Claim Construction Chart, Inv. No. 337-TA-1403 (Nov. 1, 2024)
1018	Stanley Wolf, MICROCHIP MANUFACTURING (2004) (Excerpts)
1019	U.S. Patent Application Publication No. 2012/0025199
1020	U.S. Patent No. 8,288,836
1021	Sadao Adachi, Optical Constants of Crystalline and Amorphous Semiconductors, Numerical Data and Graphical Information (1st Ed. 1999) (Excerpt)
1022	U.S. Patent No. 4,644,553
1023	George Hass & Calvin D. Salzberg, <i>Optical Properties of Silicon Monoxide in the Wavelength Region from 0.24 to 14.0 Microns</i> , Vol. 44 No. 3, JOURNAL OF THE OPTICAL SOCIETY OF AM., 181 (1954)
1024	F. Lopez & E. Bernabéu, <i>Refractive Index of Vacuum-Evaporated SiO Thin Films: Dependence on Substrate Temperature</i> , ELECTRONICS & OPTICS, 13 (1990)

IV. RELEVANT LEGAL STANDARDS

30. I am not an attorney. For the purposes of this declaration, I have been informed about certain aspects of the law that are relevant to forming my opinions. I have applied the following understanding of the law.

31. I have been informed that a patent claim may be “anticipated” if each element of that claim is present either explicitly or inherently in a single prior art reference, and that the elements should be arranged in the reference as in the claim. Petitioner’s counsel has informed me that for a claimed limitation to be inherently present, the prior art need not expressly disclose the limitation, so long as the claimed limitation necessarily flows from a disclosure in the prior art.

32. I have been informed that a patent claim can be considered to have been obvious to a person of ordinary skill in the art at the time the application was filed. This means that, even if all of the requirements of a claim are not found in a single prior art reference, the claim is not patentable if the differences between the subject matter in the prior art and the subject matter in the claim would have been obvious to a person of ordinary skill in the art at the time the application was filed.

33. I have been informed that a determination of whether a claim would have been obvious should be based upon several factors, including, among others:

- the level of ordinary skill in the art at the time the application was filed;
- the scope and content of the prior art; and
- what differences, if any, existed between the claimed invention and the prior art.

34. I have been informed that a single reference can render a patent claim obvious if any differences between that reference and the claims would have been obvious to a person of ordinary skill in the art. Alternatively, the teachings of two or more references may be combined in the same way as disclosed in the claims, if such a combination would have been obvious to one having ordinary skill in the art. In determining whether a combination based on either a single reference or multiple references would have been obvious, it is appropriate to consider, among other factors:

- whether the teachings of the prior art references disclose known concepts combined in familiar ways, and when combined, would yield predictable results;
- whether a person of ordinary skill in the art could implement a predictable variation, and would see the benefit of doing so;
- whether the claimed elements represent one of a limited number of known design choices, and would have a reasonable expectation of success by those skilled in the art;
- whether a person of ordinary skill would have recognized a reason to combine known elements in the manner described in the claim;
- whether there is some teaching or suggestion in the prior art to make the modification or combination of elements claimed in the patent; and

- whether the innovation applies a known technique that had been used to improve a similar device or method in a similar way.

35. Petitioner's counsel has informed me that one of ordinary skill in the art has ordinary creativity and is not an automaton. Petitioner's counsel has informed me that in considering obviousness, it is important not to determine obviousness using the benefit of hindsight derived from the patent being considered.

36. I understand that various objective or "real world" factors may be indicative of non-obviousness. I understand that such factors include:¹

- the commercial success of the claimed invention;
- the existence of a long-felt, unresolved need for a solution to the problem solved by the claimed invention;
- failed attempts to solve the problem solved by the claimed invention;
- copying of the claimed invention;
- unexpected results of the claimed invention;
- praise for the claimed invention by others in the relevant field; and

¹ I am not aware of any objective evidence of non-obviousness having been identified in connection with the '714 patent.

- willingness of others to accept a license under the patent because of the merits of the claimed invention.

V. TECHNOLOGY BACKGROUND

37. Since the early 2000s, digital cameras and camcorders have become increasingly popular, largely due to the development of advanced image sensors. These sensors play a critical role in converting visual information into electrical signals, which are then processed to create digital images or videos. At the heart of an image sensor lies an array of light-sensitive pixels, each of which is a photodiode capable of detecting light. The photodiode's function is to convert incoming light photons into electrons; the quantity of electrons collected at each pixel determines the pixel's brightness. By assembling this data across all pixels, the sensor constructs a coherent image or video corresponding to the captured scene.

38. In an ideal scenario, an image sensor would achieve perfect efficiency, converting every photon that strikes it into a collected electron. However, in practice, some photons are lost during the conversion process. The efficiency of this conversion is quantified by a metric known as external quantum efficiency, or quantum efficiency for short. The '714 patent defines quantum efficiency as the ratio of electrons collected per photons incident on an optoelectronic device. '714 Patent, 4:31-36. Some incident photons may be lost because they are reflected off before reaching the semiconductor layer including a photodiode; others may be lost because they pass through the

semiconductor layer without being absorbed. To mitigate such losses, it is common practice to include in an image sensor microstructures that let more light into the semiconductor layer including a photodiode, as well as microstructures that reflect and scatter light that leaves the semiconductor layer back into the semiconductor layer.

39. One such well-known form of reflector is what is known as a distributed Bragg reflector (“DBR”), which is a structure formed by alternating materials with different refractive indices. Because of the different refractive indices of the layers, each layer boundary causes a partial reflection of light, and increasing the number of layers can thereby increase reflectivity. Schubert, 171. Distributed Bragg reflectors are known to be “well suited for inclusion between the substrate and the active layers” in semiconductor-based optical structures such as LEDs and optical sensors. *See* Schubert, 170.

40. Photodiodes are typically fabricated by doping a semiconductor layer to create a junction, which is used for sensing light. A photodiode junction is then connected to a neighboring metallization layer, which carries the electrical signal to external circuits that integrate the signals from all pixels to form a complete image. In the design of image sensors, the side of the semiconductor layer where the photodiode junction and the metallization layer are located is referred to as the “front side,” while the opposite side is known as the “backside.” Image sensors can be designed to receive

light from either the front side (front side illuminated, or FSI) or the backside (backside illuminated, or BSI), each offering different advantages and trade-offs.

41. Front side illuminated sensors are easier and less costly to manufacture, but they suffer from greater light loss because the incident light must pass through the metallization layer before reaching the photodiode junction. This can reduce the sensor's overall efficiency and image quality, especially in low-light conditions. Conversely, backside illuminated sensors are more challenging and expensive to produce but offer superior performance because the incident light directly reaches the photodiode junction without passing through the metallization layer. This design reduces light loss and improves the sensor's quantum efficiency, leading to better image quality, particularly in demanding lighting environments.

VI. OVERVIEW OF U.S. PATENT NO. 11,721,714

A. Summary

42. The '714 patent relates to image sensor pixels and elements for trapping light within such pixels. '714 patent, 6:16-20. The patent states that a reduction in the size of pixels in an image sensor can sacrifice image quality. '714 patent, 1:26-28. According to the patent, reduced pixel size for image sensors tends to increase electrical and optical cross-talk between adjacent pixels, and image signal to noise tends to decrease. '714 patent, 1:29-30. The patent purportedly provides for semiconductor devices with, for example, "enhanced light detection properties."

'714 patent, 6:13-16. An exemplary embodiment from the '714 patent is depicted below.

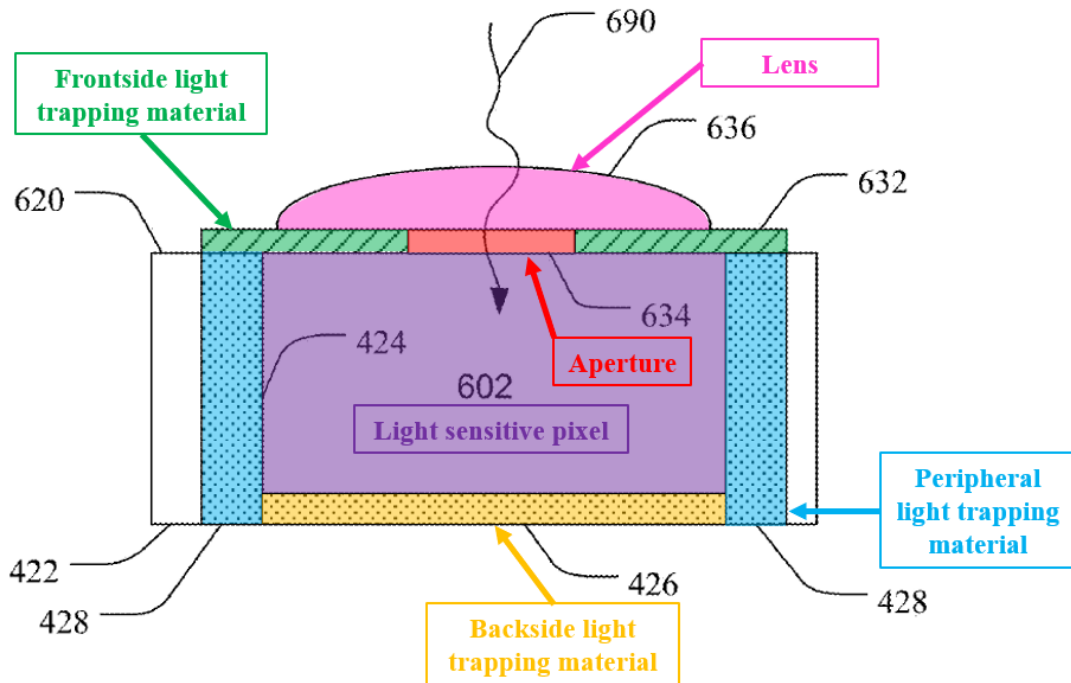


Fig. 6

'714 patent, Fig. 6 (annotated).

43. Figure 6 is a cross-sectional view of a light trapping pixel in accordance with an embodiment discussed in the patent. '714 patent, 3:46-48. I understand that during prosecution the applicant stated that the claims of the '714 patent are directed towards the embodiment depicted in Figure 6. See Ex-1002, 95 ("Applicant elects, without traverse, claims 1-20 represented by the species of FIG. 6.").

44. The patent relates to "light trapping elements" that can "isolate neighboring pixels in an image sensor." '714 patent, 6:18-20. The isolation elements

can be configured “to optically and/or electrically isolate neighboring pixels from one another in addition to trapping light within the pixel.” ’714 patent, 6:20-22. The patent also refers to isolation elements as “trench isolation features” or “sidewalls.” ’714 patent, 7:42-43.

45. The patent broadly asserts that a “variety of reflective materials can be utilized in constructing the isolation features in order to provide optical isolation, light trapping, and/or electrical isolation,” and that “any such material capable of incorporation into a photosensitive device” is within the patent’s scope. ’714 patent, 7:64-8:1. Examples of such materials include a Bragg reflector or a metal reflector, including for example “silver, aluminum, gold, platinum, reflective metal nitrides, reflective metal oxides, and the like.” ’714 patent, 8:1-9. The isolation elements can be doped to affect properties of the material with respect to electrical isolation. ’714 patent, 8:13-16.

46. According to the patent, a light sensitive pixel can have “a light incident surface, a backside surface opposite the light incident surface, and a peripheral sidewall disposed into at least a portion of the pixel and extending at least substantially around the pixel periphery.” ’714 patent, 1:43-48. Furthermore, the pixel can include “a backside light trapping material substantially covering the backside surface and a peripheral light trapping material substantially covering the peripheral sidewall.” ’714 patent, 1:46-49. Light that contacts the peripheral light

trapping material or backside light trapping material is “reflected back toward the pixel.” ’714 patent, 1:53-56. The patent states that “light entering the pixel that is not absorbed will interact with and be reflected internally” by backside or peripheral sidewall light trapping materials, for example. ’714 patent, 12:26-31. Light is “effectively maintained inside the pixel until it is absorbed.” ’714 patent, 12:31-32. There may also be an “array” of light trapping pixels. ’714 patent, 1:57-58.

47. The isolation element can include at least two layers comprising material having a lower optical refractive index² as compared to the material of a third layer disposed or sandwiched between those two layers. ’714 patent, 8:36-40. In this case, the isolation element functions as a Bragg reflector. ’714 patent, 8:35-36. The patent states that a large index of refraction “mismatch” can result in “total reflection at the trench side walls.” ’714 patent, 9:26-28.

B. Level of Ordinary Skill in the Art

48. It is my understanding that factors defining the level of ordinary skill in the art include: (1) the types of problems encountered in the art; (2) the prior art solutions to those problems; (3) the rapidity with which innovations are made; (4) the sophistication of technology; and (5) the educational level of active workers in the field.

² Herein I use the term “refractive index” to refer to optical refractive index.

49. In my opinion, a person of ordinary skill in the art (“POSITA”) as of March 2012 would have had a Bachelor’s degree in engineering, physics, or a related or equivalent field, and two or more years of experience researching, developing, designing, and/or evaluating image sensors using photonics. A person with less or different education but more relevant practical experience, or vice versa, may also meet this standard.

50. I met this definition of a POSITA as of March 2012. I applied this definition of a POSITA in forming my opinions in this declaration. I understand that SiOnyx, LLC (“SiOnyx” or “Patent Owner”) asserted the ’714 patent in a related case, *Sensors with Pixels and Products Containing the Same*. Inv. No. 337-TA-1403 (the “Related Case”). I understand that Patent Owner’s expert in the Related Case opined that “[t]he level of ordinary skill for the Asserted Patents should be defined as a person having at least a bachelor’s degree in electrical engineering, materials science, or physics, (or an equivalent technical degree), at least two years of experience in optoelectronics, and at least three years of work experience in semiconductor manufacturing. Further a master’s degree or Ph.D. in a relevant field may substitute for some work experience or vice versa.” I met Patent Owner’s definition of a POSITA as of March 2012. My opinion remains the same under Patent Owner’s definition.

C. Claim Construction

51. I understand that in this proceeding, the claims should be construed in accordance with their ordinary and customary meaning in light of the specification, as understood by one of ordinary skill in the art. I have applied those plain and ordinary meanings in my analysis, except where otherwise noted.

52. I understand that, in the Related Case, Petitioner and Patent Owner have proposed constructions for certain terms of the '714 patent. *See* Ex-1014; Ex-1015; Ex-1016; Ex-1017. To the extent those constructions bear on my analysis I address them below.

VII. CLAIMS ANALYSIS

A. Ground 1: Claims 1-6 and 9-11 Are Anticipated, or at a Minimum Obvious, Based on Hwang

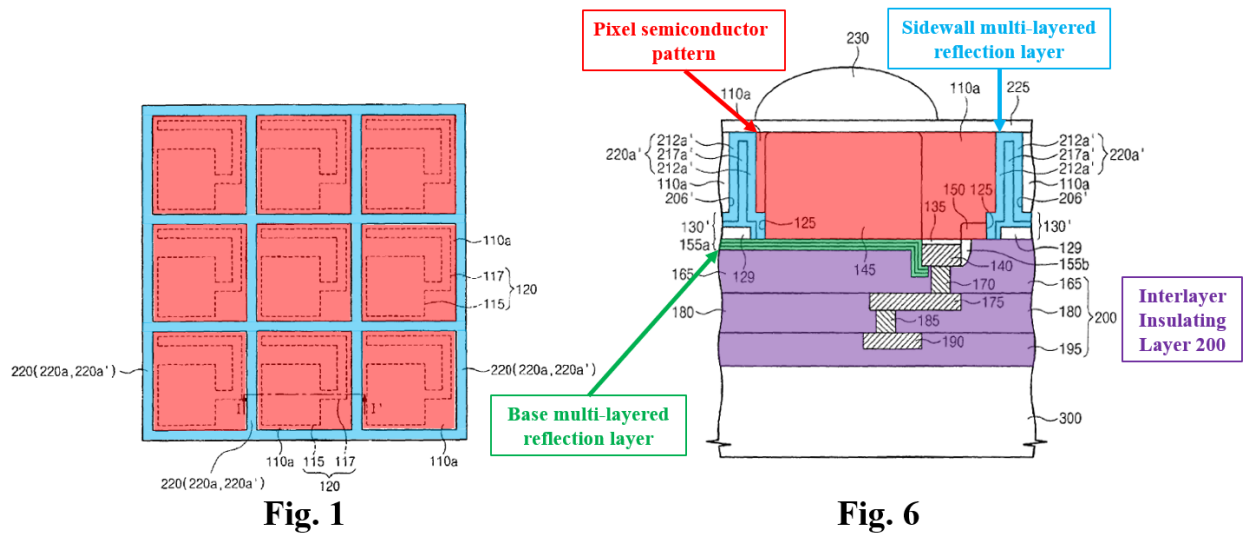
1. Overview of Hwang

53. U.S. Patent No. 7,675,099 (“Hwang”) (Ex-1005) is a U.S. patent that I understand is prior art to the '714 patent. It is directed to “an image sensor with an increased spectral sensitivity,” that is “capable of minimizing interference between neighboring pixels” through use of a “base multi-layered reflection layer” and a “side wall multi-layered reflection layer.” Hwang, 1:52-67.

54. Hwang identifies a problem in that longer wavelength light is less likely to be absorbed completely by a photodiode, thus reducing spectral sensitivity. Hwang, 1:41-48. Similar to the '714 patent, Hwang is concerned with improving image quality

by increasing the percent of incident light absorbed by the photodiode. Hwang, 1:31-36. As Hwang explains, “[t]he higher the percentage of incident light absorbed by the photodiode, the higher the spectral sensitivity.” Hwang, 1:31-34.

55. To that end, Hwang discloses an image sensor with base and sidewall reflection layers. For example, Figures 1 and 6 below illustrate a plan view of an image sensor and a cross-sectional view of an image sensor, respectively. Hwang, 4:59-63.



Hwang Figs. 1, 6.³ Figure 6 depicts a “pixel semiconductor pattern 110a [that] has a photodiode 145 disposed therein,” Hwang, 5:57-58, “[a] base multi-layered reflection layer 155a,” Hwang, 7:45-47, and a “sidewall multi-layered reflection layer 220a’,” Hwang, 11:64-67.

56. As Hwang explains, these base and sidewall reflection layers serve to increase light sensitivity of the sensor and reduce interference across pixels:

[A] base multi layered reflection layer is disposed between the photodiode and the interlayer insulating layer. Thus, light that is incident on the photodiode is ***reflected by the base multi-layered reflection layer*** and re-enters the photodiode. Resultantly, the ***sensitivity of the image sensor is improved.***

Also, a sidewall multi-layered reflection layer encloses the sidewalls of the pixel semiconductor patterns forming the photodiode. Therefore, incidence of the light reflected by the base multi-layered reflection layer on neighboring pixels can be

³ Figure 6 uses differently arranged sidewall multi-layered reflection layers than Hwang’s first embodiment (Figure 2) but otherwise is the same as Hwang’s first embodiment. See Hwang, 11:57-60. Therefore, a POSITA would appreciate that Hwang’s disclosures for elements in Figure 2 (including layer 220 comprising layers 210 and 215) are pertinent to corresponding elements in Figure 6 (including layer 220a’ comprising layers 212a’ and 217a’).

minimized. As a result, interference between pixels can be minimized by the sidewall multi-layered reflection layer.

Hwang, 15:36-48; *see also* Hwang, 8:61-9:14, 10:19-40.⁴ Thus, as explained further below, Hwang discloses a *light trapping device* including a *backside light trapping material* (base reflection layer) and *peripheral light trapping material* (sidewall reflection layer), in accordance with the challenged claims.

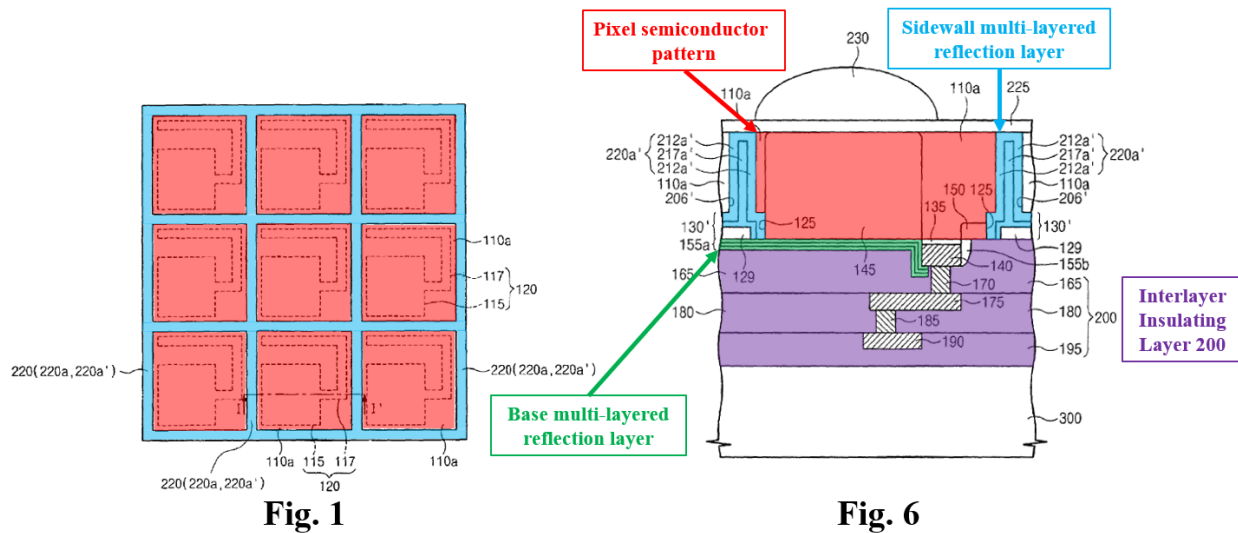
2. Claim 1

a) 1[pre]: “A light trapping device, comprising:”

57. Hwang teaches or suggests this preamble.

58. Hwang discloses an “image sensor that converts incident light to electrical signals.” Hwang, 1:14-18. For example, Figure 1 shows “a plan view of an image sensor,” Hwang, 4:59-60, and Figure 6 shows a “sectional view of FIG. 1 ... for describing an alternate embodiment of an image sensor....” Hwang, 5:8-10.

⁴ All emphasis added except where otherwise noted.



Hwang Figs. 1, 6 (annotated).

59. Hwang discloses a “sidewall multi-layered reflection layer 220a’ is disposed within a groove 206’ formed between pixel semiconductor patterns 110a’.” Hwang, 11:64-66. Hwang further discloses “[a] base multi-layered reflection layer 155a is interposed between the photodiode 145 and the interlayer insulating layer 200.” Hwang, 7:45-47.

60. These reflective layers allow Hwang’s image sensor to trap light by reflecting light back into the pixel. *See, e.g.*, Hwang, 9:10-11 (“The light reflected by the ... surfaces [of the base multi-layered reflection layer 155a] is incident again on the photodiode 145.”); 10:28-35 (“Light ... is also reflected by the [surfaces] within the sidewall multilayered reflection layer 220 [layer 220a’ in Figure 6]. As a result ... absorption efficiency of external light is increased.”); 15:36-48. Accordingly, Hwang’s image sensor constitutes a *light trapping device*.

- b) 1[a]: “at least one light sensitive pixel having a light incident surface, a backside surface opposite the light incident surface, and a peripheral sidewall disposed into at least a portion of the pixel and extending at least substantially around the pixel periphery;”

61. Hwang teaches or suggests this limitation.

62. Hwang’s image sensor comprises *at least one light sensitive pixel*. For example, Hwang’s image sensor includes “a plurality of pixel semiconductor patterns 110a,” that are “arranged two-dimensionally in rows and columns,” Hwang 5:52-59, as shown in annotated Figures 1 and 6 below. Hwang explains that “[e]ach pixel semiconductor pattern 110a has a photodiode 145 disposed therein.” Hwang, 5:57-58. As Hwang further explains, “[a] photodiode is a representative type of light receiver. When external light is incident on a depletion region in the photodiode, electron-hole pairs are generated, and the external light is converted to electrical

signals.” Hwang, 1:23-29. Therefore, each pixel semiconductor pattern 110a comprises a *light sensitive pixel*.⁵

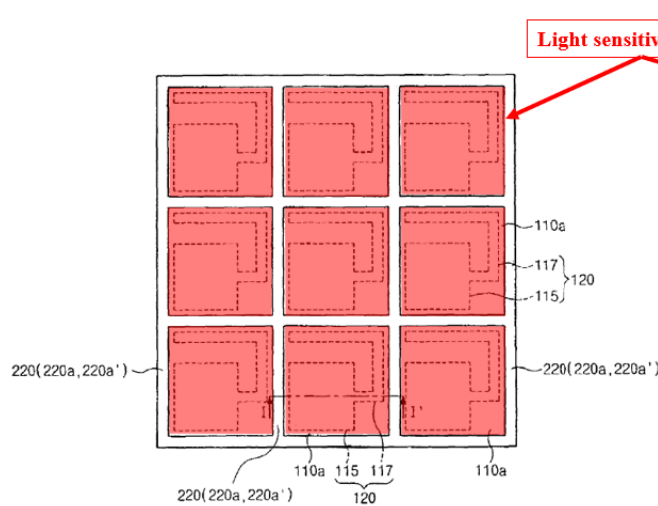


Fig. 1

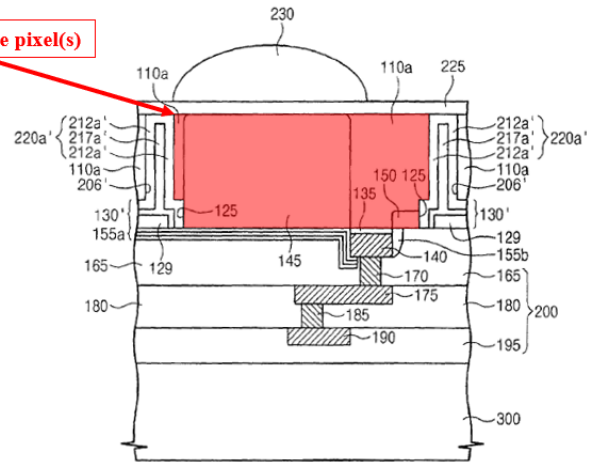


Fig. 6

Hwang Figs. 1, 6 (annotated).

63. Hwang further discloses that each pixel has a *light incident surface* and a *backside surface opposite the light incident surface*, as illustrated below.

⁵ While Hwang calls element 145 a “photodiode,” a POSITA would understand that term (i.e., the structure that converts light into an electrical signal) encompasses more than just element 145, and would further include the surrounding pixel semiconductor patterns 110a. The photodiode comprises a junction created between the differently doped semiconductor regions. See Hwang, 5:52-6:6 (“photodiodes 145 form a PN junction with the pixel semiconductor pattern 110a”).

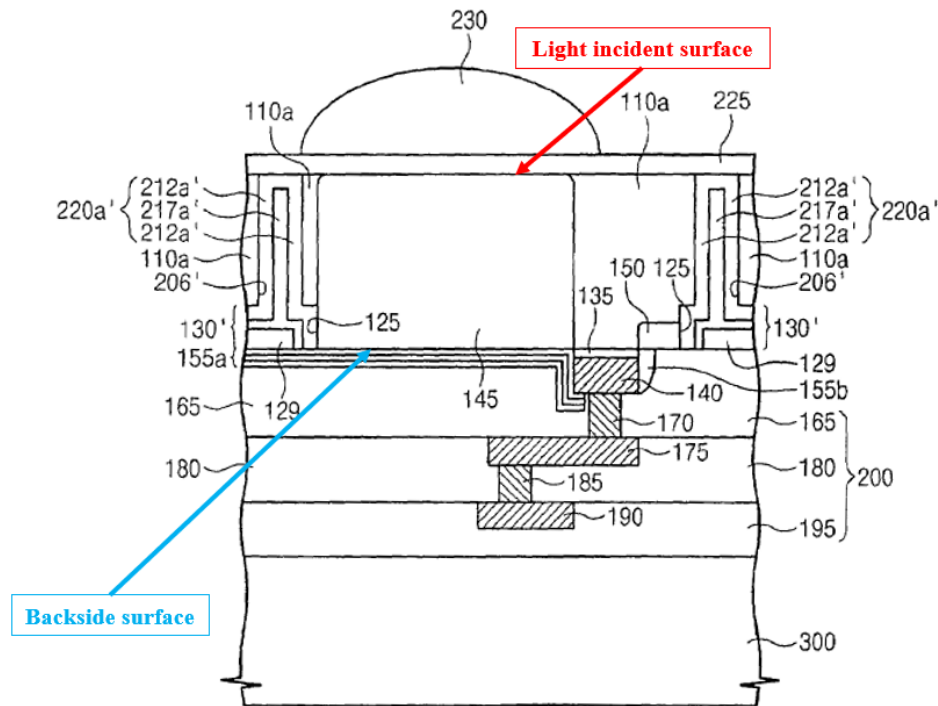


Fig. 6

Hwang, Fig. 6 (annotated).

