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Raymond et al.

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(54) **ARRAYS OF INDIVIDUALLY ORIENTED MICRO MIRRORS PROVIDING INFINITE AXIS ACTIVATION IMAGING FOR IMAGING SECURITY DEVICES**

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(Continued)

(51) **Int. Cl.**
B42D 25/29 (2014.01)
G02B 17/00 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC **G02B 27/2292** (2013.01); **B42D 25/29** (2014.10); **B42D 25/324** (2014.10);
(Continued)

(58) **Field of Classification Search**
CPC .. B42D 25/373; B42D 25/328; B42D 25/351; B42D 25/324; B42D 25/425;
(Continued)

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