64. Hwang explains that “[t]he pixel semiconductor patterns 110a have first and second surfaces in parallel, i.e., that face one another,” where “the first surface of a pixel semiconductor pattern 110a is more proximate to the substrate 300 than is the second surface.” Hwang, 6:37-40.

65. Hwang’s “second surface” constitutes a *light incident surface*. Hwang explains that “[a] color filter 225 is disposed on the second surface of the pixel semiconductor pattern 110a, and a micro lens 230 that covers the photodiode 145 is disposed on the color filter 225. External light passes through the micro lens 230 and

the color filter 225, and is incident on the second surface of the photodiode 145.”
Hwang, 8:17-22.

66. Hwang’s “first surface,” in turn, constitutes a *backside surface opposite the light incident surface*. Hwang explains that “the first surface of a pixel semiconductor pattern 110a is more proximate to the substrate 300 than is the second surface.” Hwang, 6:38-40. “[T]he first surface of the photodiode 145 is coplanar with the first surface of the pixel substrate pattern 110a.” Hwang, 6:63-65. “The first surface of the floating doped region 150 shares the same surface with the first surface of the pixel semiconductor pattern 110a.” Hwang, 7:40-42.

67. Each pixel further has a *peripheral sidewall disposed into at least a portion of the pixel*, as illustrated below.

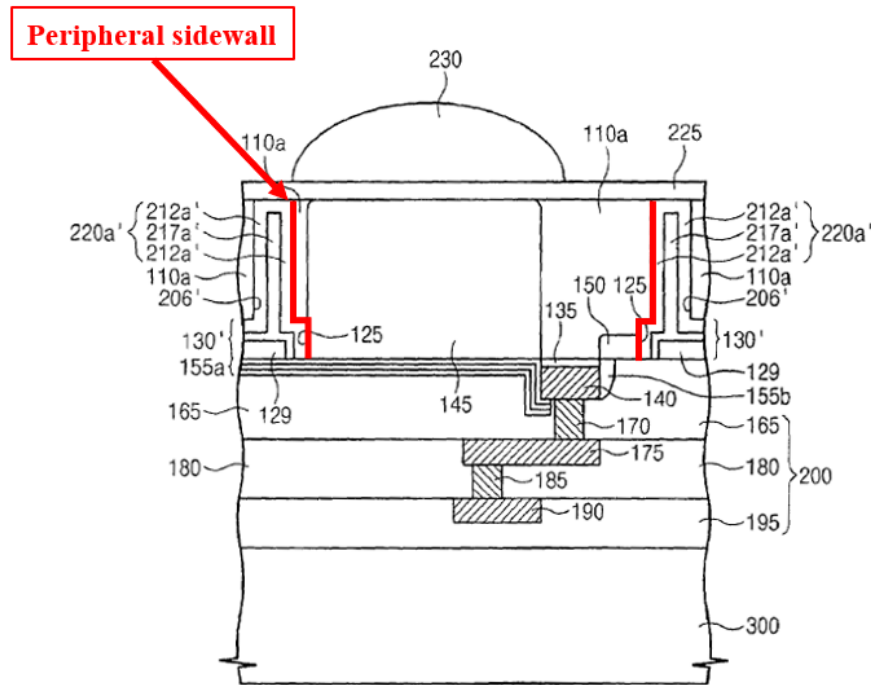


Fig. 6

Hwang, Fig. 6 (annotated).

68. Hwang discloses a “sidewall multi-layered reflection layer 220a’ is disposed within a groove 206’ formed between pixel semiconductor patterns 110a’.” Hwang, 11:64-66. Hwang further discloses that “[a] sidewall multi-layered reflection layer 220 [layer 220a’ in Figure 6] is provided between the side walls of the pixel semiconductor pattern 110a,” as shown in Figure 6. Hwang, 6:7-9. That is, Hwang discloses that its pixel semiconductor pattern 110a includes a *peripheral sidewall* where the pixel 110a contacts the sidewall reflection layer 220a’.

69. The peripheral sidewall is *disposed into at least a portion of the pixel*. As shown in Figure 6, it runs at least from the pixel’s “second surface” (*light incident*

surface) to its “first surface” (*backside surface*)—just like the peripheral sidewall 424 in the ’714 patent. See ’714 patent, Fig. 4, 11:19-20 (illustrating “peripheral sidewall 424 disposed into at least a portion of the pixel 402”).⁶

⁶ I understand that in the Related Case, Petitioner proposed that the term “a peripheral sidewall disposed into at least a portion of the pixel” is indefinite (Ex-1014, 3), and Patent Owner proposed that the term be given its “plain and ordinary meaning” and that “[t]o the extent a construction is required: peripheral trench wall that extends at least partially into the pixel” (Ex-1015, 3). I was asked to address this element under Patent Owner’s interpretation, which is satisfied by Hwang for the reasons explained above.

Fig. 6

70. Hwang further discloses the peripheral sidewall *extending at least substantially around the pixel periphery*. As illustrated in Figure 1 below, “[t]he sidewall multi-layered reflection layer 220 [layer 220a’ in Figure 6] encloses the side walls of the pixel semiconductor patterns 110a.” Hwang, 6:15-17. Thus, the *peripheral sidewall* (where the pixel 110a contacts the sidewall reflection layer 220a’) *extend[s] at least substantially around the pixel periphery*.

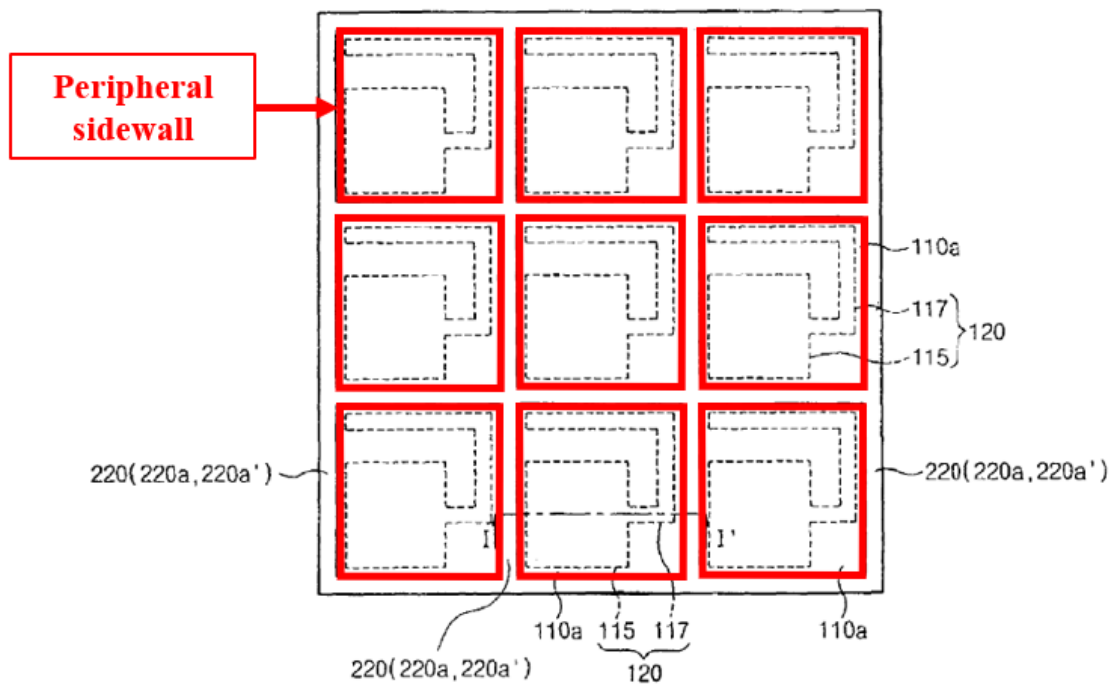


Fig. 1

Hwang, Fig. 1 (annotated).

71. Accordingly, Hwang's image sensor comprises *at least one light sensitive pixel* that meets the requirements of this claim element.

c) 1[b]: “a backside light trapping material at least partially covering the backside surface; and”

72. Hwang teaches or suggests this limitation.

73. Hwang's image sensor includes a *backside light trapping material at least partially covering the backside surface* of the pixel. Hwang discloses that a “base multi-layered reflection layer 155a is interposed between the photodiode 145 and the interlayer insulating layer 200,” Hwang, 7:45-47, as shown in the annotated Figures below.

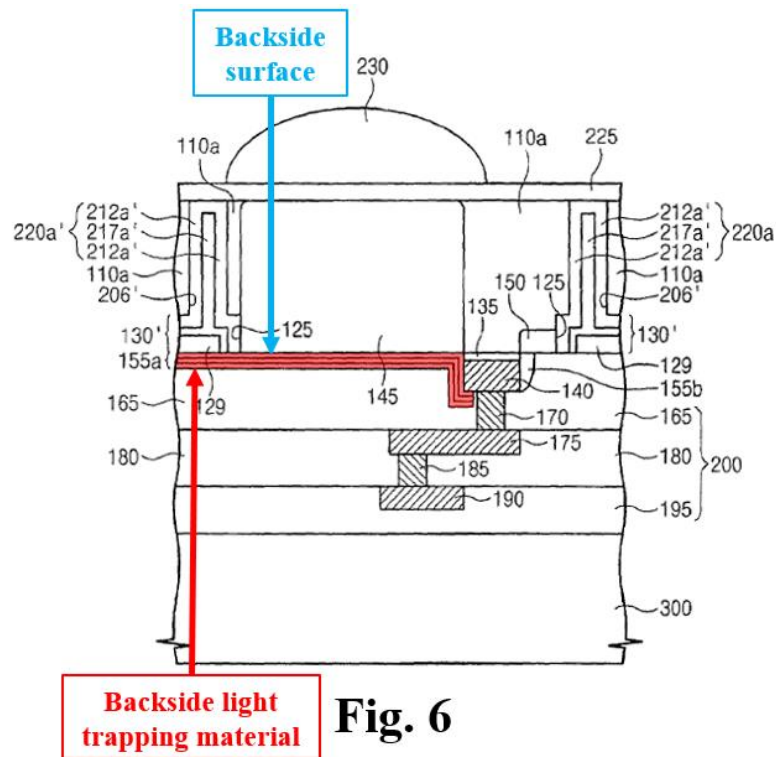


Fig. 6

Hwang Fig. 6 (annotated).

74. This base reflection layer 155a traps light by reflecting light back into the pixel, and therefore constitutes a *light trapping material*. As Hwang explains, “external light incident on the second surface of the photodiode 145 is reflected by the first boundary surface and at least one second boundary surface within the base multi-layered reflection layer 155a.” Hwang, 9:6-10. Therefore, the light reflected by the base multi-layered reflection layer 155a “is incident again on the photodiode,” thus “increas[ing] the light sensitivity of the image sensor.” Hwang, 9:11-14. Further, Hwang’s base multi-layer reflection layer 155a *at least partially cover[s] the backside surface*. Hwang explains that “the base multi-layered reflection layer 155a contacts the

first surface of the pixel semiconductor pattern 110a on which the photodiode 145 is formed,” as shown in Figure 6 above. Hwang, 8:32-35. As explained for limitation 1[a] above, the “first surface” constitutes the claimed *backside surface* of the pixel.

75. Accordingly, Hwang’s base multi-layer reflection layer 155a comprises *a backside light trapping material at least partially covering the backside surface*.

d) 1[c]: “a peripheral light trapping material substantially covering the peripheral sidewall;”

76. Hwang teaches or suggests this limitation.

77. Hwang’s image sensor includes *a peripheral light trapping material substantially covering the peripheral sidewall*. Hwang discloses that a “sidewall multi-layered reflection layer 220a’ is disposed within a groove 206’ formed between pixel semiconductor patterns 110a,” as shown in Figure 6 below. Hwang, 11:64-66. Hwang also discloses that “sidewall multi-layered reflection layer 220 [layer 220a’ in Figure 6] is disposed between the side walls of the pixel semiconductor pattern 110a.” Hwang, 9:41-43.

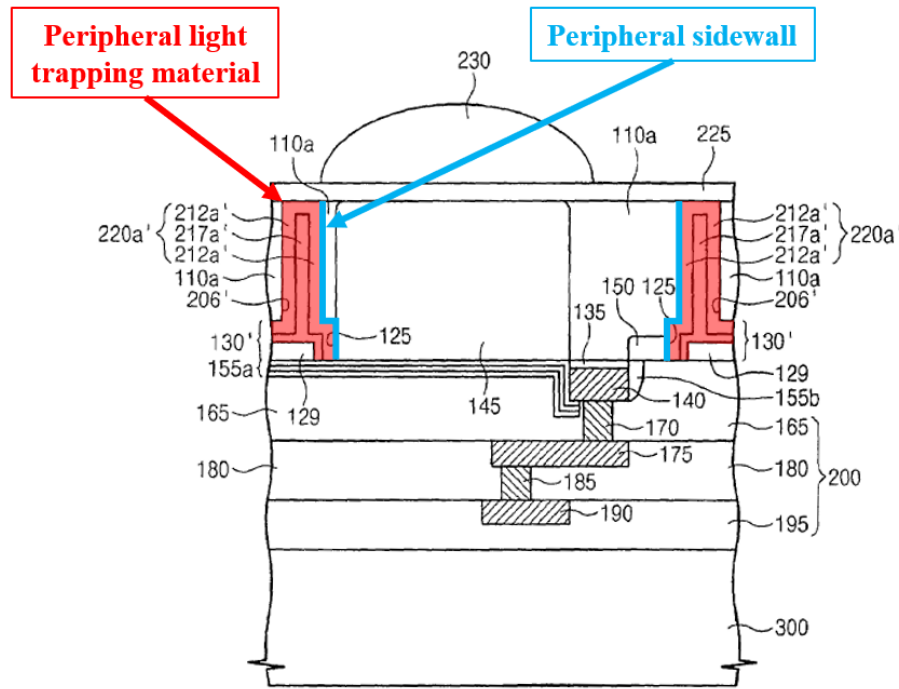


Fig. 6

Hwang, Fig. 6 (annotated).

78. This sidewall reflection layer 220a' serves to reflect light and minimize interference across pixels, and therefore constitutes a *light trapping material*. As Hwang explains, “the sidewall multi-layered reflection layer 220 [layer 220a' in Figure 6] minimizes incidence of the light incident on a photodiode 145 that it encloses being incident on other pixels. Therefore, interference of the image sensor can be minimized.” Hwang, 10:23-27. Additionally, light “is also reflected by [surfaces] within the sidewall multilayered reflection layer 220 [layer 220a' in Figure 6]. As a result, the portion of the light reflected toward the sidewall multi-layered reflection

layer 220 [220a' in Figure 6] ... is incident again on the photodiode 145, so that the absorption efficiency of external light is increased.” Hwang, 10:29-35.

79. Further, Hwang’s sidewall reflection layer 220a’ *substantially cover[s] the peripheral sidewall*. Hwang explains that “[t]he sidewall multi-layered reflection layer 220 [220a’ in Figure 6] encloses the side walls of the pixel semiconductor pattern 110a,” Hwang, 6:15-17, and that “[t]he sidewall multi-layered reflection layer 220 [220a’ in Figure 6] can contact the side walls of the pixel semiconductor patterns 110a,” as shown in Figure 6. Hwang, 9:43-45.

80. Accordingly, Hwang’s sidewall multi-layered reflection layer 220a’ comprises *a peripheral light trapping material at substantially covering the peripheral sidewall*.

e) 1[d]: “wherein light contacting the backside light trapping material or the peripheral light trapping material is reflected back toward the pixel;”

81. Hwang teaches or suggests this limitation.

82. Hwang discloses *that light contacting the backside light trapping material* (i.e., Hwang’s base multi-layered reflection layer 155a) *is reflected back towards the pixel*. Hwang discloses that “external light incident on the second surface [the light incident surface] of the photodiode 145 is reflected by the first boundary surface and at least one secondary boundary surface within the base multi-layered reflection layer 155a,” i.e., the backside light trapping material, and that “[t]he light

reflected by the first and second boundary surfaces is incident again on the photodiode 145.” Hwang, 9:6-14.

83. In addition, Hwang discloses that *light contacting the peripheral light trapping material* (i.e., Hwang’s sidewall multi-layered reflection layer 220a’) *is reflected back towards the pixel*. Hwang discloses that “[l]ight that is reflected from the first and second boundary surfaces is also reflected by the third boundary surface and also the fourth boundary surface within the sidewall multi-layered reflection layer 220 [220a’ in Figure 6],” i.e., the peripheral light trapping material, and that “[a]s a result, the portion of the light reflected toward the sidewall multi-layered reflection layer 220 [220a’ in Figure 6] from the light reflected by the first and second boundary surfaces is incident again on the photodiode 145, so that the absorption efficiency of external light is increased.” Hwang, 10:28-35.

84. Accordingly, Hwang discloses that in its image sensor *light contacting both the backside light trapping material and the peripheral light trapping material is reflected back toward the pixel*.

- f) 1[e]: “wherein at least one of the backside light trapping material or the peripheral light trapping material includes a high refractive index material sandwiched between two low refractive index materials.”

85. Hwang teaches or suggests this limitation.⁷

86. **First**, Hwang discloses that the *backside light trapping material* (i.e., Hwang’s base multi-layered reflection layer 155a) *includes a high refractive index material sandwiched between two low refractive index materials*.

87. Hwang discloses that “[t]he base multi-layered reflection layer 155a includes at least two stacked layers having different refractive indexes.” Hwang, 8:35-36. Specifically, Hwang discloses that “the base multi-layered reflection layer 155a has at least two layers with different refractive indexes,” such that “at least one boundary surface reflecting light is disposed in the base multi-layered reflection layer 155a.” Hwang, 9:1-4.

88. More specifically, Hwang discloses that “[t]he base multi-layered reflection layer 155a can include a first base multi-layered reflection layer 151 and a

⁷ I am aware that different constructions were provided for this limitation in the Related Case. I was instructed to interpret the claim such that the *two low refractive index materials* need not be different from one another, consistent with Patent Owner’s construction.

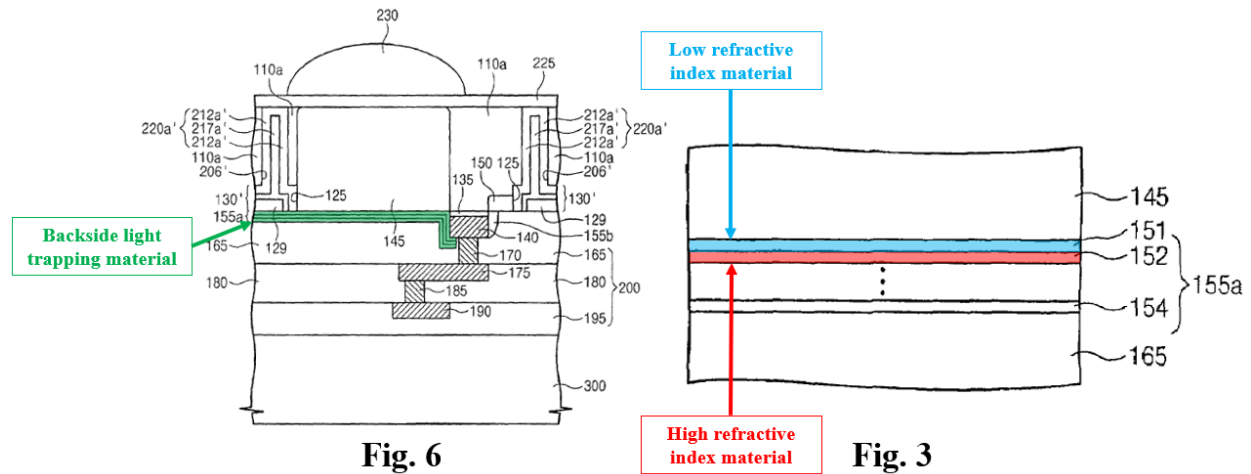
second base multi-layered reflection layer 152,” and that “[t]he reflective index of the first base multi-layered reflection layer 151 can be lower than the reflective indexes of the second base multi-layered reflection layer 152.” Hwang, 8:40-52.⁸ Hwang further discloses that “the first and second base multi-layered reflection layers 151 and 152

⁸ Hwang’s two references to a “reflective index” in 8:48-50 appear to be an error, and a POSITA would understand that Hwang meant to say “refractive index” as evidenced by Hwang’s use of the term elsewhere. *See, e.g.*, 8:42-45 (“The refractive index of the first base multi-layered reflection layer 151 is different from the refractive indexes of the second base multi-layered reflection layer 152 and the pixel semiconductor pattern 110a.”).

[are] respectively formed of silicon oxide (with a refractive index of approximately 1.46) and silicon (with a refractive index of approximately 4)...” Hwang, 9:25-30.⁹

89. Accordingly, as shown in the annotated Figures 6 and 3 below, Hwang discloses that the *backside light trapping material* (base multi-layered reflection layer 155a, highlighted green) *includes a high refractive index material* (second base layer 152, highlighted red) and a *low refractive index material* (first base layer 151, highlighted blue).

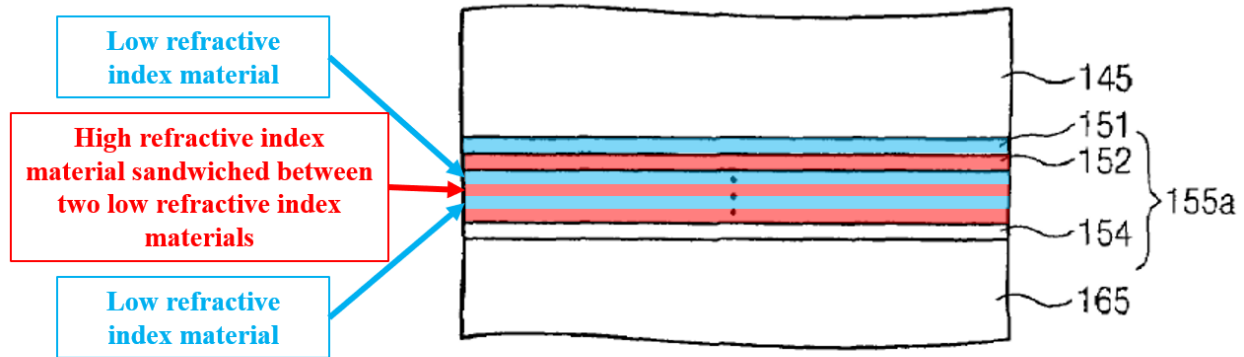
⁹ While Hwang describes layer 151 (and 210, as discussed below) as “silicon oxide,” a POSITA would understand this to be a reference to “silicon dioxide,” given the description of its refractive index being “approximately 1.46.” Hwang, 9:29-29. It is well known that the refractive index of silicon dioxide is 1.46, Schubert, 181 (“SiO₂ ($\bar{n} \approx 1.46$)”), whereas the refractive index of silicon monoxide is at least around 1.8-2.2, Ex-1022, Abstract (refractive index of “silicon monoxide” (“SiO”) ranges from 2.15 to 1.95 in the 0.40 to 0.70 micron wavelength); Ex-1023, 17 & Fig. 2 (refractive index of “silicon monoxide” ranges from about 1.8 to about 1.9 in the 1 to 5 micron wavelength range).



Hwang, Figs. 6, 3 (annotated).¹⁰

90. Hwang further discloses that “the base multi-layered reflection layer 155a can include the first and second base multi-layered reflection layers 151 and 152 alternately stacked a plurality of times.” Hwang, 8:54-56. For example, Hwang discloses that “the first and second base multi-layered reflection layers 151 and 152 [can be] alternately stacked three times...,” Hwang, 9:25-26, i.e., a base-multi layered reflection layer 155a including a layer stack of 151, 152, 151, 152, 151, 152. Accordingly, as shown in the modified and annotated Figure 3 below, Hwang discloses that the *backside light trapping material* (155a) includes a *high refractive index material* (second base layer 152, highlighted red) sandwiched between two *low refractive index materials* (the two adjacent first base layers 151, highlighted blue).

¹⁰ Figure 3 “is an enlarged view of section A in FIG. 2 for describing an embodiment of a base multi-layered reflection layer....” Hwang, 4:64.



Modified Fig. 3

Hwang, Fig. 3 (annotated, modified).

91. **Second**, Hwang discloses that the peripheral light trapping material (i.e., Hwang's sidewall multi-layered reflection layer 220a') *includes a high refractive index material sandwiched between two low refractive index materials*.

92. Hwang discloses that "sidewall multi-layered reflection layer 220a' includes a first sidewall reflection layer 212a' and a second sidewall reflection layer 217a'," wherein "[t]he second sidewall reflection layer 217a' is disposed below the first sidewall reflection layer 212a." Hwang, 11:64-12:12. Specifically, Hwang discloses that "[t]he sidewall multi-layered reflection layer 220 [220a' in Figure 6] ha[s] a second sidewall reflection layer 215 [217a' in Figure 6] interposed between two first sidewall reflection layers 210 [212a' in Figure 6]," Hwang, 10:49-50.

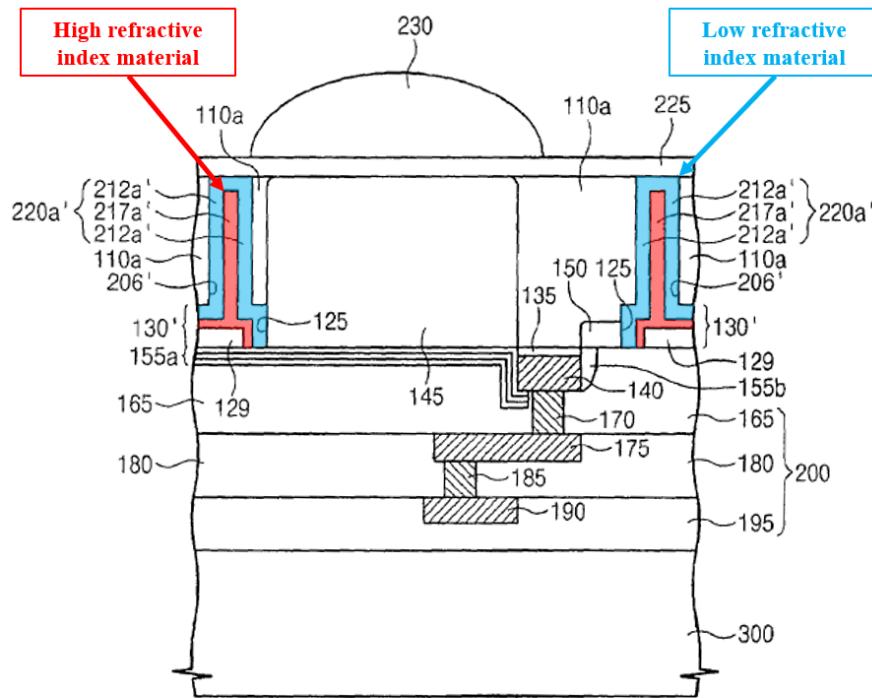


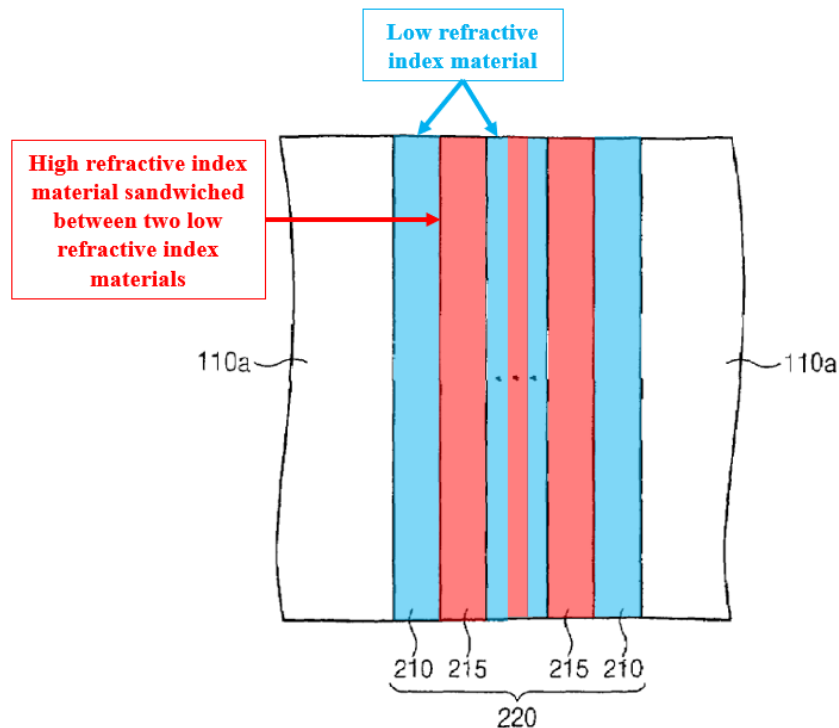
Fig. 6

Hwang, Fig. 6 (annotated).

93. Hwang further discloses that “first sidewall reflection layer 212a’” has “a lower refractive index than ... the second sidewall reflection layer 217a’.” Hwang, 12:4-7. Hwang explains that “[t]he first sidewall reflection layer 210 [212a’ in Figure 6] can be a silicon oxide layer or a layer of air (with a refractive index of 1),” and that “[t]he second sidewall reflection layer 215 [217a’ in Figure 6] can be a silicon layer.” Hwang, 10:2-5. As Hwang explains, silicon oxide and silicon have refractive indexes of approximately 1.46 and 4, respectively. Hwang, 9:28-30.

94. Hwang explains that “[t]he first and second sidewall reflection layers 212a’ and 217a’ can be alternatively disposed at least once,” i.e., they can be

alternatively stacked a plurality of times. Hwang, 12:24-25. As illustrated below, Hwang accordingly teaches use of a *peripheral light trapping material* including a *high refractive index material* (second sidewall reflection layer 217a'), sandwiched between two low refractive index materials (first sidewall reflection layer 212a').



Modified Fig. 4

Hwang, Fig. 4 (annotated, modified).¹¹

¹¹ As explained above, Figure 2's (and Figure 4's) layer 220 corresponds to Figure 6's 220a', layer 210 corresponds to Figure 6's 212a', and layer 215 corresponds to Figure 6's 217a'.

95. Thus, as shown in the annotated Figure 4 and 6 above, Hwang discloses that the *peripheral light trapping material includes a high refractive index material* (second sidewall reflection layer 217a', highlighted red) *sandwiched between two low refractive index materials* (the two adjacent first sidewall reflection layers 212a', highlighted blue).

96. Accordingly, Hwang's image sensor comprises both a *backside light trapping material* and a *peripheral light trapping material* that meet the requirements of this claim limitation.

3. Claim 2: "The device of claim 1, wherein the two low refractive index materials have a refractive index of less than about 2.1."

97. Hwang teaches or suggests this claim. As discussed for claim 1[e] above, Hwang discloses low refractive index materials 151 (used in the backside light trapping material) and 212a' (used in the peripheral light trapping material) that are both "formed of silicon oxide (with a refractive index of approximately 1.46)...." Hwang, 9:25-30; *see also* Hwang, 8:40-52, 10:2-5. In such a structure, the two low refractive index materials would *have a refractive index of less than about 2.1* (i.e., approximately 1.46).

4. **Claim 3: “The device of claim 2, wherein at least one of the two low refractive index material includes a member selected from the group consisting of an oxide, a nitride, oxynitrides, a gas, at least a partial vacuum, and combinations thereof.”**

98. Hwang teaches or suggests this claim. As discussed for claim 1[e] above, Hwang discloses low refractive index materials 151 (used in the backside light trapping material) and 212a' (used in the peripheral light trapping material) that are both “formed of silicon oxide....” Hwang, 9:25-30; *see also* Hwang, 8:40-52, 10:2-5. In such a structure, the two low refractive index materials would comprise *an oxide* (i.e., a “silicon oxide,” specifically silicon dioxide).

5. **Claim 4: “The device of claim 2, wherein the at least one of the two low refractive index materials includes a member selected from the group consisting of silicon oxide, silicon nitride, silicon dioxide, and combinations thereof.”**

99. Hwang teaches or suggests this claim. As discussed for claim 1[e] above, Hwang discloses low refractive index materials 151 (used in the backside light trapping material) and 212a' (used in the peripheral light trapping material) that are both “formed of silicon [di]oxide....” Hwang, 9:25-30; *see also* Hwang, 8:40-52, 10:2-5. In such a structure, the two low refractive index materials would comprise *silicon dioxide*.

6. Claim 5: “The device of claim 1, wherein the high refractive index material includes a material having a refractive index of greater than or equal to about 2.1.”

100. Hwang teaches or suggests this claim. As discussed for claim 1[e] above, Hwang discloses high refractive index materials 152 (used in the backside light trapping material) and 217a' (used in the peripheral light trapping material) that are both “formed of ... silicon (with a refractive index of approximately 4). . . .” Hwang, 9:25-30; *see also* Hwang, 8:40-52, 10:2-5. In such a structure, the high refractive index material would have *a refractive index of greater than or equal to about 2.1* (i.e., approximately 4).

7. Claim 6: “The device of claim 5, wherein the high refractive index material includes a member selected from the group consisting of polycrystalline silicon, amorphous silicon, single crystal silicon, multicrystalline silicon, nanocrystalline silicon, germanium, and combinations thereof.”

101. Hwang teaches or suggests this claim. As discussed for to claim 1[e] above, Hwang's *high refractive index material* 152 (used in the backside light trapping material) and 217a' (used in the peripheral light trapping material) are both “formed of ... silicon (with a refractive index of approximately 4). . . .” Hwang, 9:25-30; *see also* Hwang, 10:2-5.

102. It would be obvious to a POSITA that this silicon would be one of *polycrystalline silicon, amorphous silicon, single crystal silicon, multicrystalline silicon, nanocrystalline silicon, ... and combinations thereof.*

103. First, a POSITA would understand that a reference to “silicon,” without modification, as described in Hwang typically pertains to *single crystal silicon*.

104. Second, to the extent that Hwang’s disclosure of “silicon” may be ambiguous as to the specific type of silicon, this claim still would have been obvious, because a POSITA would have had a limited number of types of silicon from which to choose, and in fact the group of silicon materials specified in this claim (i.e., *polycrystalline silicon, amorphous silicon, single crystal silicon, multicrystalline silicon, nanocrystalline silicon, and combinations thereof*) encompasses all forms of silicon. See Ex-1018, 145 (stating that “[s]olid matter exists in crystalline and amorphous forms,” and listing “[t]he three different forms of solid-material: (a) Single-Crystal, (b) Poly-Crystalline, (c) Amorphous.”), 114 (“Silicon-films can be either amorphous, polycrystalline, or single-crystal, depending on the deposition-parameters and the substrate material.”).

8. **Claim 9: “The device of claim 1, wherein at least one of the backside light trapping material and the peripheral light trapping material includes a first material sandwiched between two second materials, wherein the first material has a higher refractive index as compared to the two second materials, and wherein the difference in refractive index between the first material and the two second materials is at least 0.2.”**

105. Hwang teaches or suggests this claim. As discussed for claim 1[e], Hwang discloses that both the backside light trapping material and peripheral light

trapping material include a first material (layers 152 and 217a', respectively) "formed of ... silicon (with a refractive index of approximately 4)." Hwang, 9:25-30; *see also* Hwang, 10:2-5, sandwiched between two second materials (layers 151 and 212a', respectively) "formed of silicon oxide (with a refractive index of approximately 1.46)," Hwang, 9:25-30; *see also* Hwang, 8:40-52, 10:2-5. In such a structure, the *backside light trapping material* would include a first material (i.e., silicon, having a refractive index of approximately 4) *sandwiched between two second materials* (i.e., silicon dioxide, having a refractive index of 1.46), *wherein the first material has a higher refractive index* (i.e., approximately 4) *as compared to the two second materials* (i.e., 1.46), *and wherein the difference in refractive index between the first material and the two second materials is at least 0.2* (i.e., a difference of approximately $4 - 1.46 = 2.54$).

9. Claim 10: "The device of claim 1, wherein the peripheral sidewall extends completely around the pixel periphery."

106. Hwang teaches or suggests this claim. As discussed for claim 1[a] above, Hwang discloses that "[t]he sidewall multi-layered reflection layer 220 [220a' in Figure 6] encloses the side walls of the pixel semiconductor patterns 110a." Hwang, 6:15-17. Therefore, as shown in annotated Figure 1 below, the *peripheral sidewall* where the pixel 110a contacts the sidewall reflection layer 220 [220a' in Figure 6] *extends completely around the pixel periphery*.

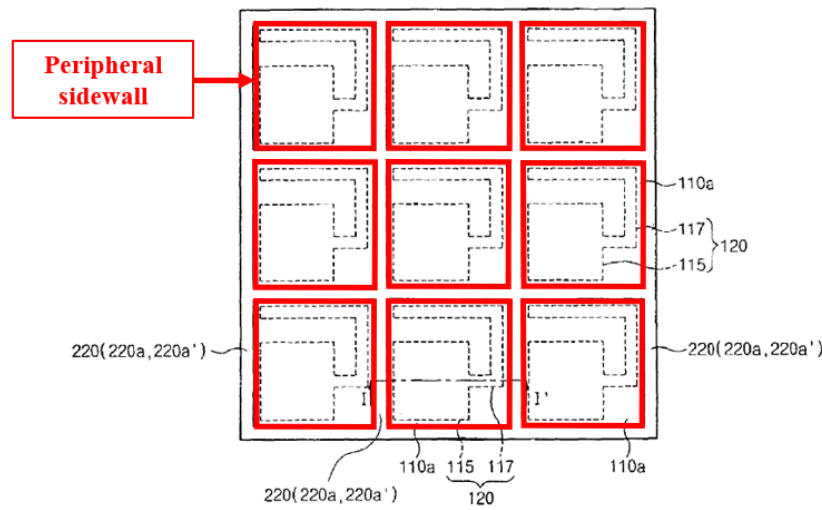


Fig. 1

Hwang, Fig. 1 (annotated).

10. Claim 11: “The device of claim 1, wherein the peripheral sidewall extends from the light incident surface to the backside surface.”

107. Hwang teaches or suggests this claim. As explained above for claim 1[a], and as shown in the annotated Figure 6 below, the *peripheral sidewall* where the pixel semiconductor pattern 110a contacts the sidewall multi-layered reflection layer 220a' extends from the light incident surface to the backside surface.



Fig. 6

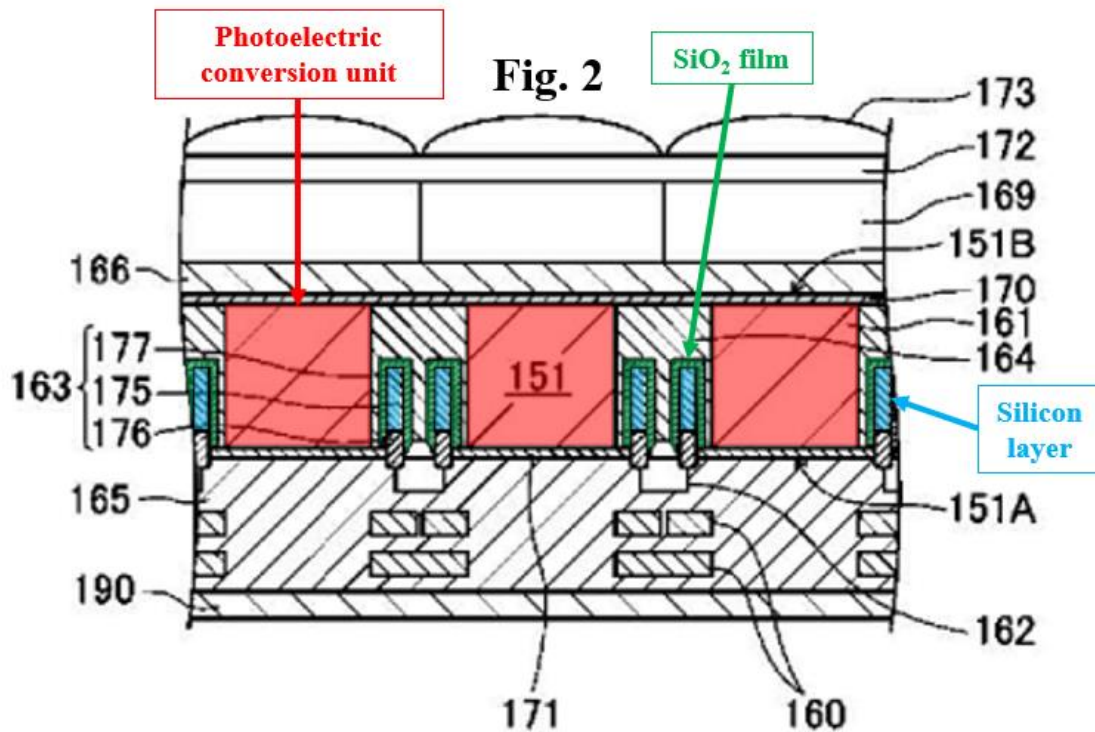
Hwang, Fig. 6 (annotated).

B. Ground 2: Claims 6-8 Are Obvious Based on Hwang and Mori

1. Overview of Mori

108. Japanese Patent Application Publication No. 2011-119558 (“Mori”) (English translation, Ex-1007, original document, Ex-1006) is a Japanese patent application publication that I understand is prior art to the ’714 patent.

109. Mori is directed to a “solid-state imaging device”—i.e., an image sensor—in which the pixels are separated by a “partition part” comprising silicon and silicon oxide layers. Mori, [0012]-[0013]. An exemplary embodiment from Mori is depicted in Figure 2 below.



Mori, Fig. 2 (annotated).

110. Figure 2 is a cross-sectional view depicting three pixels in Mori's imaging device. Mori, [0020], [0022]. Specifically, Figure 2 depicts three "[p]hotoelectric conversion units 151," (i.e., pixels, highlighted red) which each "contain[] a photodiode." Mori, [0021]. Figure 2 also depicts a multi-layered "partition part 163" that separates these pixels, Mori, [0023], and serves to reduce "color mixing [or 'crosstalk'] due to obliquely incident light," Mori, [0027]. This partition part "has a silicon layer 175 formed on the light incident surface 151B side" (highlighted blue), Mori, [0028], and "a side SiO₂ film 177 formed on its bottom and side surfaces" (highlighted green), Mori, [0030].

111. Mori teaches that this multi-layer Si/SiO₂ partition solves a problem in conventional imaging devices, in which a partition member “made of a light-reflective material such as tungsten is formed inside the semiconductor substrate so as to separate adjacent pixels.” Mori, [0005]. As Mori explains:

A single crystal epitaxial layer cannot easily be formed on the embedded member because metal and silicon have different lattice constants. ***Therefore, the silicon layer formed on the embedded member contains many crystal defects.*** As a result, the charge generated when dark increases, and the sensitivity of the solid-state imaging device decreases.

Mori, [0007]. That is, the crystal defects can cause what is known in the art as “dark current”—i.e., the unwanted flow of electric charge when no light is incident on the photodiode (when the pixel should be “off”). See Ex-1020, 1:25-28 (“dark current, which is detected as a very small current when an electric charge (electron) generated from a minute defect in a substrate interference of a light receiving surface is input as a signal”).

112. To address these problems, Mori provides for a partition part having a silicon layer (e.g. layer 175) “made of amorphous silicon or polycrystalline silicon,” Mori, [0011], and a “side silicon oxide film [e.g., SiO₂ film 177] formed between the silicon layer and the semiconductor substrate,” Mori, [0013]. “With this configuration, crystal defects on the side surface of the groove for forming the partition part can be

reduced, and the charges generated when dark can be reduced in order to achieve high sensitivity.” Mori, [0013].

113. Mori also discloses doping the SiO₂ film layer in order to further mitigate dark current stemming from crystal defects. Figure 3C below illustrates the formation of the Si/ SiO₂ partition. First, the side SiO₂ film 177 is “formed on the side surface of [a] partition groove 174.” Mori, [0036]. Then, “[i]n order to prevent charges generated when dark due to crystal defects in the partition groove 174 from flowing into the photoelectric conversion unit 161, p-type impurities are preferably injected into the side walls of partition groove 174 after forming the side SiO₂ film 177.” Mori, [0036]. That is, the SiO₂ film 177 on the side walls is doped with p-type impurities, resulting in an excess of positively charged carriers (or “holes”). “Subsequently, a silicon layer 175 is formed in the partition groove 174,” in order to complete formation of the Si/SiO₂ partition. Mori, [0036].

Fig. 3(b)

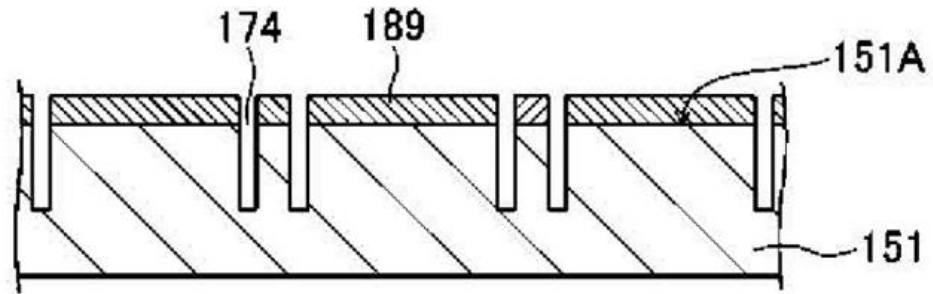
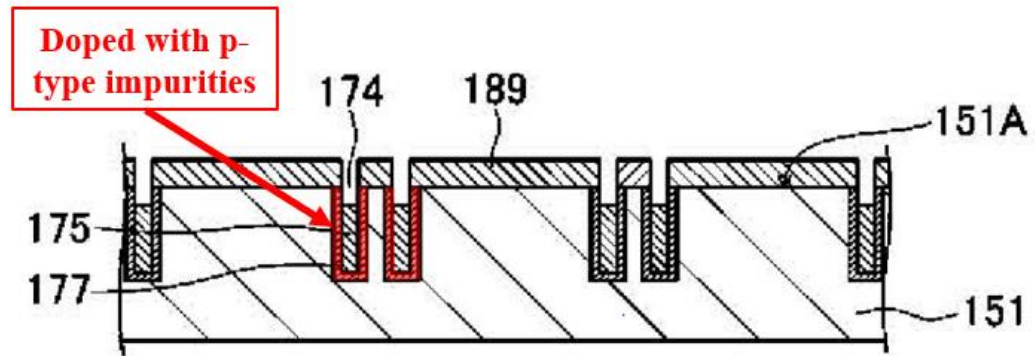


Fig. 3(c)



Mori, Figs. 3(b)-(c) (annotated).

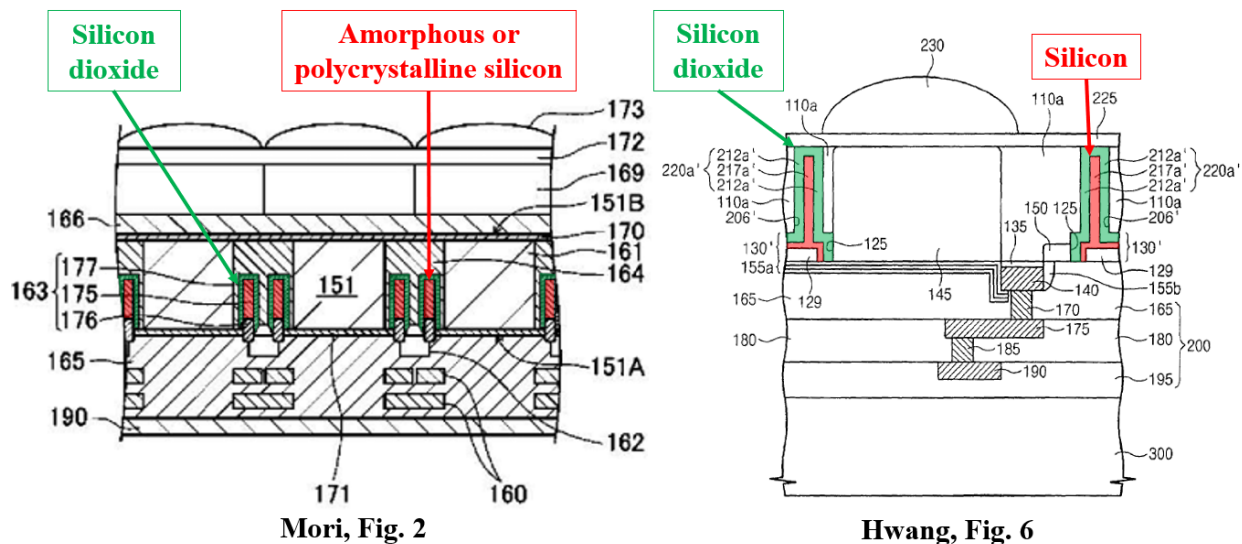
2. **Claim 6: “The device of claim 5, wherein the high refractive index material includes a member selected from the group consisting of polycrystalline silicon, amorphous silicon, single crystal silicon, multicrystalline silicon, nanocrystalline silicon, germanium, and combinations thereof.”**

114. As explained in Ground 1 above, this claim would have been obvious in light of Hwang alone, given that Hwang discloses that the high reflective index material in its base and sidewall reflection layers is “silicon,” and given that a POSITA would understand this to refer to *single crystal silicon*. However, to the extent that Hwang’s disclosure of “silicon” may be ambiguous as to the specific type of silicon, this claim still would have been obvious, because Mori specifically teaches the use of

amorphous silicon and *polycrystalline silicon* for use in a similar silicon/silicon dioxide sidewall layer.

115. As explained above for Ground 1, claim 1[e], Hwang's image sensor includes a peripheral multi-layer reflection layer (layer 220a') disposed along the pixel sidewall and comprising a layer of silicon (layer 217a', the *high refractive index material*) sandwiched between layers of silicon dioxide (layer 212a', the *low refractive index material*), as shown in Hwang's Figure 6.

116. Mori similarly discloses a multi-layer partition disposed between adjacent pixels of an image sensor and comprising a layer of silicon (silicon layer 175) sandwiched between layers of silicon dioxide (side SiO₂ film 177), as shown in Mori's Figure 2. That is, both references utilize a similar silicon/silicon dioxide film disposed at the pixel sidewalls:



Mori, Fig. 2 (annotated); Hwang, Fig. 6 (annotated). See also Mori, Fig. 6 (depicting

partition part 163 spanning along the entire side of photoelectric conversion unit 161). And in both references, the silicon/silicon dioxide film is used to mitigate against interference between pixels. *Cf.* Hwang, 15:46-48 (“interference between pixels can be minimized by the sidewall multi-layered reflection layer”) with Mori, [0027] (Si/SiO₂ partition serves to reduce “color mixing [or ‘crosstalk’] due to obliquely incident light”).

117. Mori further teaches that its “silicon layer 175 [is] made of amorphous silicon or polycrystalline silicon.” Mori, [0027]. Mori thus shows that amorphous silicon and polycrystalline silicon are suitable materials that may be included in a multi-layer silicon/silicon dioxide film disposed along the sidewalls of an image sensor pixel, and used to mitigate against interference between pixels. Mori also teaches that such a multi-layer film can help protect against crystal defects, among other advantages. *See* Mori, [0013].

118. Accordingly, it would have been obvious to use either amorphous or polycrystalline silicon for the “silicon” layer in Hwang (i.e., the *high refractive index material*). And as Mori demonstrates, using amorphous or polycrystalline silicon would lead to predictable results—i.e., the creation of a “partition part formed between photoelectric conversion units” that allows for “the sensitivity of the solid-state imaging device [to] be improved,” Mori, [0012], consistent with Hwang’s objective of using a sidewall reflection layer so that “incidence of the light reflected by the base

multi-layered reflection layer on neighboring pixels can be minimized,” (Hwang, 15:44-46).

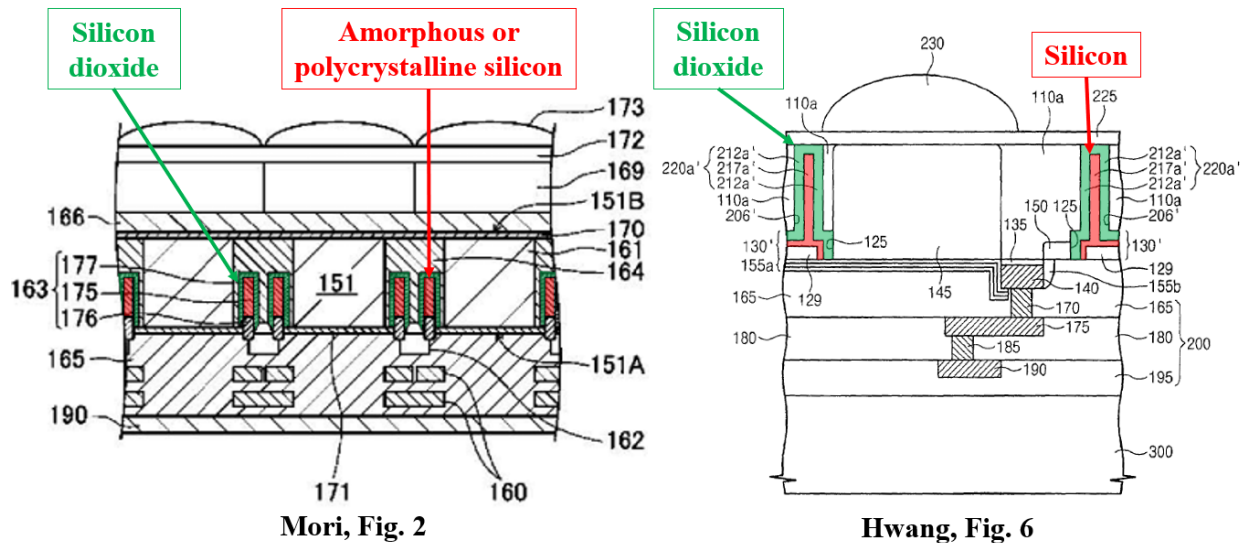
119. Finally, as discussed for Ground 1, claim 6 above, there are a finite number of types of silicon. Choosing either amorphous or polycrystalline silicon, as done in Mori, would at least be obvious to try, in light of Mori’s teachings.

120. Therefore, it would have been obvious in view of Mori to use a *high refractive index material* in Hwang’s image sensor that consisting of *amorphous silicon* or *polycrystalline silicon*.

3. Claim 7: “The device of claim 1, wherein at least one of the two low refractive index materials is doped with a dopant to create a surface field.”

121. This claim would have been obvious based on Hwang in view of Mori.

122. As explained for claim 6 above, Mori is similar to Hwang in that both references disclose image sensors that include a multi-layer film comprising a layer of silicon (Mori layer 175, Hwang layer 217a’) sandwiched between layers of silicon dioxide (Mori SiO₂ film 177, Hwang layer 212a’), used to mitigate against interference between pixels:



Mori, Fig. 2 (annotated); Hwang, Fig. 6 (annotated).

123. Mori further teaches that it is advantageous in such a film to dope the silicon dioxide layer (Mori's SiO₂ layer 177) with p-type impurities, as explained in the overview of Mori above. See Mori, [0036]. As Mori explains, this doping is advantageous in order to mitigate dark current stemming from crystal defects—i.e., to “prevent charges generated when dark due to crystal defects in the partition groove 174 from flowing into the photoelectric conversion unit 161.” Mori, [0036].

124. Accordingly, Mori teaches that Mori's side SiO₂ film is *doped with a dopant to create a surface field* as set forth in this limitation. The '714 patent does not explain how doping the low refractive index material operates to create a surface field. Rather, its only disclosure relating to such doping is that: “[I]t can also be beneficial to dope the sidewalls to create a surface field that will improve electrical isolation between the pixels. In one aspect, it can also be beneficial to dope the low refractive

index material of the Bragg-type reflectors to increase such electrical isolation.” ’714 patent, 10:15-19. That is, the ’714 patent teaches that doping in such a manner as in Mori serves to increase electrical isolation between the pixels via a surface field. Thus, Mori’s doped SiO₂ film 177 along the side of its pixel (photoelectric conversion unit 161) would constitute a *low refractive index material doped with a dopant to create a surface field* to the extent that is contemplated by the limited disclosure of the ’714 patent.

125. As a POSITA would recognize, doping Mori’s silicon dioxide layer with p-type impurities would lead to an excess of positive charges, creating an electric field at the surface of the layer. In other words, Mori teaches that its silicon dioxide layer is *doped with a dopant to create a surface field*.

126. Based on Mori’s teaching, it is obvious to similarly dope Hwang’s silicon oxide layers 212a’—such that this *low refractive index material* (Hwang’s silicon oxide layers) is *doped with a dopant to create a surface field* in the same manner as Mori’s SiO₂ film. Hwang’s silicon oxide layer 212a’ adjoins the side of Hwang’s pixel (pixel semiconductor pattern 110a), just like Mori’s side SiO₂ film 177 adjoins Mori’s pixel. A POSITA would have recognized that doping Hwang’s silicon oxide layer 212a’ with p-type impurities would similarly mitigate dark current stemming from crystal defects in Hwang’s sensor.

127. A POSITA would reasonably expect success in making this modification, given that Hwang has the same arrangement of a silicon/silicon dioxide film disposed at the sidewall between pixels as in Mori. A POSITA would recognize that this doping could be readily implemented in Hwang's sensor. Moreover, this doping could be readily implemented in Hwang's image sensor, e.g., in the manufacturing steps shown in Hwang's figures 20/21 after applying layer 212a' in grooves 206'.

128. Therefore, it would have been obvious in view of Mori for *at least one of the two low refractive index materials* in Hwang to be *doped with a dopant to create a surface field*.

4. Claim 8: “The device of claim 7, wherein the dopant is boron or antimony.”

129. This claim would have been obvious based on Hwang in view of Mori.

130. As explained for claim 7 above, it would have been obvious in view of Mori to dope Hwang's silicon dioxide layer (the *low refractive index material*) with p-type impurities—i.e., a p-type dopant. It further would be obvious to use boron as the p-type dopant, given that boron is one of the most commonly used p-type dopants for Si-based systems. *See, e.g.,* Ex-1018, 27-28 (explaining that Column-IV materials (e.g., Si) are commonly doped with Column-III-dopants (e.g., boron)). A POSITA would have recognized that using boron as a p-type dopant for silicon-based systems is a known technique that would have yielded predictable results, particularly in light

of boron's similar use as a p-type dopant in other similar light trapping devices. *See, e.g.,* Ex-1019, [0011] (“[t]he substrate 35 is a silicon substrate doped with a P-type dopant such as boron, in which case the substrate 35 is a P-type substrate”). Additionally, this claim would have been obvious, because a POSITA would have had a limited number of types of p-type dopants from which to choose, therefore, it would have been obvious to a POSITA to try using boron as the p-type dopant.

131. Accordingly, Hwang in view of Mori teaches or suggests that *the dopant is boron or antimony*.

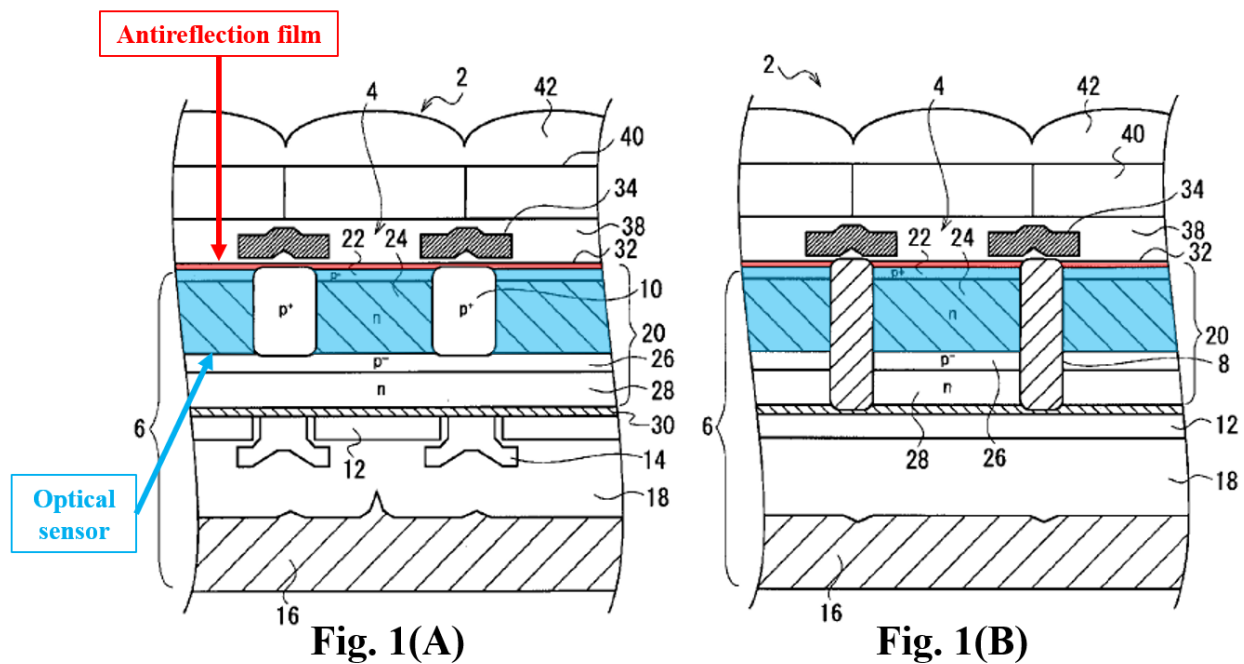
C. Ground 3: Claims 12-13 Are Obvious Based on Hwang and Kasuga

1. Overview of Kasuga

132. U.S. Patent No. 7,285,808 (“Kasuga”) (Ex-1008) is a U.S. patent that I understand is prior art to the '714 patent. It is directed to a “solid-state imaging device,”—i.e., an image sensor. Kasuga, 1:11-12. Like the '714 patent, Kasuga is concerned with improving image quality by using reflective surfaces to increase the amount of incident light absorbed by the photodiode. *See generally* Kasuga, 4:57-5:07, 5:38-43.

133. For example, as shown in 1(A)-(B) below, an “antireflection film 32 is formed on the surfaces of the optical sensors 4 to prevent the reflection of light entering the optical sensors.” Kasuga, 4:4-7. This antireflection film also creates internal reflections within the sensor that further improve sensitivity. As Kasuga explains,

“multiple reflection of light occurs between the antireflection film 32 and one of the first and the second transfer electrodes 12 and 14 and the insulating film 30.” Kasuga, 5:23-25. “As a result, sufficient sensitivity can be obtained even when the size, especially the thickness, of the optical sensors 4 is reduced, and thus the size of the solid-state imaging device 2 can be reduced.” Kasuga, 5:28-31.



Kasuga, Figs. 1(A)-(B).¹²

¹² In Figure 1, the arrow leading from the optical sensors 4 is pointing to 22 and 24 instead of a physical point on the sensor. Kasuga explains that “the optical sensors 4 are composed of, for example, p⁺ regions 22 ... and n-type regions 24.” Kasuga, 3:45-48.

2. Claim 12: “The device of claim 1, further comprising a frontside light trapping material at least partially covering the light incident surface.”

134. This claim would have been obvious based on Hwang in view of Kasuga.

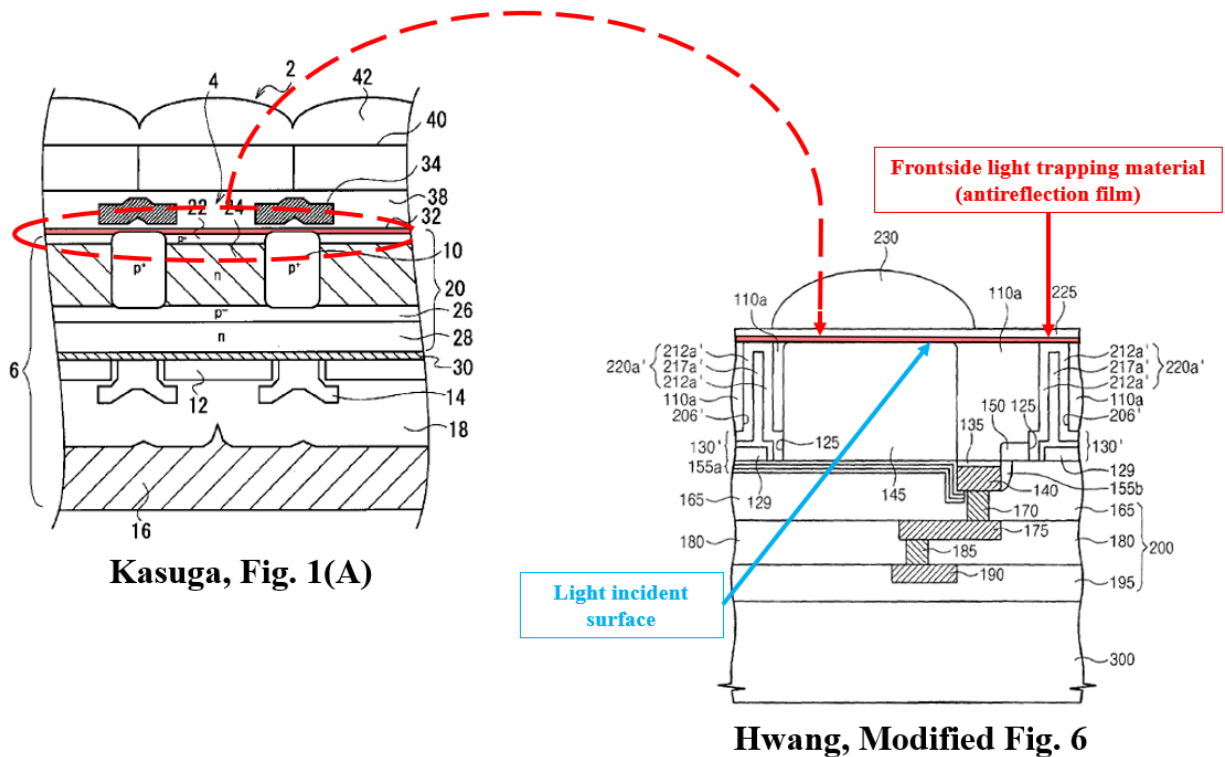
135. Kasuga’s image sensor includes an antireflection film 32 that constitutes a *frontside light trapping material* as recited in this claim. As part of its imaging device, Kasuga discloses that “[a]n antireflection film 32 is formed on the surfaces of the optical sensors 4,” as shown in Figures 1(A) and 1(B). Kasuga, 4:4-7.

136. Kasuga explains that “[t]he antireflection film 32 is formed on the surfaces of the optical sensors 4 to prevent the reflection of light entering the optical sensors 4, so that the amount of light entering the optical sensors 4 increases.” Kasuga, 4:4-7. Kasuga further explains that, by using an antireflection film, “[e]ven if the returning light passes through the optical sensors 4 again, it is reflected by the top surface or the bottom surface of the antireflection film 32, and is converted into electric charge by the optical sensors 4.” Kasuga, 5:18-22. Kasuga’s antireflection film 32 thus allows for “multiple reflection of light [to] occur between the antireflection film 32 and at least one of the first and second transfer electrodes 12 and 14 and the insulating film 30.” Kasuga, 5:22-25. This results in “the total distance which light travels in the optical sensors 4 [to] increase[], and the photoelectric conversion of incident light [being] extremely efficient,” and “[a]s a result, sufficient sensitivity can be obtained

even when the size, especially the thickness, of the optical sensors 4 is reduced, and thus the size of the solid-state imaging device 2 can be reduced.” Kasuga, 5:25-31.

137. Kasuga explains that “when the material and the thickness of the antireflection film 32 are suitably selected such that light reflected by the top surface of the antireflection film 32 and light reflected by the bottom surface of the antireflection film 32 interfere with each other so as to intensify each other, the intensity of the reflected light [attempting to leave the photodiode] further increases and the sensitivity [of the imaging device] can be further increased.” Kasuga, 5:33-42.

138. It would have been obvious to use such an antireflection film in Hwang’s image sensor to improve its efficiency in a similar manner. That is, a POSITA would have been motivated to form an antireflection film as taught in Kasuga on Hwang’s light incident surface, as shown below in the annotated versions of Kasuga, Figure 1(A), and the modified Hwang, Figure 6.



Kasuga, Fig. 1(A) (annotated); Hwang, Fig. 6 (annotated, modified).

139. As shown above, this modification would result in Hwang’s image sensor having a *frontside light trapping material* (the antireflection film) *at least partially covering the light incident surface* (i.e., Hwang’s “second surface” at the top of pixel semiconductor pattern 110a,” as discussed above for ground 1, element 1[a]).

140. A POSITA would have been motivated to make this modification, as adding Kasuga’s antireflection film 32 to Hwang’s image sensor would result in “multiple reflection[s] of light [to] occur[] between the antireflection film 32,” Hwang’s base multi-layered reflection layer 155a, and Hwang’s sidewall multi-layered reflection layer 220a’. Kasuga, 5:17-22. That is, “[e]ven if the returning light

passes through the optical sensors,” it will be “reflected by the ... antireflection film 32” back into the optical sensors and “converted into electric charge by the optical sensors.” Kasuga, 5:17-21. As Kasuga explains, this would result in “the total distance which light travels in the optical sensors [Hwang’s semiconductor pattern 110a] [to] increase[], and the photoelectric conversion of incident light [to be] extremely efficient.” Kasuga, 5:25-28.

141. Additionally, a POSITA would reasonably have expected success in making this modification, given the similarities between Hwang and Kasuga’s image sensors. A POSITA would recognize that the antireflection film 32 could be readily implemented in Hwang’s sensor. For example, in the manufacturing steps shown in Hwang figures 13/14 and 16/17, Hwang, “[a] color filter 225 is disposed on the second surface of the pixel semiconductor pattern 110a.” Hwang, 8:17-18. A POSITA would recognize that the antireflection film 32 could be placed between Hwang’s color filter 225 and its pixel semiconductor pattern 110a, similarly to how the “antireflection film 32 is formed on the surfaces of the optical sensors 4,” beneath the “color filter 40.” Kasuga, 4:4-14. *See also* Kasuga, Fig. 1.

3. Claim 13: “The device of claim 12, wherein the frontside light trapping material is an antireflective layer coating.”

142. This claim would have been obvious based on Hwang in view of Kasuga.

143. As explained for claim 12 above, it would have been obvious for a POSITA to incorporate Kasuga's antireflection film onto the light incident surface of Hwang's image sensor. This antireflection film constitutes *an antireflective layer coating*, as it serves to "prevent the reflection of light entering the optical sensors." Kasuga, 4:4-7.

D. Ground 4: Claims 12 and 14-16 Are Obvious Based on Hwang and Kim

1. Overview of Kim

144. U.S. Patent Application Publication No. 2009/0160000 ("Kim") (Ex-1009) is a U.S. patent application publication that I understand is prior art to the '714 patent. It is directed to an "an image sensor" for "improve[d] light efficiency." Kim, Abstract. Like the '714 patent, Kim is concerned with using reflective films to increase the percent of light absorbed by the photodiode. Kim, [0011] ("In the image sensor ... the reflective films can be formed to be inclined and bent on and/or over the respective photodiodes, thereby returning light reflected from the photodiodes to the photodiodes to a maximum extent. Thus, there is an effect of reducing loss of light reflected from the photodiodes and improving light efficiency.").

145. For example, as shown in Figures 2-3 below, "[r]eflective film frames 104 [are] formed on and/or over photodiodes 102," and then "[r]eflective films 106 ... cover reflective film frames 104 and have openings 107 for receiving light." Kim,

[0015]. These reflective films also create internal reflections within the sensor that improve sensitivity. As Kim explains, the reflective films allow for “[l]ight 105 reflected from photodiodes 102 [to be] returned to photodiodes 102 after being reflected by reflective films 106.” Kim, [0018]. As shown in Figures 2 and 3 below, Kim also uses “[m]icro lenses 116 [to] serve to concentrate a larger amount of light on and/or over photodiodes 102.” Kim, [0017].

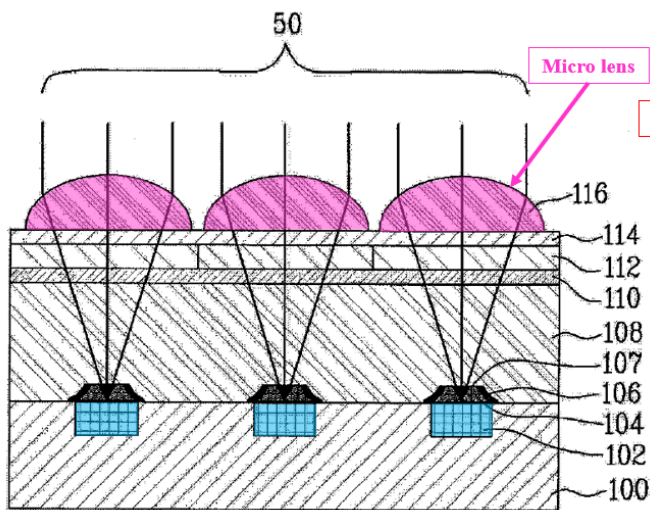


Fig. 2

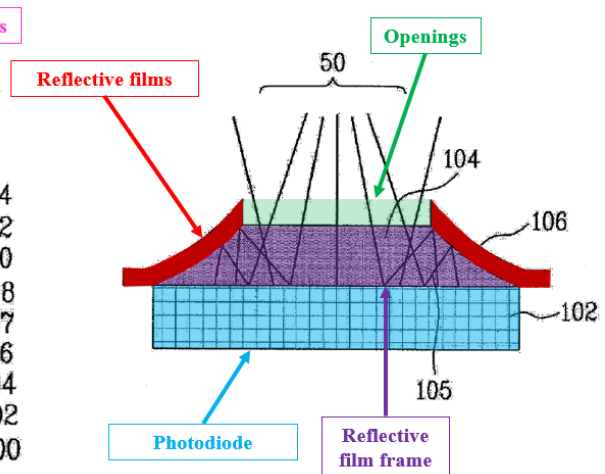


Fig. 3

Kim, Figs. 2-3 (annotated).

2. **Claim 12: “The device of claim 1, further comprising a frontside light trapping material at least partially covering the light incident surface.”**

146. This claim would have been obvious based on Hwang in view of Kim.

147. Kim’s image sensor includes reflective films 106 that constitute a *frontside light trapping material*, as recited in this claim. As part of its image sensor, Kim discloses an “[i]nterlayer insulating film 108 [is] formed on and/or over

semiconductor substrate 100 including reflective films 106.” Kim, [0017]. Kim further discloses that “[t]he image sensor in accordance with [its] embodiments ... can include any structure so long as reflective films 106 and reflective film frames 104 are respectively disposed on and/or over photodiodes 102 to have a structure to receive light into photodiodes 102.” Kim, [0016].

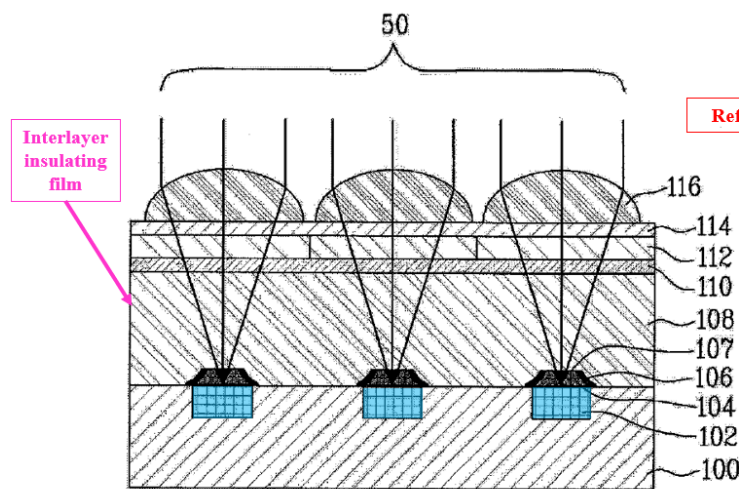


Fig. 2

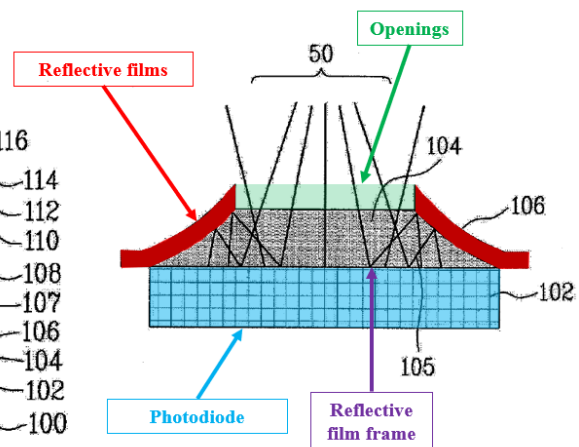


Fig. 3

Kim, Figs. 2-3 (annotated).

148. Kim explains that “[l]ight 105 reflected from photodiodes 102 can return to photodiodes 102 after being reflected by reflective films 106.” Kim, [0018]. Accordingly, as shown in the annotated figures above and below, Kim discloses a frontside light trapping material (reflective films 106) at least partially covering the light incident surface (top surface of photodiodes 102).

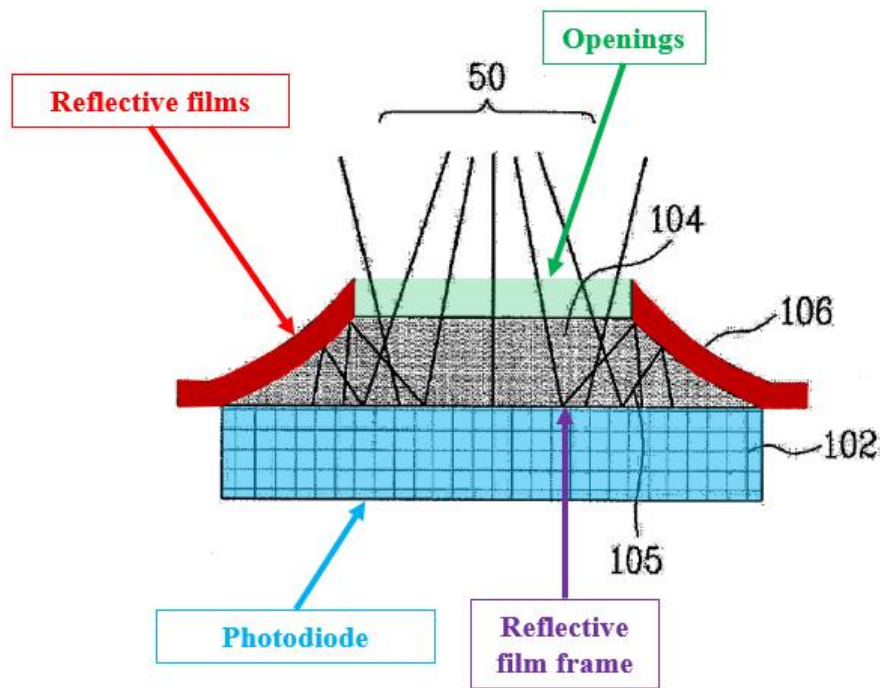


Fig. 3

Kim, Fig. 3 (annotated).

149. Kim explains that “the reflective films can be formed to be inclined and bent on and/or over the respective photodiodes, thereby returning light reflected from the photodiodes to the photodiodes to a maximum extent,” which results in “an effect of reducing loss of light reflected from the photodiodes and improving light efficiency.” Kim, [0011].

150. It would have been obvious to use such reflective films 106 and corresponding openings 107 in Hwang’s image sensor to reduce loss of light reflected from the photodiodes and improve light efficiency, as taught by Kim. This modification would result in Hwang’s image sensor having a *frontside light trapping*

material (the reflective films) *at least partially covering the light incident surface* (i.e., Hwang’s “second surface” at the top of the pixel semiconductor pattern 110a, as discussed above for ground 1, element 1[a]).

151. A POSITA would have been motivated to make this modification, as adding Kim’s reflecting film 106 to Hwang’s image sensor would allow for light “reflected from photodiodes 102 [Hwang’s semiconductor pattern 110a] [to] return to [Hwang’s semiconductor pattern 110a] after being reflected by reflective films 106.” Kim, [0018]. A POSITA would understand that this reflection would increase the sensitivity of Hwang’s image sensor, as shown in Hwang’s teaching that “sensitivity of the image sensor is improved,” because “light that is incident on the photodiode is reflected by the base multi-layered reflection layer and re-enters the photodiode.” Hwang 15:38-41.

152. Additionally, a POSITA would have had a reasonable expectation of success in implementing the reflective film of Kim in the image sensor of Hwang. A POSITA would recognize that Kim’s reflective films 106 having opening 107 and reflective film frames 104 could be readily implemented in Hwang’s image sensor. Kim explains that its “image sensor ... can include any structure so long as reflective films 106 and reflective film frames 104 are respectively disposed on and/or over photodiodes 102 to have a structure to receive light into photodiodes 102.” Kim, [0016]. For example, in the manufacturing steps shown for Hwang’s substantially

similar embodiments in figures 13/14 and 16/17, Hwang explains that “[a] color filter 225 is disposed on the second surface of the pixel semiconductor pattern 110a.” Hwang, 8:17-18. A POSITA would understand that Kim’s reflective films 106 and reflective film frames 104 could be similarly formed between Hwang’s color filter 225 and its pixel semiconductor 110a, similarly to how in Kim the reflecting film frame 104 and reflecting film 106 having opening 107 are formed between its photodiode 102 and color filter 112. Kim, [0015]; *see also* Kim, Fig. 2.

3. Claim 14: “The device of claim 12, wherein the frontside light trapping material is a reflective layer having an aperture to allow entry of light into the pixel, wherein the reflective layer is operable to reflect light impinging thereupon from inside the pixel back into the pixel.”

153. This claim would have been obvious based on Hwang in view of Kim.

154. Kim’s reflective films 106 containing “openings 107 for receiving light,” Kim, [0015], constitute *a frontside light trapping material that is a reflective layer having an aperture*. As explained for claim 12 above, Kim discloses that “[l]ight 105 reflected from photodiodes 102 can return to photodiodes 102 after being reflected by reflected films 106,” Kim, [0018], i.e., the reflective films 106 are *operable to reflect light impinging thereupon from inside the pixel back into the pixel*.

155. Accordingly, Kim reflective films 106 containing “openings 107 for receiving light,” Kim, [0015], constitute *a frontside light trapping material that is a reflective layer (106) that has an aperture (107) to allow entry of light (50) into the*

pixel, wherein the reflective layer is operable to reflect light impinging thereon from inside the pixel back into the pixel, as shown in the annotated Figure 3 below.

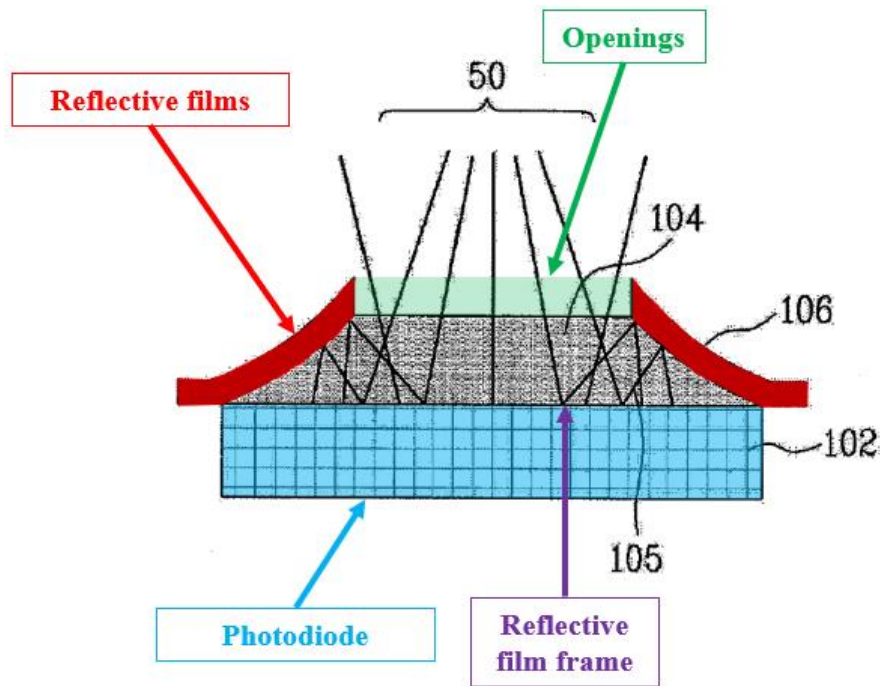


Fig. 3

Kim, Fig. 3 (annotated).

156. As explained for claim 12 above, it would be obvious to a POSITA to form Kim's reflective films 106 and openings 107 on Hwang's light incident surface. A POSITA would understand that Kim's reflective films 106 and openings 107 would operate in a similar fashion in Hwang's image sensor, i.e., allow light to enter the pixel through the openings 107 and cause light incident on the reflective films 106 to be reflected back into the pixel. For example, Hwang discloses a backside layer that causes light to be reflected back into the pixel, as explained for claim 1[b]

above, and thus would cause light to be incident to Kim's reflective films 106 which would then be reflected back into the pixel.

4. Claim 15: "The device of claim 14, further comprising a lens functionally coupled to the aperture and operable to focus incident light through the aperture and into the pixel."

157. This claim would have been obvious based on Hwang in view of Kim.

158. Kim's image sensor includes *a lens coupled to the aperture and operable to focus incident light through the aperture and into the pixel*. Specifically, Kim discloses "a plurality of micro lens 116 corresponding to a respective photodiode 102," as shown in Figure 2. Kim, [0016]. Kim explains that the "[m]icro lenses 116 can serve to concentrate a larger amount of light on and/or over photodiodes 102," Kim, [0017], by directing light through "openings 107," Kim, [0015], as shown in the annotated Figures 2 and 3 below.

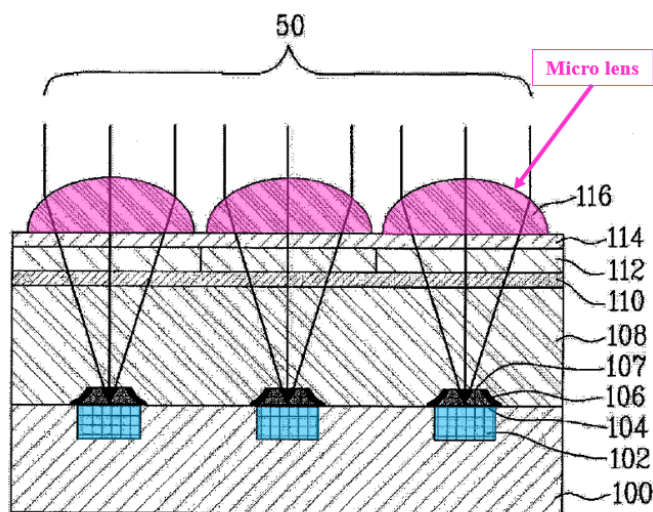


Fig. 2

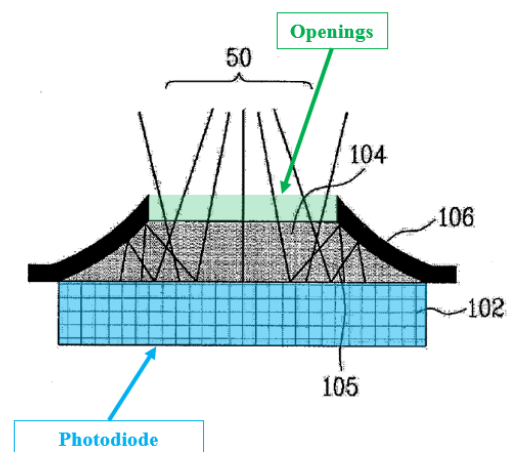


Fig. 3

Kim, Fig. 2 (annotated).

159. Like Kim, Hwang discloses a “micro lens,” and explains that “[e]xternal light passes through the micro lens 230 and the color filter 225, and is incident on the second surface of the photodiode 145.” Hwang, 8:20-22.

160. As explained for claim 12 above, it would have been obvious to incorporate Kim’s openings 107 into Hwang’s image sensor. Using such a lens in Hwang’s image sensor would have been obvious. Indeed, Hwang’s image sensor already includes a “micro lens 230,” which “[e]xternal light passes through” before being “incident on the second surface [i.e., the *light incident surface*].” Hwang, 8:20-22. When incorporating Kim’s reflective films 106 with openings 107 into Hwang’s image sensor, it would be obvious that such a lens should be configured to concentrate the light through the openings (as taught in Kim), in order to ensure that the light enters the pixel. That is, it would be obvious to use a lens that is *functionally coupled to the aperture and operable to focus incident light through the aperture and into the pixel*.

161. A POSITA would reasonably expect success that the lens in this modification would function in a similar fashion to Kim’s, i.e., *focus incident light through the aperture and into the pixel*, as Hwang already includes a microlens, and configuring a lens to direct light in a desired manner is straightforward and commonplace when designing light sensors. Also as explained for claims 12 and 14 above, Hwang’s image sensor incorporating Kim’s aperture would result in light that passes through the lens being focused through the aperture and into the pixel.

162. Accordingly, Hwang in view of Kim teaches or suggests *a lens functionally coupled to the aperture and operable to focus incident light through the aperture and into the pixel.*

5. Claim 16: “The device of claim 14, wherein the aperture has an effective surface area of 90% of the incident light surface total surface area.”

163. This claim would have been obvious based on Hwang in view of Kim.

164. As explained for claims 12 and 14 above, Kim discloses an image sensor with a frontside light trapping material having an aperture. Kim further discloses that its aperture can have *an effective surface area of 90% of the incident light surface total surface area*. Specifically, Kim discloses that “openings 107 can occupy between 70 to 90% of the uppermost surface area of photodiodes 102.” Kim, [0015].

165. As described for claims 12 in 14 above, it would have been obvious to create the aperture described in Kim in Hwang’s image sensor. In particular, based on Kim’s teachings, it would have been obvious to form the *aperture* to have *an effective surface area of 90% of the incident light surface total surface area*. A POSITA would have understood that increasing the size of the aperture would allow more light to be collected, which would provide a motivation to choose the upper bound of Kim’s range.

166. Nevertheless, designing the aperture to be 90% of the incident light surface total surface area would be nothing more than a design choice, as evidenced by the '714 patent's failure to identify any particular benefit of doing so. *See* '714 patent, 12:13-15.

167. Accordingly, Hwang in view of Kim teaches or suggests this claim.

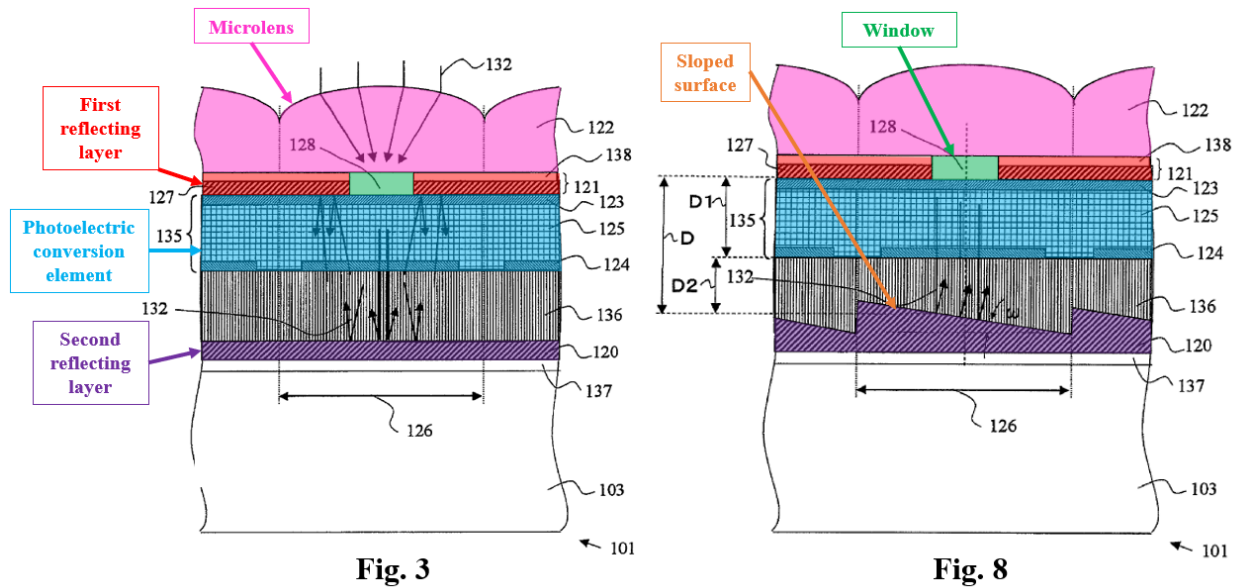
E. Ground 5: Claims 12, 14-15, and 17-18 Are Obvious Based on Hwang and Konno

1. Overview of Konno

168. U.S. Patent No. 7,709,775 (“Konno”) (Ex-1010) is a U.S. patent that I understand is prior art to the '714 patent. It is directed to a “solid-state imaging element,”—i.e., an image sensor. Konno, Abstract. Like the '714 patent, Konno is concerned with increasing image quality by using reflective surfaces to increase the amount of incident light absorbed by the photodiode. *See generally* Konno, 2:49-55.

169. For example, as shown in Figures 3 and 8 below, the “second reflecting layer 120 and the first reflecting layer 121 sandwich the ... photoelectric conversion element 135.” Konno, 8:22-25. As Konno explains, “[t]he second reflecting layer 120 and the first reflecting layer 121 have a function of confining photons which entered into the solid-state imaging element [] between the both,” Konno, 8:31-33, and, as a result “most of the photons can be absorbed with the photoelectric conversion film 125,” Konno, 10:8-13, to improve sensitivity. Konno explains that

the “second reflection layer 120, ... can be formed by forming a thin film of a metal such as aluminum and silver by deposition or the like.” Konno, 8:31-38. Figures 3 and 8 also depict a “microlens 122” which “concentrates photons which entered into the solid-state imaging element 110, and leads them to the light entrance window 128.” Konno, 9:4-9. Figure 8 of Konno is similar to Figure 3, but includes a “reflecting surface of the second reflecting layer 120 [that] inclines,” i.e., a sloped surface. Konno, 15:35-40.



Konno, Figs. 3, 8 (annotated).

2. **Claim 12: “The device of claim 1, further comprising a frontside light trapping material at least partially covering the light incident surface.”**

170. This claim would have been obvious based on Hwang in view of Konno.

171. Konno's solid-state imaging element includes a first reflecting layer 121 that constitutes a *frontside light trapping material*, as recited in this claim. As part of its image sensor, Konno discloses that its "solid-state imaging element 110 has a structure where a reflecting layer (second reflecting layer) 120, a transparent layer 136, and a photoelectric conversion element 135, a reflecting layer (first reflecting layer) 121 and microlens 122 are formed on a substrate 103," to improve detection sensitivity, as shown in the annotated Figure 3 below. Konno, 8:18-22. A "light entrance window 128 through which the incident photons 132 transmit is formed in the first reflecting layer 121." Konno, 8:56-58.

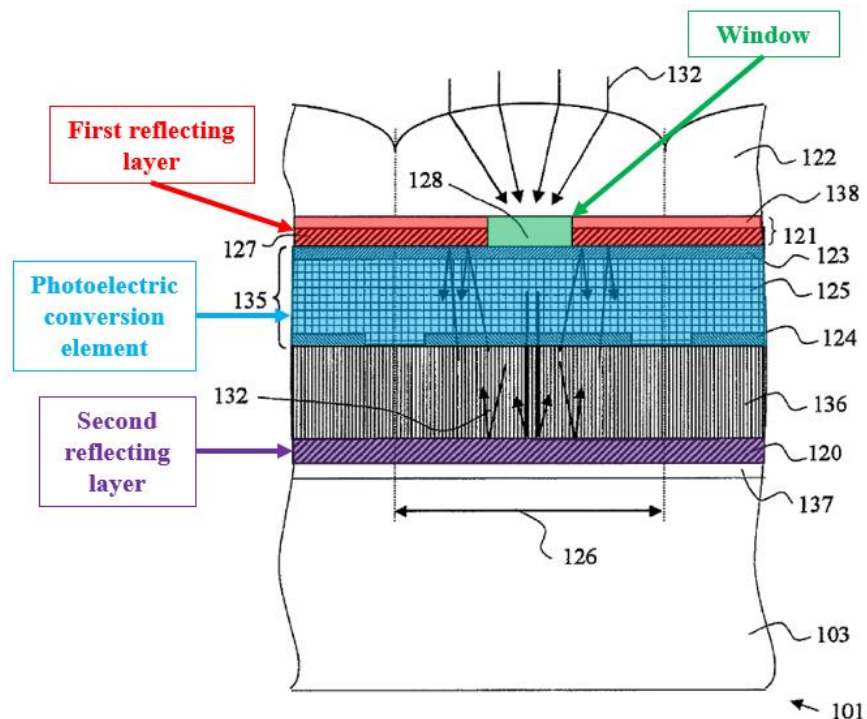


Fig. 3

Konno, Fig. 3 (annotated).

172. Konno explains that “photons which entered from the light entrance window 128 can be effectively confined between the first and second reflection layers 121 and 120 to ... improve detection sensitivity.” Konno, 11:65-12:3.

173. Konno explains that “[t]he second reflecting layer 120 and the first reflecting layer 121 have a function of confining photons which entered into the solid-state imaging element 110 between the both.” Konno, 8:31-33. Konno further explains that because “the photons which entered into the solid-state imaging element 110 are reciprocated between the second reflecting layer 120 and the first reflecting later 121, [the] amount of reciprocating photons ... can be increased....” Konno, 10:14-18. As Konno explains, “photons which entered from the light entrance window 128 can be effectively confined between the first and second reflection layers 121 and 120 to increase the amount of photons participating in photoelectric conversion by the photoelectric conversion element 135 and thereby improve detection sensitivity.” Konno, 11:65-12:3.

174. It would have been obvious to use Konno’s first reflective layer 121 and light entrance window 128 in Hwang’s image sensor to reduce loss of light reflected from the photodiodes and improve light efficiency, as taught by Konno.



176. A POSITA would have been motivated to make this modification, as adding Konno's first reflective layer 121 to Hwang's image sensor would allow for light to be reflected from the first reflective layer back into Hwang's semiconductor pattern 110a, thus increasing its efficiency. Specifically, Konno explains that using the first reflective layer 121 allows for "[t]he second reflecting layer 120 and the first reflecting layer 121 [to] have a function of confining photons which entered into the

solid-state imaging element [] between the both....” Konno, 8:31-33. A POSITA would have had a reasonable expectation of success because, for example, Hwang’s base multi-layered reflection layer 155a would serve to reflect light back to Konno’s first reflective layer 121.

177. A POSITA would have had a reasonable expectation of success in implementing the reflective layer of Konno in the image sensor of Hwang. A POSITA would recognize that the first reflective layer 121 and light entrance window 128 could be readily implemented in Hwang’s image sensor. For example, in the manufacturing steps shown for Hwang’s substantially similar embodiments in figures 13/14 and 16/17, Hwang explains that “[a] color filter 225 is disposed on the second surface of the pixel semiconductor pattern 110a.” Hwang, 8:17-18. A POSITA would recognize that the first reflective layer 121 and light entrance window 128 could be placed between Hwang’s color filter 225 and its pixel semiconductor pattern 110a, similarly to how in Konno the first reflective layer 121 and light entrance window 128 are formed above the photoelectric conversion element 135. *See generally* Konno, 8:18-30, Figs. 3-4.

3. Claim 14: “The device of claim 12, wherein the frontside light trapping material is a reflective layer having an aperture to allow entry of light into the pixel, wherein the reflective layer is operable to reflect light impinging thereupon from inside the pixel back into the pixel.”

178. This claim would have been obvious based on Hwang in view of Konno.

179. Konno’s reflective films 106 containing a “light entrance window 128 through which the incident photons 132 transmit,” Konno, 8:56-58, constitute *a frontside light trapping material that is a reflective layer*. As explained for claim 12 above, Konno discloses a frontside light trapping material, i.e., a “first reflecting layer 121,” Konno, 8:23, having an aperture, i.e., a “light entrance window 128 through which the incident photons 132 transmit [that] is formed in the first reflecting layer 121,” as shown in Figure 3. Konno, 8:56-58. Konno further explains that “a part of the photons which passed through the photoelectric conversion film 125 reach the reflecting surface 127 of the first reflecting layer [121], are reflected again, and [again] reach the photoelectric conversion film 125,” Konno, 10:4-8, i.e., the first reflecting layer 121 *is operable to reflect light impinging thereupon from inside the pixel back into the pixel*.

180. Accordingly, Konno discloses a *frontside light trapping material that is a reflective layer (121) having an aperture (128) to allow entry of light (132) into the*

pixel, wherein the reflective layer is operable to reflect light impinging thereon from inside the pixel back into the pixel.

181. As explained for claim 12 above, it would be obvious to a POSITA to form Konno's second reflection layer 121 and light entrance window 128 on Hwang's light incident surface. A POSITA would understand that Konno's second reflection layer 121 and light entrance window 128 would operate in a similar fashion in Hwang's image sensor, i.e., allow light to enter the pixel through the light entrance window and cause light incident on the second reflection layer 121 to be reflected back into the pixel. For example, like Konno, Hwang discloses a backside layer that causes light to be reflected back into the pixel, as explained for claim 1[b] above, and thus would cause light to be incident to Konno's second reflection layer 121 which would then be reflected back into the pixel. Konno, 10:4-8.

4. Claim 15: “The device of claim 14, further comprising a lens functionally coupled to the aperture and operable to focus incident light through the aperture and into the pixel.”

182. This claim would have been obvious based on Hwang in view of Konno.

183. Konno's solid-state imaging element includes a microlens 122 *functionally coupled to the aperture and operable to focus incident light through the aperture and into the pixel.* Specifically, Konno discloses “[t]he microlens 122 is formed from convex lenses ... and it concentrates photons which entered into the solid-

in annotated Figure 3 below. Konno, 9:4-9.

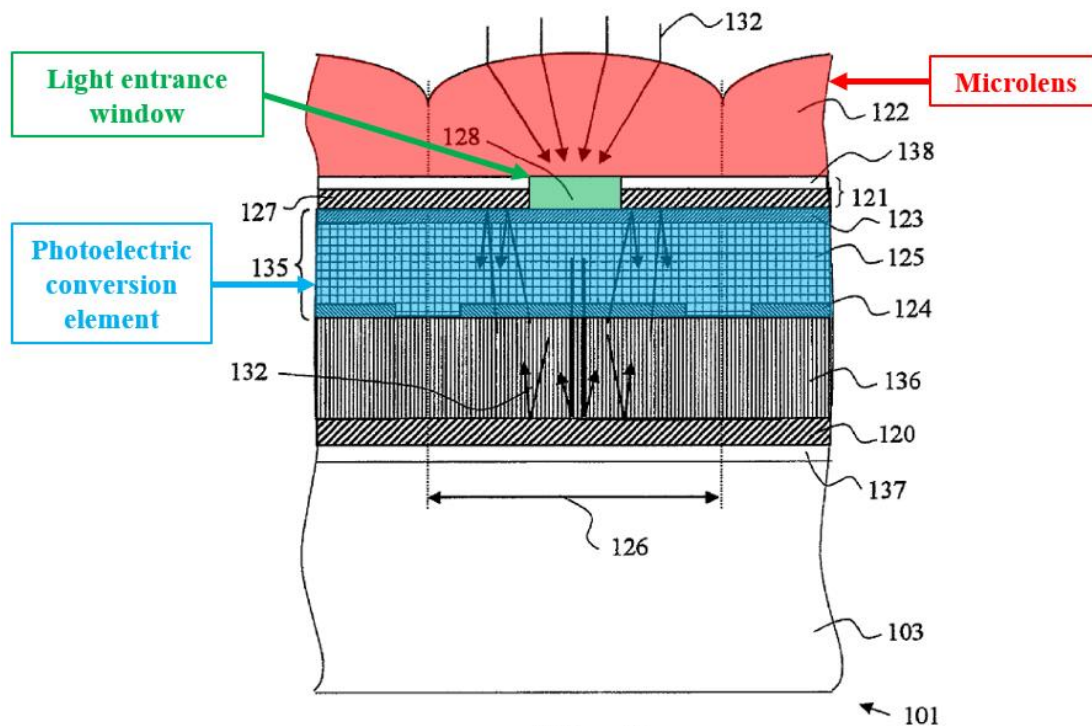


Fig. 3

Konno, Fig. 3 (annotated).

entrance window 128 (i.e., its *aperture*) into Hwang’s image sensor.

185. As explained for to claim 12 above, it would have been obvious to incorporate Konno's light entrance window 128, i.e., its aperture, into Hwang's image sensor. Also as explained for claims 12 and 14 above Hwang's image sensor incorporating Konno's aperture would result in light that passes through the lens being focused through the aperture and into the pixel. When incorporating Konno's first reflecting layer 121 and light entrance window 128 into Hwang's image sensor, it would be obvious that such a lens should be configured to concentrate the light through the window (as taught in Konno), in order to ensure that the light enters the pixel. That is, it would be obvious to use a lens that is *functionally coupled to the aperture and operable to focus incident light through the aperture and into the pixel*. This modification results in Hwang's image sensor having a *lens functionally coupled to the aperture and operable to focus incident light through the aperture and into the pixel*.

186. Moreover, a POSITA would reasonably expect success in using such a lens in Hwang's image sensor, as Hwang already includes a microlens, and configuring a lens to direct light in a desired manner is straightforward and commonplace when designing light sensors.

5. Claim 17: "The device of claim 1, wherein at least one of the backside light trapping material and the peripheral light trapping material is a metal layer."

187. This claim would have been obvious based on Hwang in view of Konno.

188. As explained in Ground 1, claim 1[b] above, Hwang discloses a backside light trapping material comprising base multi-layered reflection layer 155a. However, a POSITA would have recognized that there were other known materials and material combinations to use in such backside light trapping materials, each of which having its own benefits and considerations. For example, Schubert, discusses “[d]ifferent types of reflectors” to use in optoelectronic devices, i.e., “a metallic reflector, distributed Bragg reflector (DBR), hybrid reflector, total internal reflector (TIR), and a triple-layer omni-directional reflector (ODR).” Schubert, 163.

189. Konno’s solid-state imaging element includes a second reflecting layer 120 constituting *a backside light trapping material that is a metal layer*. Specifically, Konno discloses “[t]he second reflection layer 120,” which “can be formed by forming a thin film of a metal such as aluminum and silver by deposition or the like,” as shown in annotated Figure 3. Konno, 8:31-38.

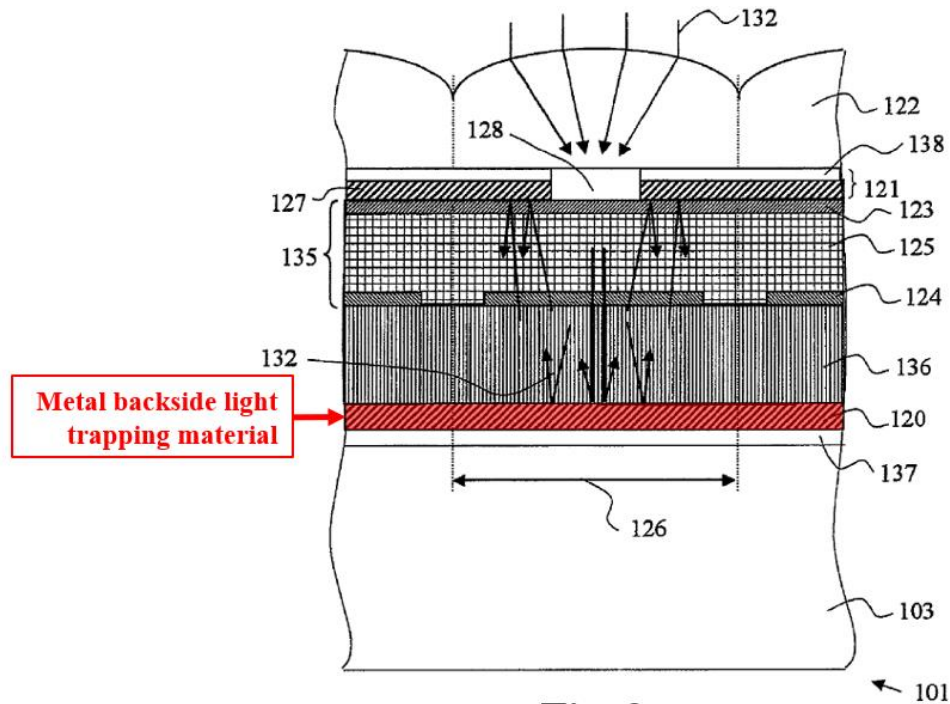
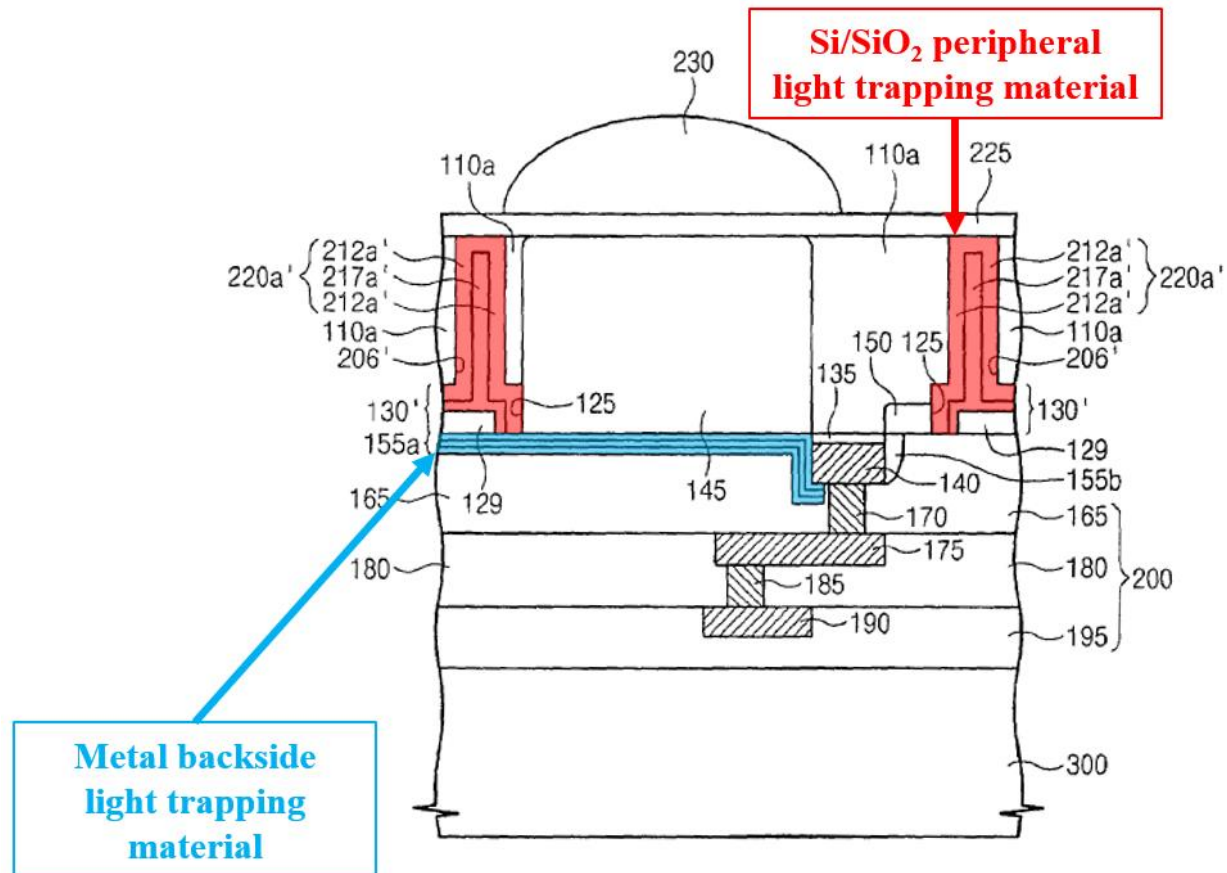


Fig. 3

Konno, Fig. 3 (annotated).

190. Konno explains that “when the reflecting layers 120 and 121 consist of metals, it is also possible to electrically connect at least one of these to ground or electrode potential of a read-out circuit, a control circuit, a power supply or the like.” Konno, 12:29-31. Konno further explains that “[b]y using such a [metal] structure, error signals and noises generated in output signals of the photodetector 101 by external noises which flow in from the outside and flow into the photo-detector 101 and detected in the photoelectric conversion element 135, wiring or the like can be thereby reduced.” Konno, 12:33-38. Therefore, it would have been obvious to use

Konno's metal backside reflective layer in Hwang's image sensor—i.e., substituting Konno's metal reflector for Hwang's base multi-layered reflection layer 155a.



Modified Fig. 6

Hwang, Fig. 6 (annotated, modified). As shown above this, modification results in Hwang's image sensor having a *backside light trapping material that is a metal layer*.¹³

¹³ Under this modification, base claim 1[e] would still be satisfied, as Hwang's image sensor still possesses an Si/SiO₂ peripheral light trapping material that includes a high refractive index material sandwiched between two low refractive index materials.

191. A POSITA would be motivated to use Konno's metal backside reflective layer in Hwang's image sensor to achieve the benefits described by Konno above. Doing so would be nothing more than a simple substitution of one known element (a multi-layer, non-metallic reflector) for another (a metal reflector), as well as the application of a known technique to improve a similar device. The results would be predictable (e.g., the ability to reflect light and make electrical contact). A POSITA would have had a reasonable expectation in making such a modification, i.e., substituting Hwang's non-metallic reflector for Konno's metal reflector. For example, the second reflecting layer 120 could be incorporated (potentially along with an intermediate insulating layer, such as the transparent layer 136) into Hwang after the manufacturing steps shown in Hwang's Figure 22 or between the manufacturing steps shown in Hwang's Figures 8 and 9. A POSITA would understand that the design of these layers could be tailored based on the use of a mask (e.g., mask 160 in Hwang), followed by a subsequent etch.

192. Accordingly, Hwang in view of Konno teaches or suggests a backside light trapping material that is a metal layer.

6. Claim 18: “The device of claim 1, wherein at least one of the backside light trapping material and the peripheral light trapping material has a sloped surface at the pixel device interface”

193. This claim would have been obvious based on Hwang in view of Konno.¹⁴

194. In Konno’s Figure 8 embodiment, the solid-state imaging element includes a second reflecting layer 120 constituting a *backside light trapping material that has a sloped surface*. Specifically, Konno discloses that “the second reflecting layer 120,” can have “incline[s],” as shown in the annotated Figure 8 below. Konno, 15:36-38.

¹⁴ I understand that in the Related Case, Petitioner proposed the that the term “sloped surface at the pixel device interface” is indefinite. Ex-1014, 3. Patent Owner has proposed that the term be given its “plain and ordinary meaning” and that “[t]o the extent a construction is required: sloped trench wall or sloped backside surface.” Ex-1015, 3. I was asked to address this claim under Patent Owner’s interpretation, which is satisfied by Hwang in view of Konno for the reasons explained herein.

Fig. 8

195. As Konno explains, such an inclined surface can be used to redirect light to other reflectors on the surface of the pixel and thereby increase sensitivity. *See, e.g.*, Konno, 15:38-40 (“Incident photons are reflected by this reflecting surface to the first reflecting layer 121 on one side of the light entrance window 128.”); Konno, 15:46-50 (“Also in this case, the inclination of the reflecting surface is designed so that most of photons which entered at the end of the light entrance window 128 except for those absorbed by the photoelectric conversion film 125 should reach to the first reflecting layer 121.”).

196. It would have been obvious to use such a backside light trapping material with an inclined surface in Hwang's image sensor to improve its efficiency in a similar manner. That is, a POSITA would have been motivated to form its base multi-layered reflection layer 155a with a sloped surface. This modification would result in Hwang's image sensor having a *backside light trapping material* (i.e., Hwang's base multi-layered reflection layer 155a, as discussed above for ground 1, element 1[b]) *that has a sloped surface at the pixel device interface*.

197. A POSITA would have been motivated to make this modification, as they would understand that such an inclined surface could be used to redirect light to Hwang's multi-layer reflection layer 220a', or to a frontside light trapping material as described for claim 12, so as to increase efficiency. The use of Konno's sloped backside material would be nothing more than the use of a known technique to improve similar devices in the same way to yield predictable results (i.e., redirection of light at the backside surface). A POSITA would have an expectation of success in implementing the sloped surface of Konno. For example, such a surface could be implemented after the manufacturing steps shown in Hwang's Figure 22 or between the manufacturing steps shown in Hwang's Figures 8/9 for a substantially similar embodiment.

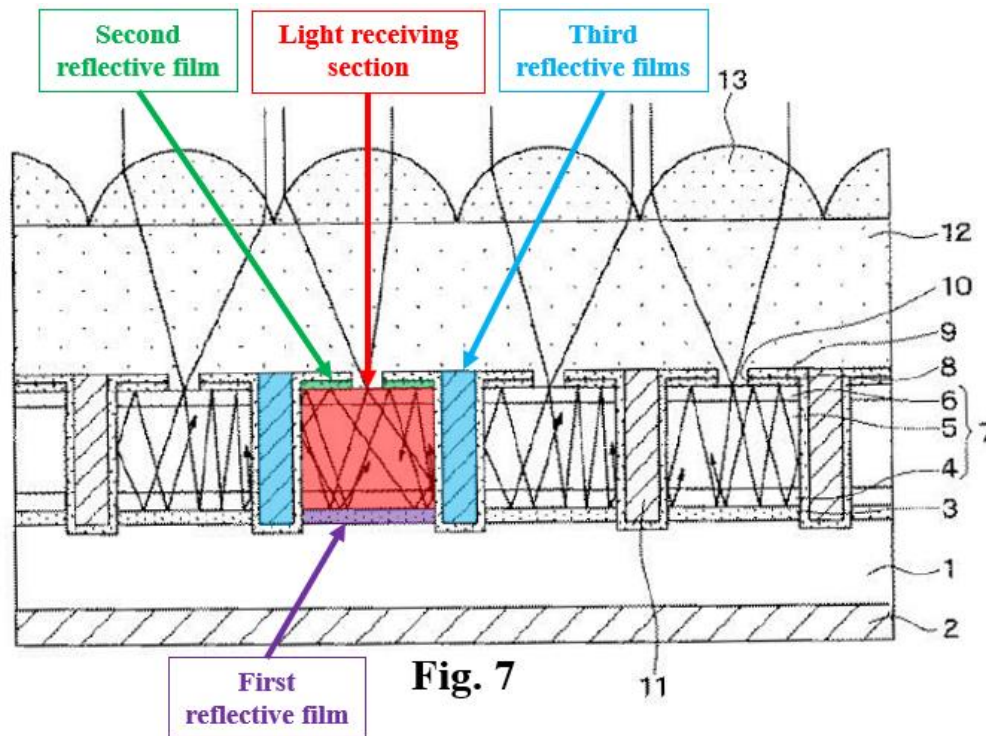
F. Ground 6: Claims 1, 5, 9-12, and 14-17 Are Obvious Based on Yamada

1. Overview of Yamada

198. Japanese Patent Application Publication No. 2009-188316 (“Yamada”) (English translation, Ex-1012, original document, Ex-1011) is a Japanese patent application publication that I understand is prior art to the ’714 patent.

199. Like the ’714 patent, Yamada is directed to an image sensor, i.e., a “light receiving element.” Yamada, [0009] (“the invention described ... is a light receiving element provided with a plurality of light receiving sections”); [0035] (“In this process, the light energy is converted into electrical energy inside the PIN photodiode 7...”). Furthermore, like the ’714 patent, Yamada is concerned with improving image quality by using reflective films to increase the percent of incident light absorbed by the photodiode, *see* Yamada, [0036], and to prevent “optical crosstalk” between neighboring light receiving sections, Yamada, [0038].

200. An exemplary embodiment from Yamada is depicted in Figure 7¹⁵ below.



¹⁵ Figure 7 is “a cross-sectional view of the light receiving element of” Yamada’s fifth embodiment. Yamada, [0049]-[0050]. Yamada explains that “[t]he light receiving element of the [fifth] embodiment is configured to share the third reflecting film 11 between neighboring light receiving sections in contrast to the first embodiment,” but that “[o]ther details are the same as in the first embodiment and are not described [with respect to the fifth embodiment].” Yamada, [0049]. Accordingly, disclosures that Yamada makes with respect to the first embodiment are discussed herein with respect to the fifth embodiment.

Yamada, Fig. 7 (annotated).

201. Yamada's light receiving element includes "a plurality of light receiving sections (7)," each of which is provided with "a first reflective film (3) arranged at a bottom surface of the light receiving section (7), a second reflective film (8) arranged opposing the first reflective film (3) at a front surface of the light receiving section (7) and formed with a through-hole (10) ... , [and] third reflective films (11) arranged at side surfaces of the light receiving section (7)." Yamada, [0009].

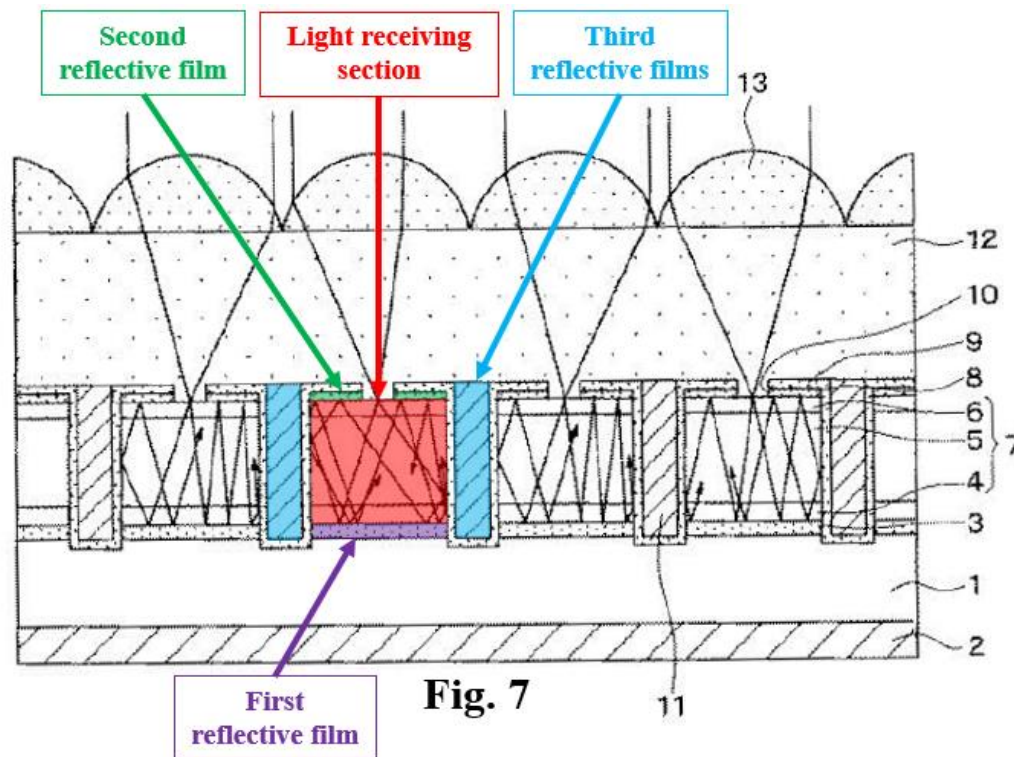
202. Yamada's "light receiving section (7) can be composed of a PIN photodiode." Yamada, [0016]. As Yamada explains, "when light is incident to the PIN photodiode 7, that light is reflected by the first reflective film 3, the second reflective film 8, and the third reflective film 11 so as to be confined within the PIN photodiode 7." Yamada, [0036].

2. Claim 1

a) 1[pre]: "A light trapping device, comprising:"

203. Yamada teaches or suggests this preamble.

204. Yamada discloses "a light receiving element [that is] provided with a plurality of light receiving sections (7)," Yamada, [0009], each of which "can be composed of a PIN photodiode," Yamada, [0004] which convert "light energy ... into electrical energy," Yamada, [0035].



Yamada, Fig. 7 (annotated).

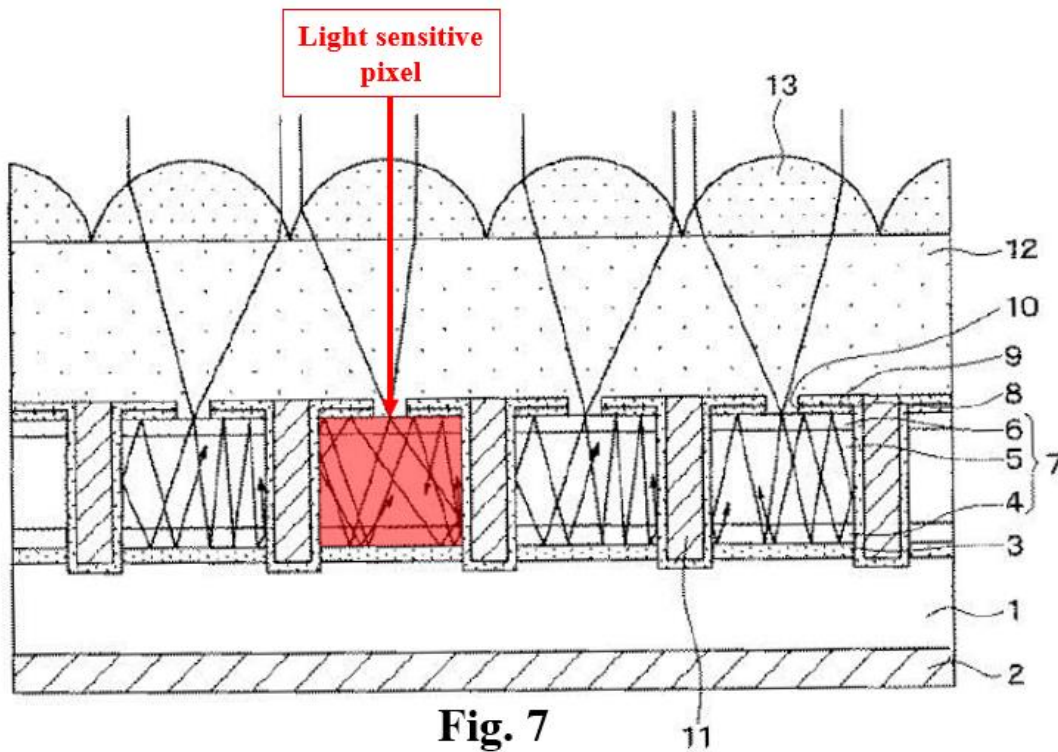
205. As shown in Figure 7 above, Yamada discloses a “first reflective film (3),” “second reflective film (8)” and “third reflective films (11)” surrounding the PIN photodiode such that light “is confined within the light receiving section 7,” Yamada, [0010], i.e., to trap light by reflecting light back into the pixel. Specifically, Yamada explains that its light receiving element serves to trap light: “[L]ight that enters the light receiving section (7) is reflected by the first reflective film (3), the second reflective film (8) and the third reflective films (11) so as to be confined within the light receiving section 7.” Yamada, [0010].

206. Accordingly, Yamada's light receiving element constitutes a *light trapping device*.

- b) 1[a]: “at least one light sensitive pixel having a light incident surface, a backside surface opposite the light incident surface, and a peripheral sidewall disposed into at least a portion of the pixel and extending at least substantially around the pixel periphery;”

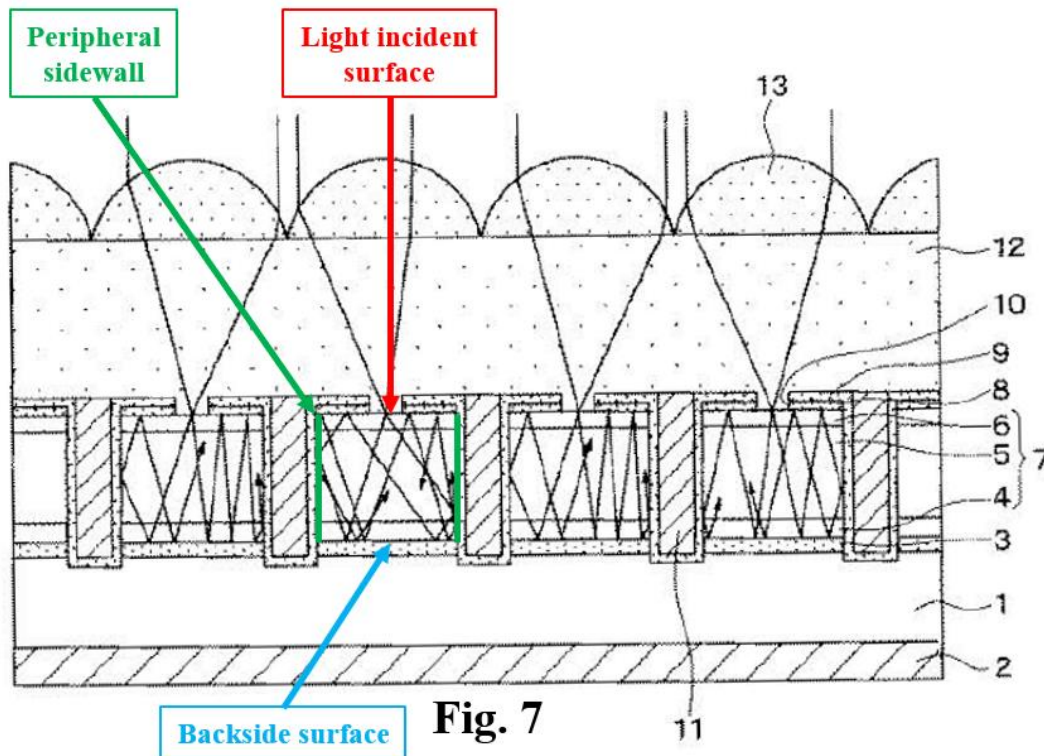
207. Yamada teaches or suggests this limitation.

208. Yamada discloses a light receiving element that comprises *at least one light sensitive pixel*. For example, Yamada discloses “a light receiving element [that is] provided with a plurality of light receiving sections (7),” as shown in Figure 7. Yamada, [0009]. Yamada explains that “[t]he light receiving section[s] (7) can be composed of a PIN photodiode,” Yamada, [0016], and that “light energy is converted into electrical energy inside the PIN photodiode 7 and a photocurrent caused by an electron-hole pair is generated to detect the light incident on the PIN photodiode 7,” Yamada, [0035].



Yamada, Fig. 7 (annotated).

209. Each pixel (light receiving section) in Yamada has a *light incident surface*, a *backside surface opposite the light incident surface*, and a *peripheral sidewall*, as illustrated below.



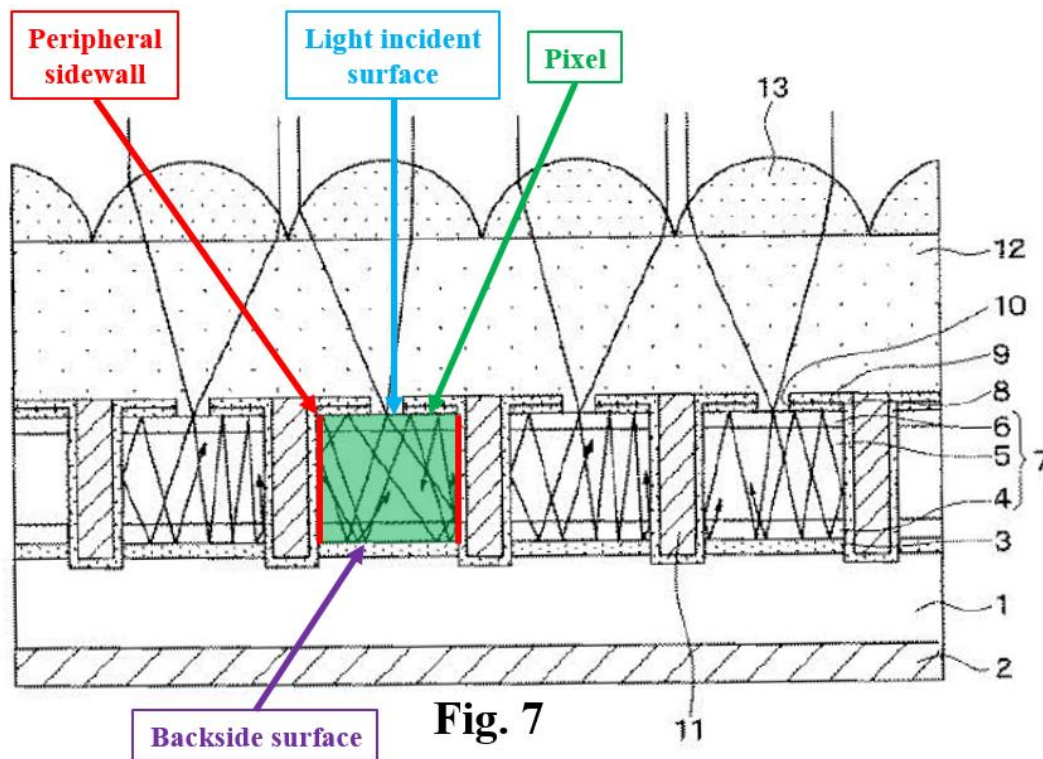
Yamada, Fig. 7 (annotated).

210. Yamada explains that each “light receiving element is provided with a first reflective film (3) arranged at a bottom surface of the light receiving section (7), a second reflective film (8) arranged opposing the first reflective film (3) at a front surface of the light receiving section (7) ... [and] third reflective films (11) arranged at side surfaces of the light receiving section (7)....” Yamada, [0009]. The “front surface” constitutes a *light incident surface*, since “light [that] is incident from the front surface ... is converted into electrical energy” such that “detection is made of the light.” Yamada, [0004]. The “bottom surface” opposes the front surface and thus constitutes

a *backside surface opposite the light incident surface*. The “side surfaces” constitute *peripheral sidewalls*, as they are on the sides of the light receiving element.

211. These peripheral sidewalls are *disposed into at least a portion of the pixel*. As shown in the annotated Figure 7 below, they run from the pixel's' light incident surface to the pixels' backside surface—just like the peripheral sidewall 424 of the '714 patent. See '714 patent, Fig, 4, 11:19-20.¹⁶

¹⁶ I understand that in the Related Case, Petitioner proposed that the term “a peripheral sidewall disposed into at least a portion of the pixel” is indefinite (Ex-1014, 3), and Patent Owner proposed that the term be given its “plain and ordinary meaning” and that “[t]o the extent a construction is required: peripheral trench wall that extends at least partially into the pixel” (Ex-1015, 3). I was asked to address this element under Patent Owner's interpretation, which is satisfied by Yamada for the reasons explained above.



Yamada, Fig. 7 (annotated).

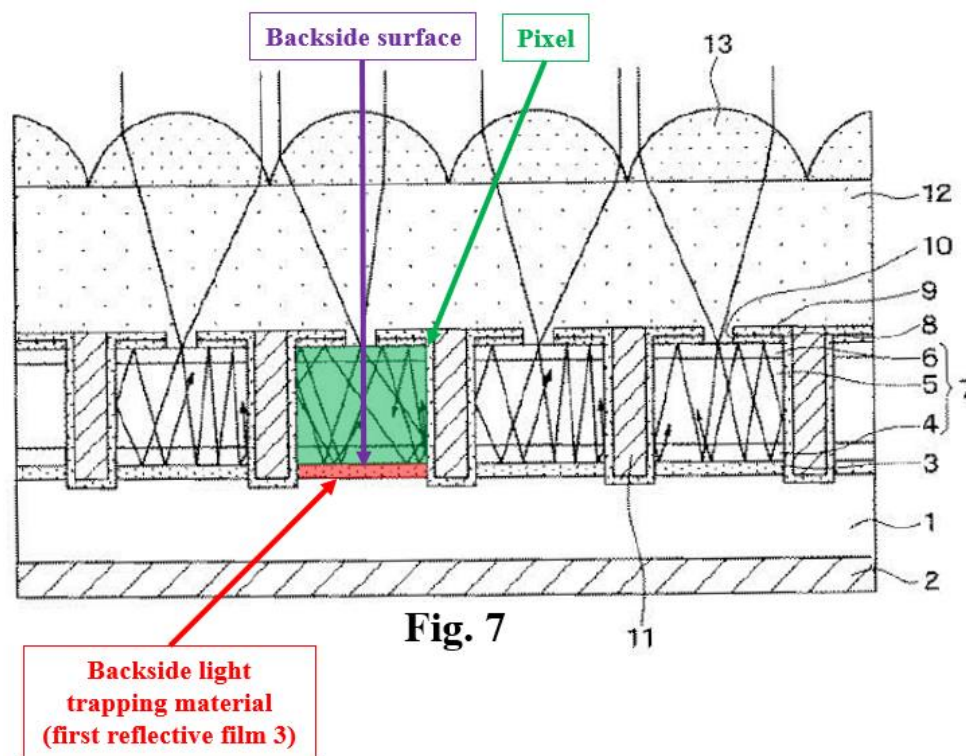
212. Yamada further discloses the peripheral sidewalls *extending at least substantially around the pixel periphery*. Yamada discloses that “[e]ach of the embodiments is configured such that the entire side surfaces of the PIN photodiode 7 is covered by the third reflective films 11....” Yamada, [0056]. Yamada further explains that “the PIN photodiode 7 is surrounded by the ... third reflective film 11, so when light is incident to the PIN photodiode 7, that light is reflected by ... the third reflective films 11 so as to be confined within the PIN photodiode 7.” Yamada, [0036].

213. Accordingly, Yamada’s light receiving element comprises *at least one light sensitive pixel* that meets the requirements of this claim element.

c) 1[b]: “a backside light trapping material at least partially covering the backside surface; and”

214. Yamada teaches or suggests this limitation.

215. Yamada’s light receiving element includes a *backside light trapping material at least partially covering the backside surface* of the pixel. Yamada discloses a “first reflective film (3),” that is “arranged at a bottom surface [*backside surface*] of the light receiving section (7),” Yamada, [0009], as shown in the annotated Figure 7 below.



Yamada, Fig. 7 (annotated).

216. This first reflective film 3 traps light by reflecting light back into the pixel, and therefore constitutes a *light trapping material*. Yamada explains that

“light that enters the light receiving section (7) is reflected by the first reflective film (3) ... so as to be confined within the light receiving section (7).” Yamada, [0010]. Specifically, Yamada explains that “[t]his first reflective film 3 is configured so that the light to be detected is reflected [back into the light receiving section 7] with a high reflectance of at least 99 percent.” Yamada, [0022]. Further, Yamada’s first reflective film 3 *at least partially cover[s] the backside surface*. Yamada explains that the “first reflective film (3) [is] arranged at a bottom surface of the light receiving section (7).” Yamada, [0009]. As explained for limitation 1[a] above, the “bottom surface” constitutes the claimed *backside surface* of the pixel.

217. Accordingly, Yamada’s first reflective film (3) comprises *a backside light trapping material at least partially covering the backside surface*.

d) 1[c]: “a peripheral light trapping material substantially covering the peripheral sidewall;”

218. Yamada teaches or suggests this limitation.

219. Yamada’s light receiving element includes *a peripheral light trapping material substantially covering the peripheral sidewall*. Yamada discloses that “third reflective films (11) [are] arranged at [the] side surfaces of the light receiving section (7).” Yamada, [0009], as shown in Figure 7 below.

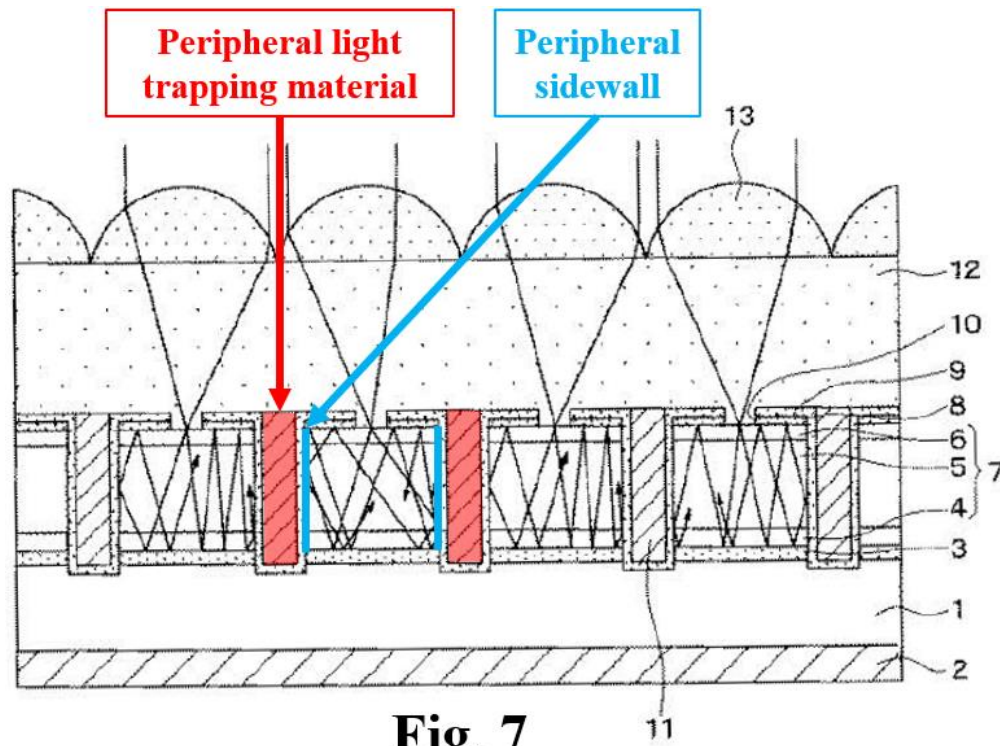


Fig. 7

Yamada, Fig. 7 (annotated).

220. The third reflective film 11 serves to reflect light and minimize interference across pixels, and therefore constitutes a *light trapping material*. As Yamada explains, “light that enters the light receiving section (7) is reflected by ... the third reflective films (11) so as to be confined within the light receiving section 7,” and that “the side surfaces of the light receiving section (7) are covered by the third reflective films (11), preventing optical crosstalk between neighboring light receiving sections.” Yamada, [0010].

221. Further, Yamada’s third reflective film 11 *substantial cover[s] the peripheral sidewall*. As shown in Figure 7, Yamada’s third reflective film 11

substantially covers the peripheral sidewall. This is consistent with Yamada explanation that “since the sides of PIN photodiode 7 are covered with the third reflective films 11, no incident light escapes from the sides of the PIN photodiode 7 and no optical crosstalk occurs between neighboring PIN photodiodes 7.” Yamada, [0038].¹⁷

222. Accordingly, Yamada’s third reflective film 11 comprises *a peripheral light trapping material at least partially covering the peripheral sidewall*.

e) **1[d]: “wherein light contacting the backside light trapping material or the peripheral light trapping material is reflected back toward the pixel;”**

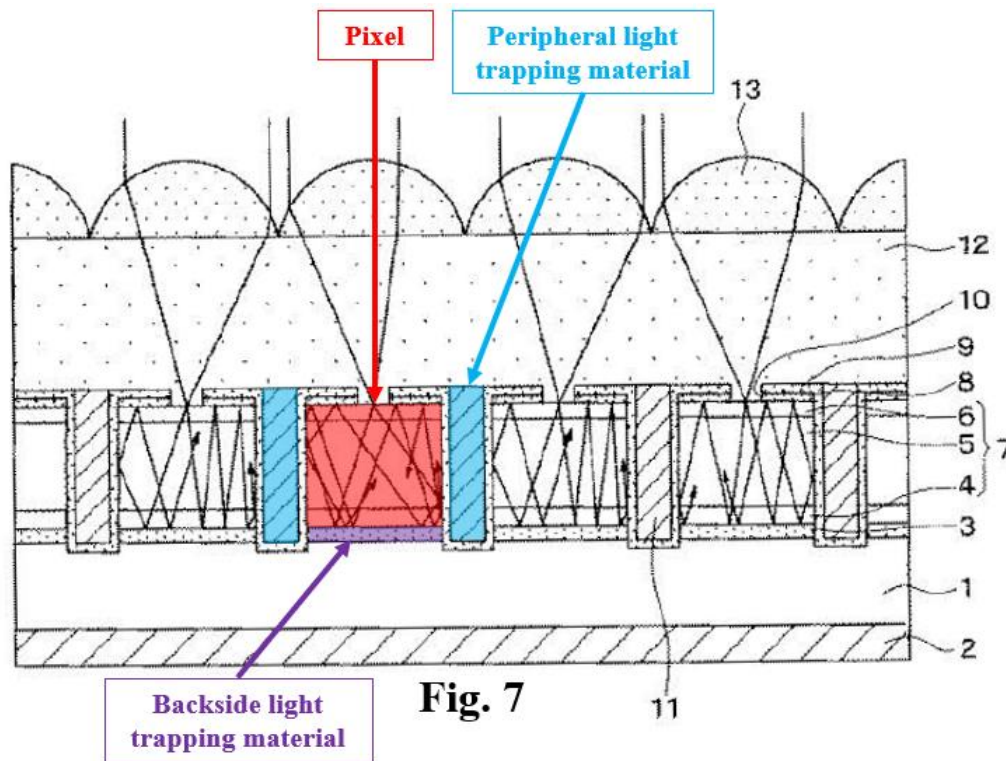
223. Yamada teaches or suggests this limitation.

224. Yamada discloses that *light contacting the backside light trapping material* (i.e., Yamada’s first reflective film 3) and *the peripheral light trapping*

¹⁷ To the extent that this claim element could arguably be interpreted to require that the peripheral light trapping material be in direct contact with the peripheral sidewall of the pixel, Yamada would still satisfy the element, as a POSITA would understand that Yamada’s third reflective film 11 and the surrounding first insulating film 9 would collectively constitute *a peripheral light trapping material* that directly contacts and covers the *peripheral sidewall* (the side surfaces of Yamada’s light receiving sections 7).

material (i.e., Yamada's third reflective film 11) is reflected back towards the pixel.

Yamada discloses that "light that enters the light receiving section (7) is reflected by the first light reflective film (3) ... and the third reflective films (11) so as to be confined within the light receiving section 7." Yamada, [0010]. As shown in Figure 7 below, the light reflected off the backside and peripheral light trapping materials is reflected back toward the pixel.



Yamada, Fig. 7 (annotated).

225. Accordingly, Yamada discloses that in its light receiving element *light contacting both the backside light trapping material and the peripheral light trapping material is reflected back toward the pixel.*

- f) 1[e]: “wherein at least one of the backside light trapping material or the peripheral light trapping material includes a high refractive index material sandwiched between two low refractive index materials.”

226. Yamada teaches or suggests this limitation.¹⁸

227. Yamada discloses that the *backside light trapping material* (i.e., Yamada’s first reflective film 3) *includes a high refractive index material sandwiched between two low refractive index materials*.

228. Yamada discloses that “the first reflective film 3 [i.e., the *backside light trapping material*] is composed of a semiconductor multilayer film,” for example,

¹⁸ I am aware that different constructions were provided for this limitation in the Related Case. I was instructed to interpret the claim such that the *two low refractive index materials* need not be different from one another, consistent with Patent Owner’s construction. I also understand that, in the Related Proceeding Petitioner proposed to construe *low refractive index materials(s)* to mean “material(s) that have a refractive index less than 2.1,” while Patent Owner proposed that it also may encompass “[m]aterial that has ... a refractive index that is at least 0.2 less than the high refractive index material.” Ex-1017, 3 (cleaned up). For purposes of Ground 6, I was instructed to interpret the claim such that the term *low refractive index materials* means a material with a refractive index that is at least 0.2 less than the high refractive index material.

“an $\text{Al}_x\text{Ga}_{1-x}\text{P}$ semiconductor multilayer film.” Yamada, [0021]. Yamada further explains that “[t]he composition ratio of X of $\text{Al}_x\text{Ga}_{1-x}\text{P}$ is changed, as appropriate,” such that “the semiconductor multilayer film is composed by alternating layers of semiconductor films with a low refractive index and a high refractive index.” Yamada, [0021]. A POSITA would understand that choosing a ratio of 1 would result in aluminum phosphide, which is a low refractive index material with a refractive index of “ $2.75 \pm .1$ at 2.8eV,” Ex-1021, 153 or “about 2.8,” at 530nm, Ex-1022, 5:11-12, and that choosing a ratio of 0 would result in gallium phosphide, which is a high refractive index material with a refractive index of approximately 3.5 at 500nm, Schubert, Table 10.1.

229. It would also be obvious to a POSITA that Yamada’s disclosure of alternating layers of low and high refractive index materials in its first reflective film 3 is describing, or at a minimum strongly suggesting, a distributed Bragg reflector (“DBR”)—i.e., a structure formed by alternating materials with different refractive indices—which would consist of multiple pairs of low and high refractive index material. Schubert, 171 (“A DBR is a multi-layer reflector consisting of typically 5–50 pairs of two materials with different refractive indices.”). Such a reflector would have at least *one high refractive index material* (gallium phosphide) *sandwiched between two low refractive index materials* (aluminum phosphide).

230. Accordingly, Yamada light receiving element comprises a *backside light trapping material* that meets the requirements of this claim element.

3. Claim 5: “The device of claim 1, wherein the high refractive index material includes a material having a refractive index of greater than or equal to about 2.1.”

231. Yamada teaches or suggests this claim. As discussed for claim 1[e] above, Yamada teaches or suggests that the high refractive index materials in its first reflective film 3 (the backside light trapping material) may be formed of gallium phosphide, which has a refractive index of approximately 3.5.

4. Claim 9: “The device of claim 1, wherein at least one of the backside light trapping material and the peripheral light trapping material includes a first material sandwiched between two second materials, wherein the first material has a higher refractive index as compared to the two second materials, and wherein the difference in refractive index between the first material and the two second materials is at least 0.2.”

232. Yamada teaches or suggests this claim. As discussed for claim 1[e], Yamada teaches or suggests that that its first reflective film 3 (the *backside light trapping material*) includes a first material formed of gallium phosphide (with a refractive index of approximately 3.5) sandwiched between two second materials formed of aluminum phosphide (with a refractive index of approximately 2.75). In such a structure, the *backside light trapping material* would include a first material (i.e., gallium phosphide, having a refractive index of approximately 3.5) sandwiched

between two second materials (i.e., aluminum phosphide, having a refractive index of approximately 2.75), wherein the first material has a higher refractive index (i.e., approximately 3.5) as compared to the two second materials (i.e., approximately 2.75), and wherein the difference in refractive index between the first material and the two second materials is at least 0.2 (i.e., a difference of approximately $3.5 - 2.75 = 0.75$).

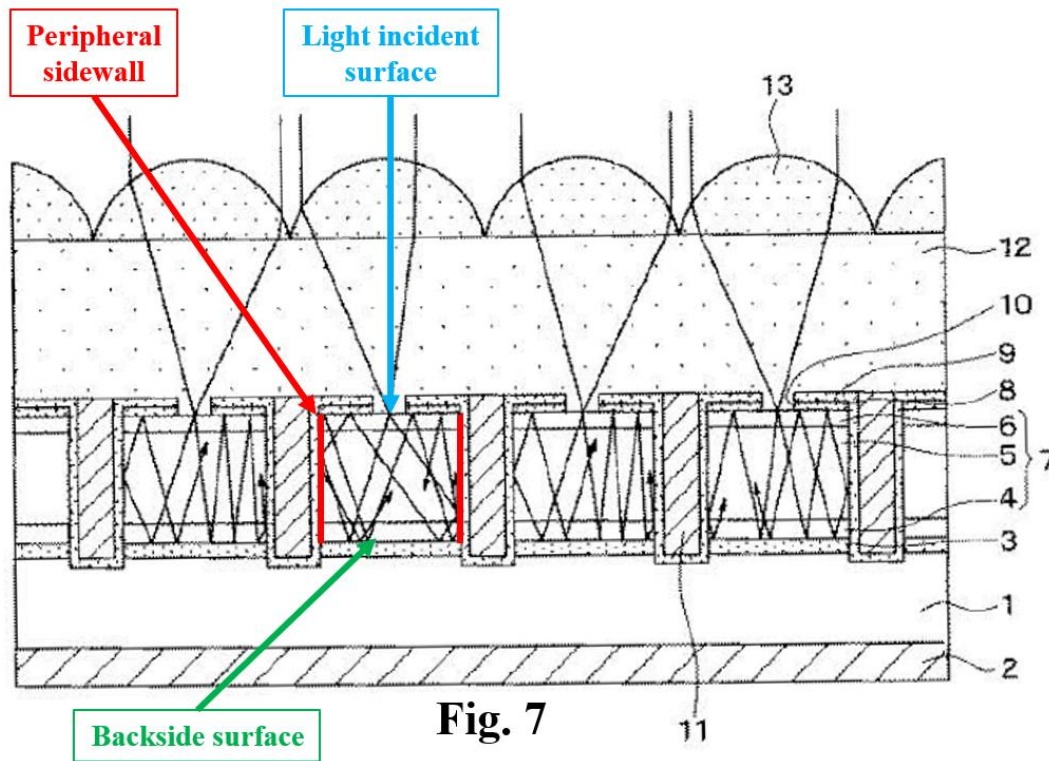
5. Claim 10: “The device of claim 1, wherein the peripheral sidewall extends completely around the pixel periphery.”

233. Yamada teaches or suggests this claim. As discussed for claim 1[a] above, Yamada discloses that “[e]ach of the embodiments is configured such that the entire side surfaces of the PIN photodiode 7 is covered by the third reflective films 11,” Yamada, [0056], and further explains that “the PIN photodiode 7 is surrounded by the ... third reflective film 11, so when light is incident to the PIN photodiode 7, that light is reflected by ... the third reflective films 11 so as to be confined within the PIN photodiode 7,” Yamada, [0036]. Accordingly, Yamada’s light receiving element comprises a *peripheral sidewall extending completely around the pixel periphery*.

6. Claim 11: “The device of claim 1, wherein the peripheral sidewall extends from the light incident surface to the backside surface.”

234. Yamada teaches or suggests this claim. As discussed for claims 1[a] and 10 above, and as shown in the annotated figure below, Yamada’s peripheral

sidewall extends fully from the light incident surface to the backside surface, allowing for light to be “confined within the PIN photodiode 7.” Yamada, [0036].



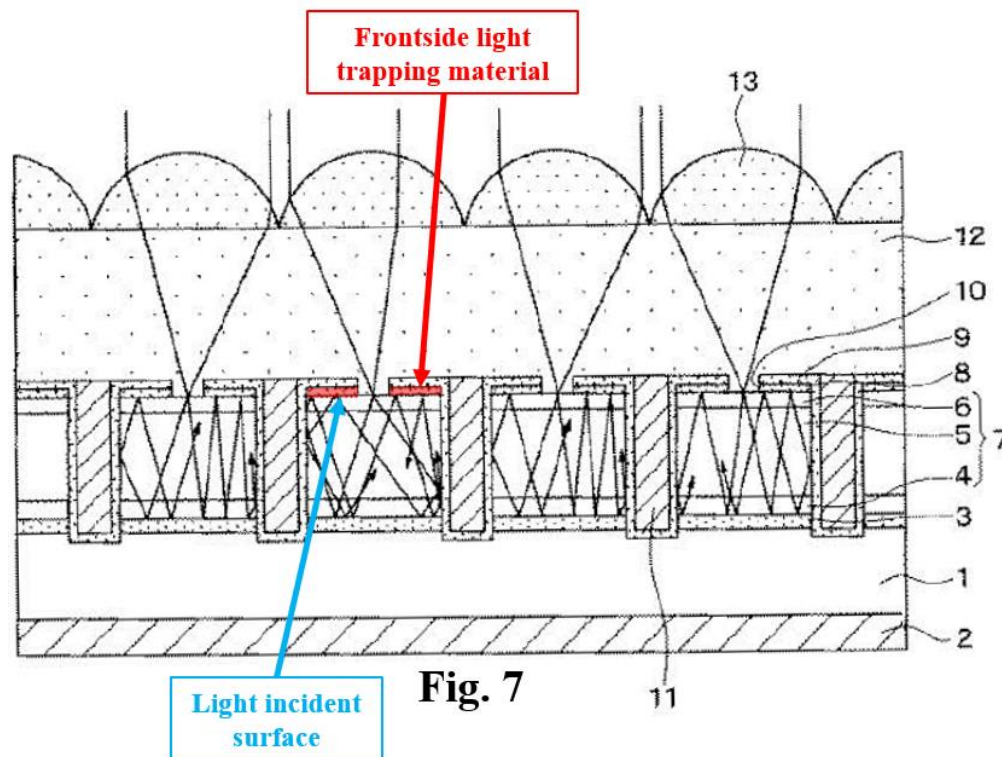
Yamada, Fig. 7 (annotated). See also Yamada, [0056] (“Each of the embodiments is configured such that the entire side surfaces of the PIN photodiode 7 is covered by the third reflective films 11....”).

7. Claim 12: “The device of claim 1, further comprising a frontside light trapping material at least partially covering the light incident surface.”

235. Yamada teaches or suggests this claim.

236. Yamada’s light receiving element includes *a frontside light trapping material at least partially covering the light incident surface*. Yamada discloses a

“second reflective film (8) arranged opposing the first reflective film (3) at a front surface of the light receiving section (7),” Yamada, [0009], as shown in the annotated Figure 7 below.



Yamada, Fig. 7 (annotated).

237. Yamada explains that “light that enters the light receiving section (7) is reflected by ... the second reflective film (8) ... so as to be confined within the light receiving section (7).” Yamada, [0010]. Specifically, Yamada explains that “this second reflective film 8 ... is configured so that the light to be detected is reflected [back into the light receiving section 7] with a high reflectance of at least 99 percent.” Yamada, [0024].

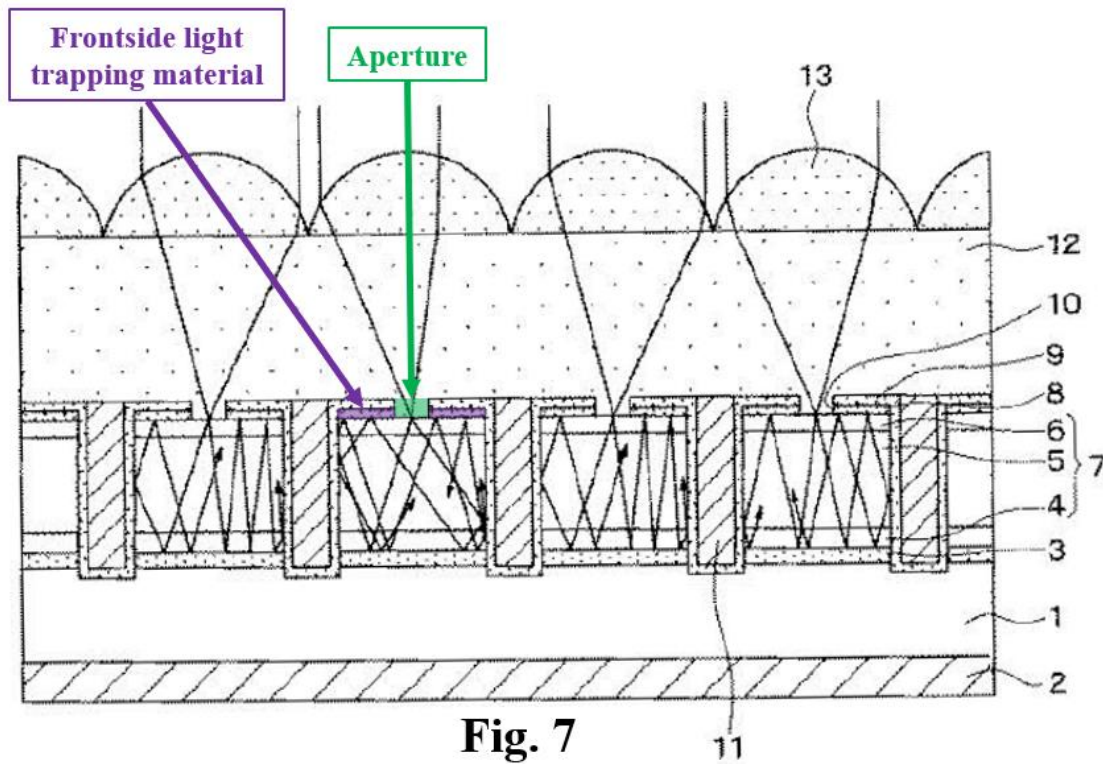
238. Accordingly, Yamada's second reflective film 8 comprises a *frontside light trapping material at least partially covering the light incident surface*.

8. **Claim 14: “The device of claim 12, wherein the frontside light trapping material is a reflective layer having an aperture to allow entry of light into the pixel, wherein the reflective layer is operable to reflect light impinging thereupon from inside the pixel back into the pixel.”**

239. Yamada teaches or suggests this claim.

240. As explained for claim 12 above, Yamada discloses a *frontside light trapping material that is a reflective layer*.

241. Yamada further discloses a *frontside light trapping material that is a reflective layer and has an aperture*. Yamada discloses that the “second reflective film (8) [i.e., a frontside light trapping material] [is] arranged opposing the first reflective film (3) at a front surface of the light receiving section (7) and [is] formed with a through-hole (10) [i.e., an aperture]....” Yamada, [0009], as shown in annotated Figure 7 below.



Yamada, Fig. 7 (annotated).

242. Yamada further discloses that the *aperture allow[s] entry of light into the pixel*. Specifically, Yamada discloses that the “through-hole (10) expose[s] a portion of the front surface of the light receiving section (7)” to light. Yamada, [0009].

243. Yamada further discloses that the *reflective layer is operable to reflect light impinging thereupon from inside the pixel back into the pixel*. Specifically, Yamada discloses that “light that enters the light receiving section (7) [through the through-hole (10)] is reflected by the first reflective film (3), the second reflective film (8) [i.e., the frontside light trapping material] and the third reflective film (11)

so as to be confined within the light receiving section 7,” Yamada, [0010]. As shown in the annotated Figure 7 below, including by the arrows showing internal reflections within the light receiving section, the second reflective film (8) reflects light impinging thereupon from inside the pixel back into the pixel.

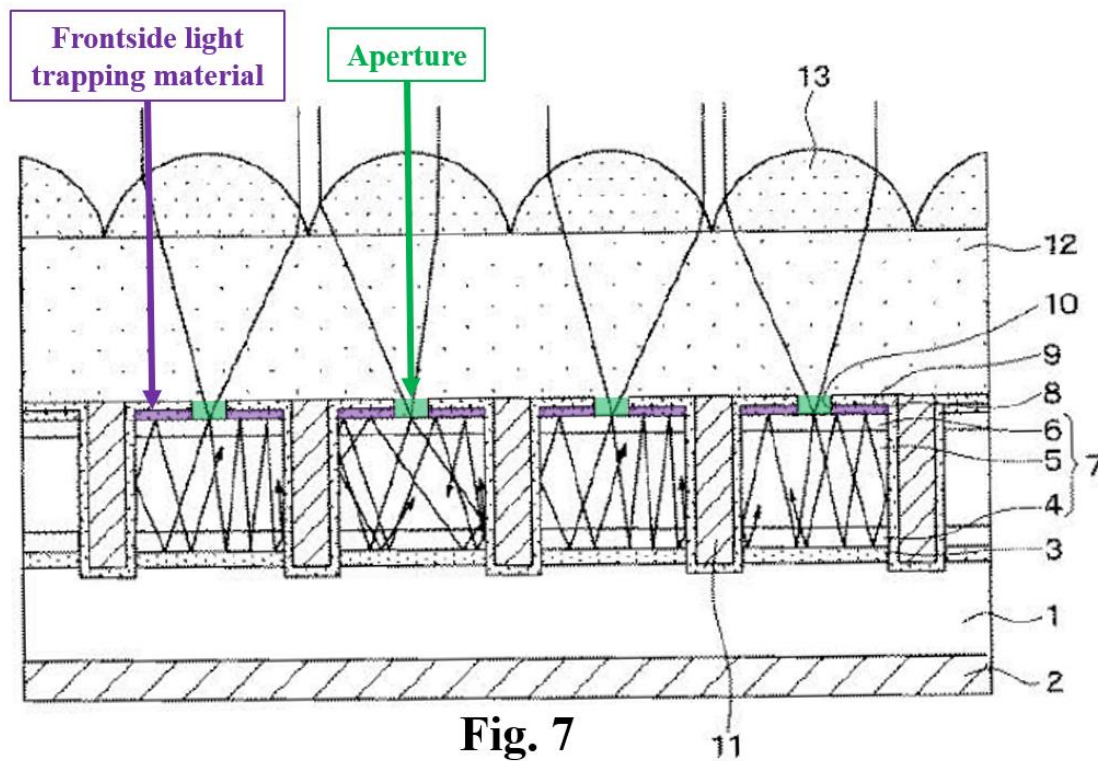


Fig. 7

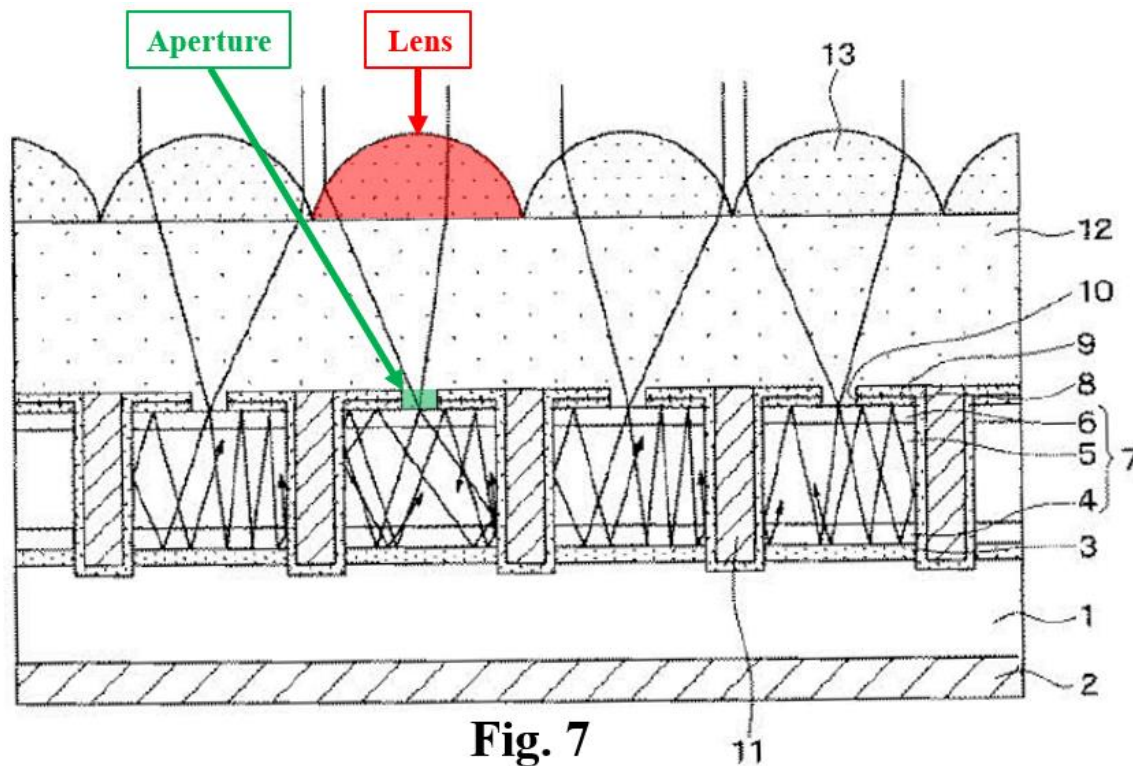
Yamada, Fig. 7 (annotated).

244. Accordingly, Yamada teaches or suggest *a frontside light trapping material that is a reflective layer having an aperture to allow entry of light into the pixel, wherein the reflective layer is operable to reflect light impinging thereupon from inside the pixel back into the pixel.*

9. Claim 15: “The device of claim 14, further comprising a lens functionally coupled to the aperture and operable to focus incident light through the aperture and into the pixel.”

245. Yamada teaches or suggests this claim.

246. Yamada discloses *a lens functionally coupled to the aperture and operable to focus incident light through the aperture and into the pixel*. Specifically, Yamada discloses “a microlens (13) arranged at the front surface side of the light receiving section (7), configured so as to gather light at the exposed portion of the front surface of the light receiving section (7), and making the gathered light enter the light receiving section (7).” Yamada, [0009]. Yamada further discloses that the microlens (13) “is configured such that when the light gathered by the microlens (13) is made to enter the light receiving section (7) from the exposed portion of the front surface of the light receiving section (7), the entering light incident from an oblique direction with respect to the front surface of the light receiving section (7) is reflected by the first film (3), the second reflective film (8), and the third reflective films (11) so as to be confined inside the light receiving section (7),” Yamada, [0009], as shown in the annotated Figure 7 below.



Yamada, Fig. 7 (annotated).

247. Accordingly, Yamada teaches or suggests this claim.

10. Claim 16: “The device of claim 14, wherein the aperture has an effective surface area of 90% of the incident light surface total surface area.

248. Yamada teaches or suggests this claim.

249. As explained for claims 12 and 14 above, Yamada discloses a light receiving element with a frontside light trapping material having an aperture. However, Yamada is silent as to the aperture’s effective surface area.

250. It would have been obvious to form the aperture to have *an effective surface area of 90% of the incident light surface total surface area*. A POSITA

would have understood that increasing the size of the aperture would allow more light to be collected. Indeed, light trapping devices with structures similar to Yamada disclose that apertures can have *an effective surface area of up to 90% of the incident light surface total surface area*, as described for Ground 1, claim 16 above. For example, Kim teaches an example of a light trapping device with an aperture that can have a surface area of up to 90 of the incident light surface total surface area. See Kim, [0015] (“openings 107 can occupy between 70 to 90% of the uppermost surface area of photodiodes 102.”).

251. Nevertheless, designing the aperture to be 90% of the incident light surface total surface area is nothing more than a design choice, as evidenced by the ’714 patent’s failure to identify any particular benefits of doing so. See ’714 patent, 12:13-15.

252. Accordingly, Yamada teaches or suggests this claim.

11. Claim 17: “The device of claim 1, wherein at least one of the backside light trapping material and the peripheral light trapping material is a metal layer.”

253. Yamada teaches or suggests this claim.

254. Yamada discloses that the *peripheral light trapping material is a metal layer*. As explained for claim 1[c] above, Yamada discloses a peripheral light trapping material, i.e., the third reflective film 11. Yamada further discloses that “[t]he third reflective film (11) can be composed of a metal [such as aluminum].”

Yamada, [0012]. Specifically, Yamada discloses that “[t]hird reflective films 11 [can be] composed of a metal such as Al....” Yamada, [0026].

255. Accordingly, Yamada teaches or suggests this claim.

G. Ground 7: Claim 18 Is Obvious Based on Yamada and Konno

1. Overview of Konno

256. As explained in Ground 5 above, Konno is directed to a solid state imaging device. Among other things, Konno discloses a “reflecting surface of the second reflecting layer 120 [that] inclines.” Konno, 15:35-40.

2. Claim 18: “The device of claim 1, wherein at least one of the backside light trapping material and the peripheral light trapping material has a sloped surface at the pixel device interface”

257. This claim would have been obvious based on Yamada in view of Konno.¹⁹

¹⁹ I understand that in the Related Case, Petitioner proposed that the term “sloped surface at the pixel device interface” is indefinite. Ex-1014, 3. Patent Owner has proposed that the term be given its “plain and ordinary meaning” and that “[t]o the extent a construction is required: sloped trench wall or sloped backside surface.” Ex-1015, 3. I was asked to address this claim under Patent Owner’s interpretation, which is satisfied by Yamada in view of Konno for the reasons explained herein.

258. In Konno's Figure 8 embodiment, the solid-state imaging element includes a *backside light trapping material* that *has a sloped surface*. Specifically, Konno discloses that “the second reflecting layer 120,” can have “incline[s],” as shown in the annotated Figures 8 below. Konno, 15:36-38.

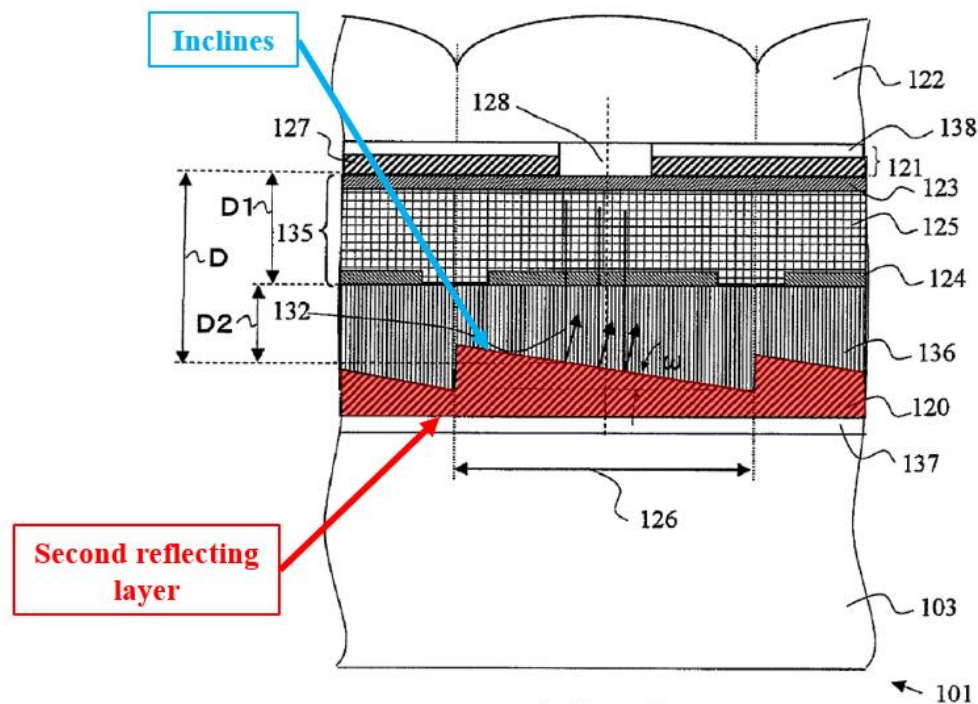


Fig. 8

Konno, Fig. 8 (annotated).

259. As Konno explains, such an inclined surface can be used to redirect light to other reflectors on the surface of the pixel and thereby increase sensitivity. *See, e.g.*, Konno, 15:38-40 (“Incident photons are reflected by this reflecting surface to the first reflecting layer 121 on one side of the light entrance window 128.”); Konno, 15:46-50 (“Also in this case, the inclination of the reflecting surface is designed so that most of

photons which entered at the end of the light entrance window 128 except for those absorbed by the photoelectric conversion film 125 should reach to the first reflecting layer 121.”).

260. It would have been obvious to use such a backside light trapping material with an inclined surface in Yamada’s light receiving element to improve its efficiency in a similar manner. That is, a POSITA would have been motivated to form its first reflective film 3 with a sloped surface. This modification would result in Yamada’s light receiving element having a *backside light trapping material* (i.e., Yamada’s first reflective film 3, as discussed above for ground 1, element 1[b]) *that has a sloped surface at the pixel device interface*.

261. A POSITA would have been motivated to make this modification, as it they would understand that such an inclined surface could be used to redirect light to Yamada’s third reflective films (11) or second reflective film (8). A POSITA would have an expectation of success in implementing the sloped surface of Konno. For example, such a surface could be implemented during, for example, the manufacturing steps shown for a substantially similar embodiment of Yamada shown in Yamada’s Figure 2(a).

H. Ground 8: Claims 1-6, 9-12, and 14-17 Are Obvious Based on Yamada and Schubert

1. Overview of Schubert

262. E. Fred Schubert, *Light-Emitting Diodes* (2nd ed. 2006) (“Schubert”) (Ex-1013) is an excerpt of a textbook titled “Light Emitting Diodes” that I understand is prior art to the ’714 patent.

263. Like the ’714 patent, Schubert discusses the use of reflectors in optoelectronic devices. Specifically, Schubert is a textbook chapter titled “Reflectors,” and discusses potential reflectors, including distributed Bragg reflectors, that a POSITA may use as well as the characteristics of an ideal reflector. Schubert, 163.

2. Claim 1

a) 1[pre]-1[d]

264. Yamada teaches or suggests these limitations for the same reasons discussed above for Ground 6.

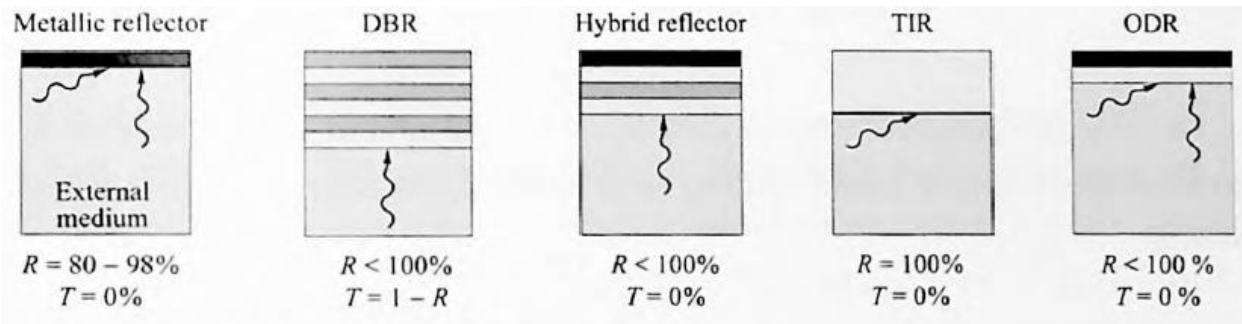
b) 1[e]: “wherein at least one of the backside light trapping material or the peripheral light trapping material includes a high refractive index material sandwiched between two low refractive index materials.”

265. Yamada alone teaches or suggests this limitation for the same reasons as discussed in Ground 6 above for claim 1[e]. Additionally this limitation would

have been obvious for the following additional reasons (even if *low refractive index material* is interpreted to require a refractive index of less than 2.1²⁰).

266. As explained in Ground 6 above, Yamada discloses a peripheral light trapping material comprising third reflective film 11 that “can be composed of a metal” such as aluminum. Yamada, [0012]. However, a POSITA would have recognized that there were other known materials and material combinations to use in such peripheral light trapping materials, each of which having its own benefits and considerations. For example, Schubert discusses the “[d]ifferent types of reflectors” to use in optoelectronic devices, i.e., “a metallic reflector, distributed Bragg reflector (DBR), hybrid reflector, total internal reflector (TIR), and a triple-layer omni-directional reflector (ODR).” Schubert, 163.

²⁰ I am aware that different constructions were provided for this limitation in the Related Case. I was instructed to interpret the claim such that the *two low refractive index materials* need not be different from one another, consistent with Patent Owner’s construction. In Ground 6, I was asked to interpret the claim such that the term *low refractive index materials* means a material with a refractive index that is at least 0.2 less than the high refractive index material. Here, however, this limitation would have been obvious based on Yamada and Schubert under both parties constructions for the term *low refractive index materials*.



Schubert, Fig. 10.1.

267. As a common example of a DBR, Schubert further discloses alternating layers of silicon dioxide (having a refractive index of 1.46) and silicon (having a refractive index of 3.51). Schubert, 177. Such a Si/SiO₂ DBR comprises a *high refractive index material* (silicon layer) *sandwiched between two low refractive index materials* (silicon dioxide layers), as a DBR is a “multi-layer reflector consisting of typically 5–50 pairs of two materials with different refractive indices,” Schubert, 171.

268. It would have been obvious to use a Si/SiO₂ DBR in place of Yamada’s peripheral third reflective films 11 and first insulator 9, such that Yamada’s light receiving element includes a *peripheral light trapping material* (the Si/SiO₂ DBR) that *includes a high refractive index material* (silicon, having a refractive index of 3.51) *sandwiched between two low refractive index materials* (silicon dioxide, having a refractive index of 1.46). Indeed, Schubert teaches that Si/SiO₂ is a known DBR option that “yield[s] high reflectivity,” Schubert 172. As explained in the Mori overview above, a POSITA would further have understood that that isolation elements

comprising a metal thinly insulated from the photodiode exhibit increased dark current. As Mori explains “Furthermore, metal is embedded in the silicon material, ... [t]his also increases crystal defects in the silicon layer and increases charges generated when dark, resulting in a decrease in sensitivity.” Mori, [0008]. *See also* Mori, [0007]. A known solution to this problem was replacing such metal isolation elements, like Yamada’s, with Si/SiO₂ partitions. For example, Mori explains that

[I]n the partition part 163 in the solid-state imaging device of the present embodiment, a silicon layer 175 is embedded in a partition groove....

The partition part 163 also has a side SiO₂ film 177 formed on the bottom and side surfaces of the partition groove. Thereby, crystal defects occurring on the side surfaces of the separation trenches can be reduced, and a decrease in sensitivity caused by charges generated when dark can be suppressed.

Mori, [0029]-[0030].

269. A POSITA would have had a reasonable expectation of success in making such a combination. As explained for claim 1[b] in Ground 6 above, Yamada’s third reflective films are used to reflect light back into the photodiode. Schubert teaches that Si/SiO₂ DBRs “yield high reflectivity,” Schubert 172, and “high-contrast materials Si ($\bar{n} \approx 3.5$ at $\lambda = 1 \mu m$) and SiO₂ ($\bar{n} \approx 1.46$) are natural candidates for [omni-directional reflectors],” Schubert, 181. *See also* Schubert, Fig. 10.8 (showing a Si/SiO₂

reflector with four pairs having a 100% reflectance at approximately 1-1.4 μ m), 170 (“DBR’s reflectivity can be increased by increasing the number of reflector pairs...”). Indeed, Si/SiO₂ reflectors were used as light trapping materials in similar known image sensors. *E.g.*, Hwang, 9:25-30 (using silicon and silicon dioxide as alternating layers in its backside reflection layer); Mori, [0029]-[0030].

270. Therefore, using a Si/SiO₂ DBR would have been nothing more than a simple substitution of a Si/SiO₂ DBR for a metal layer to obtain predictable results (e.g., high reflectivity, reduced dark current, and omnidirectional characteristics).

271. Accordingly, a POSITA would have been motivated to replace Yamada’s third reflective films 11 and first insulator 9 with Schubert’s Si/SiO₂ DBR. Schubert’s Si/SiO₂ DBR is a “multi-layer reflector consisting of typically 5–50 pairs of two materials with different refractive indices.” Schubert, 171. Such reflectors have at least one *high refractive index material* (silicon, having a refractive index of 3.51) *sandwiched between two low refractive index materials* (silicon dioxide, having a refractive index of 1.46).

3. Claim 2: “The device of claim 1, wherein the two low refractive index materials have a refractive index of less than about 2.1.”

272. This claim would have been obvious based on Yamada in view of Schubert. As discussed for claim 2 above, it would have been obvious in view of Schubert to use a peripheral light trapping material in Yamada comprising

alternating layers of silicon dioxide (a low refractive index material, with a refractive index of 1.46) and silicon (a high refractive index material, with a refractive index of 3.51). In such a structure, the two low refractive index materials would comprise silicon dioxide, having *a refractive index of less than about 2.1*.

4. **Claim 3: “The device of claim 2, wherein at least one of the two low refractive index material includes a member selected from the group consisting of an oxide, a nitride, oxynitrides, a gas, at least a partial vacuum, and combinations thereof.”**

273. This claim would have been obvious based on Yamada in view of Schubert. As discussed for claim 2 above, it would have been obvious in view of Schubert to use a peripheral light trapping material in Yamada comprising alternating layers of silicon dioxide (a low refractive index material, with a refractive index of 1.46) and silicon (a high refractive index material, with a refractive index of 3.51). In such a structure, the two low refractive index materials would comprise *an oxide* (i.e., silicon dioxide).

5. **Claim 4: “The device of claim 2, wherein the at least one of the two low refractive index materials includes a member selected from the group consisting of silicon oxide, silicon nitride, silicon dioxide, and combinations thereof.”**

274. This claim would have been obvious based on Yamada in view of Schubert. As discussed for claim 2 above, it would have been obvious in view of Schubert to use a peripheral light trapping material in Yamada comprising alternating layers of silicon dioxide (a low refractive index material, with a refractive

index of 1.46) and silicon (a high refractive index material, with a refractive index of 3.51). In such a structure, the two low refractive index materials would comprise *silicon dioxide*.

6. Claim 5: “The device of claim 1, wherein the high refractive index material includes a material having a refractive index of greater than or equal to about 2.1.”

275. This claim would have been obvious based on Yamada in view of Schubert. As discussed for claim 2 above, it would have been obvious in view of Schubert to use a peripheral light trapping material in Yamada comprising alternating layers of silicon dioxide (a low refractive index material, with a refractive index of 1.46) and silicon (a high refractive index material, with a refractive index of 3.51). In such a structure, the high refractive index material would have *a refractive index of greater than 2.1* (i.e., 3.51).

7. Claim 6: “The device of claim 5, wherein the high refractive index material includes a member selected from the group consisting of polycrystalline silicon, amorphous silicon, single crystal silicon, multicrystalline silicon, nanocrystalline silicon, germanium, and combinations thereof.”

276. This claim would have been obvious based on Yamada in view of Schubert. As discussed for claim 2 above, it would have been obvious in view of Schubert to use a peripheral light trapping material in Yamada comprising alternating layers of silicon dioxide (a low refractive index material, with a refractive

index of 1.46) and silicon (a high refractive index material, with a refractive index of 3.51).

277. It would be obvious to a POSITA that this silicon would be one of *polycrystalline silicon, amorphous silicon, single crystal silicon, multicrystalline silicon, nanocrystalline silicon, ... and combinations thereof*.

278. First, a POSITA would understand that a reference to “silicon,” without modification, as described in Schubert typically pertains to *single crystal silicon*.

279. Second, to the extent that Schubert’s disclosure of “silicon” may be ambiguous as to the specific type of silicon, this claim still would have been obvious, because a POSITA would have had a limited number of types of silicon from which to choose, and in fact the group of silicon materials specified in this claim (i.e., *polycrystalline silicon, amorphous silicon, single crystal silicon, multicrystalline silicon, nanocrystalline silicon, and combinations thereof*) encompasses all forms of silicon. See Ex-1018, 145 (stating that “[s]olid matter exists in crystalline and amorphous forms,” and listing “[t]he three different forms of solid-material: (a) Single-Crystal, (b) Poly-Crystalline, (c) Amorphous.”), 114 (“Silicon-films can be either amorphous, polycrystalline, or single-crystal, depending on the deposition-parameters and the substrate material.”).

8. **Claim 9: “The device of claim 1, wherein at least one of the backside light trapping material and the peripheral light trapping material includes a first material sandwiched between two second materials, wherein the first material has a higher refractive index as compared to the two second materials, and wherein the difference in refractive index between the first material and the two second materials is at least 0.2.”**

280. This claim would have been obvious based on Yamada in view of Schubert. As discussed for claim 2 above, it would have been obvious in view of Schubert to use a *peripheral light trapping material* in Yamada comprising alternating layers of silicon dioxide (a low refractive index material, with a refractive index of 1.46) and silicon (a high refractive index material, with a refractive index of 3.51). In such a structure, the *peripheral light trapping material* would include a *first material* (i.e., silicon, having a refractive index of 3.51) *sandwiched between two second materials* (i.e., silicon dioxide, having a refractive index of 1.46), *wherein the first material has a higher refractive index* (i.e., 3.51) *as compared to the two second materials* (i.e., 1.46), *and wherein the difference in refractive index between the first material and the two second materials is at least 0.2* (i.e., a difference of $3.51 - 1.46 = 2.05$).

9. Claims 10-12, 14-16

281. Yamada teaches or suggests the additional limitations of these dependent claims for the same reasons as discussed in Ground 6 above

10. Claim 17: “The device of claim 1, wherein at least one of the backside light trapping material and the peripheral light trapping material is a metal layer.”

282. Yamada teaches or suggests this limitation. Yamada teaches that its light receiving element may be “configured such that the first reflecting film 3 [*backside light trapping material*] is made of a metal such as Al,” as illustrated in Figure 6. Yamada, [0048]. A POSITA would understand that this teaching would be equally applicable to the embodiment of Figure 7. For example, Yamada explains that such a metal film can allow for “the same effect” as Yamada’s baseline “first embodiment,” which uses the same first reflecting film 3 as Figure 7. Yamada, [0048]. *See also* Yamada, [0048]-[0049] (Yamada’s first, fourth, and fifth embodiments are substantially similar).

I. Ground 9: Claims 6-8 Are Obvious Based on Yamada, Schubert, and Mori

1. Overview of Mori

283. As discussed above for Ground 2, Mori discloses a solid-state imaging device having a partition part containing a silicon layer 175 and a silicon dioxide layer 177. *See* Mori, [0020]-[0023], [0028], [0030]. Mori explains that the “silicon layer 175 [is] made of amorphous silicon or polycrystalline silicon.” Mori, [0027]. Mori also explains that “p-type impurities are preferably injected into the side walls of partition groove 174 forming the side SiO₂ film 177.” Mori, [0036].

2. **Claim 6: “The device of claim 5, wherein the high refractive index material includes a member selected from the group consisting of polycrystalline silicon, amorphous silicon, single crystal silicon, multicrystalline silicon, nanocrystalline silicon, germanium, and combinations thereof.”**

284. As explained in Ground 7 above, this claim would have been obvious in view of Yamada and Schubert alone, given that Schubert discloses that the high refractive index material in its reflection layers is “silicon,” and given that a POSITA would understand this to refer to *single crystal silicon*. However, to the extent that Schubert’s disclosure of “silicon” may be ambiguous as to the specific type of silicon, this claim still would have been obvious, because a POSITA would have had a limited number of types of silicon from which to choose, and because Mori specifically teaches the use of *amorphous silicon* and *polycrystalline silicon* for use in a similar reflection layer.

285. As discussed for claim 2 above, it would have been obvious in view of Schubert to use a backside light trapping material in Yamada comprising alternating layers of silicon dioxide and silicon.

286. Mori similarly discloses a multi-layer partition comprising layers of silicon (silicon layer 175) sandwiched between layers of silicon dioxide (side SiO₂ film 177), as shown in Mori’s Figure 2. That is, both Yamada in view of Schubert and Mori both utilize a similar silicon/silicon dioxide film disposed at the pixel border. And in both of the Yamada and Mori references, the silicon/silicon dioxide film is used to

mitigate against interference between pixels. *Cf.* Yamada, [0010] (“light that enters the light receiving section (7) is reflected by the first reflective film (3)”) with Mori, [0027] (Si/SiO₂ partition serves to reduce “color mixing [or ‘crosstalk’] due to obliquely incident light”).

287. Mori further teaches that its “silicon layer is made of amorphous silicon or polycrystalline silicon.” Mori, [0011]. Mori thus shows that amorphous silicon and polycrystalline silicon are suitable materials that may be included in a multi-layer silicon/silicon dioxide film disposed along the sidewalls of an image sensor pixel, and used to mitigate against interference between pixels. Mori also teaches that such a multi-layer film can help protect against crystal defects, among other advantages. Mori, [0013].

288. Accordingly, it would have been obvious to use either amorphous or polycrystalline silicon for the “silicon” layer in Yamada’s third reflective film 11 as modified in view of Schubert (i.e., the *high refractive index material*). And as Mori demonstrates, using amorphous or polycrystalline silicon would lead to predictable results—i.e., the creation a “partition part formed between photoelectric conversion units” that allows for “the sensitivity of the solid-state imaging device [to] be improved,” Mori, [0012], and a POSITA would have an expectation of success in doing so. Moreover, Mori, use of amorphous or polycrystalline silicon as a “partition part” to improve “the sensitivity of the solid-state imaging device,” Mori, [0012], is

consistent with Yamada's objective of using "third reflective films 11" to increase "the distance the light travels inside the light receiving section," thus improving sensitivity. Yamada, [0010]. Indeed, both Yamada and Mori are directed to photosensitive imager devices designed to increase sensitivity. Yamada, [0001] ("The present invention relates to a light receiving element capable of preventing optical crosstalk between light receiving sections and improving sensitivity of the light receiving sections."); Mori, [0012] ("Therefore, the charge generated when dark can be reduced, and the sensitivity of the solid-state imaging device can be improved.").

289. Finally, as discussed for Ground 7, claim 6 above, there are a finite number of types of silicon. Choosing either amorphous or polycrystalline silicon, as done in Mori, would at least be obvious to try, in light of Mori's teachings.

290. Accordingly, this claim would have been obvious based on Yamada in view of Schubert in further view of Mori.

3. Claim 7: "The device of claim 1, wherein at least one of the two low refractive index materials is doped with a dopant to create a surface field."

291. This claim would have been obvious based on Yamada in view of Schubert in further view of Mori.

292. As explained for claim 6 above, Mori is similar to Yamada as modified by Schubert in that both disclose image sensors that include a multi-layer film comprising a layer of silicon (Mori layer 175, high refractive index material in

Yamada's third reflective film 11) sandwiched between layers of silicon dioxide (Mori SiO₂ film 177, low refractive index material in Yamada's third reflective film 11), used to mitigate against interference between pixels.

293. Mori further teaches that it is advantageous in such a film to dope the silicon dioxide layer (Mori's SiO₂ layer 177) with p-type impurities, as explained in the overview of Mori above. *See* Mori, [0036]. As Mori explains, this doping is advantageous in order to mitigate dark current stemming from crystal defects—i.e., to “prevent charges generated when dark due to crystal defects in the partition groove 174 from flowing into the photoelectric conversion unit 161.” Mori, [0036].

294. Accordingly, Mori teaches that Mori's side SiO₂ film *is doped with a dopant to create a surface field* as set forth in this limitation. The '714 patent does not explain how doping the low refractive index material operates to create a surface field. Rather, its only disclosure relating to such doping is that: “[I]t can also be beneficial to dope the sidewalls to create a surface field that will improve electrical isolation between the pixels. In one aspect, it can also be beneficial to dope the low refractive index material of the Bragg-type reflectors to increase such electrical isolation.” '714 patent, 10:15-19. That is, the '714 patent teaches that doping in such a manner as in Mori serves to increase electrical isolation between the pixels via a surface field. Thus, Mori's doped SiO₂ film 177 along the side of its pixel (photoelectric conversion unit 161) would constitute a *low refractive index material doped with a dopant to create a*

surface field to the extent that is contemplated by the limited disclosure of the '714 patent.

295. As a POSITA would recognize, doping Mori's silicon dioxide layer with p-type impurities would lead to an excess of positive charges, creating an electric field at the surface of the layer. In other words, Mori teaches that its silicon dioxide layer is *doped with a dopant to create a surface field*.

296. Based on Mori's teaching, it is obvious to similarly dope the silicon dioxide layer in Yamada as modified by Schubert, so that at least one of *the low refractive index materials is doped with a dopant* (as taught by Mori), leading to an excess of charges that would *create a surface field* in the same manner as Mori's SiO₂ film. Yamada's (as modified by Schubert) silicon dioxide layer adjoins the side of Yamada's pixel (PIN photodiode 7), just like Mori's side SiO₂ film 177 adjoins Mori's pixel. Accordingly, a POSITA would recognize that doping the silicon dioxide layer in Yamada as modified by Schubert with p-type impurities would similarly help to mitigate dark current stemming from crystal defects in Yamada's sensor.

297. A POSITA would reasonable expect success in making this modification, given that both Yamada (as modified by Schubert) have the same arrangement of a silicon/silicon dioxide film disposed at the sidewall between pixels as in Mori. A POSITA would recognize that this doping could be readily implemented in Yamada's (as modified by Mori) image sensor, e.g., after applying the first SiO₂ layer.

298. Therefore, it would have been obvious in view of Mori for *at least one of the two low refractive index materials* in Yamada in view of Schubert to be *doped with a dopant to create a surface field*.

4. Claim 8: “The device of claim 7, wherein the dopant is boron or antimony.”

299. This claim would have been obvious based on Yamada in view of Schubert and in further view of Mori.

300. As explained for claim 7 above, it would have been obvious in view of Mori to dope the silicon dioxide layer used in Yamada as modified by Schubert (the *low refractive index material*) with p-type impurities—i.e., a p-type dopant. It further would be obvious to use boron as the p-type dopant, given that boron is one of the most commonly used p-type dopants for Si-based systems. *See, e.g.*, Ex-1018, 27-28 (explaining that Column-IV materials (e.g., Si) are commonly doped with Column-III-dopants (e.g., boron)). A POSITA would have recognized that using boron as a p-type dopant for silicon-based systems is a known technique that would have yielded predictable results, particularly in light of boron’s similar use as a p-type dopant in other similar light trapping devices. *See, e.g.*, Ex-1019, [0011] (“[t]he substrate 35 is a silicon substrate doped with a P-type dopant such as boron, in which case the substrate 35 is a P-type substrate”). Additionally, this claim would have been obvious, because a POSITA would have had a limited number of types of p-type dopants from which to

choose, therefore, it would have been obvious to a POSITA to try using boron as the p-type dopant.

301. Accordingly, Yamada in view of Schubert in further view of Mori teaches or suggests that *the dopant is boron or antimony*.

J. Ground 10: Claim 18 is Obvious Based on Yamada, Schubert and Konno

1. Claim 18: “The device of claim 1, wherein at least one of the backside light trapping material and the peripheral light trapping material has a sloped surface at the pixel device interface”

302. Yamada, Schubert, and Konno render this limitation obvious because (1) as explained for Ground 8 above, base claim 1 would have been obvious based on Yamada and Schubert, and (2) as explained for Ground 7 above using Konno’s inclined surface in Yamada’s light receiving element would have been obvious (and this is equally true for Yamada’s light receiving element as modified based on Schubert), thus satisfying the additional limitation of this dependent claim.

VIII. CONCLUSION

303. I declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code.

Executed on November 21st, 2024

Respectfully submitted,

A handwritten signature in green ink, appearing to be "Michael Lebby", written over the printed name.

Michael Lebby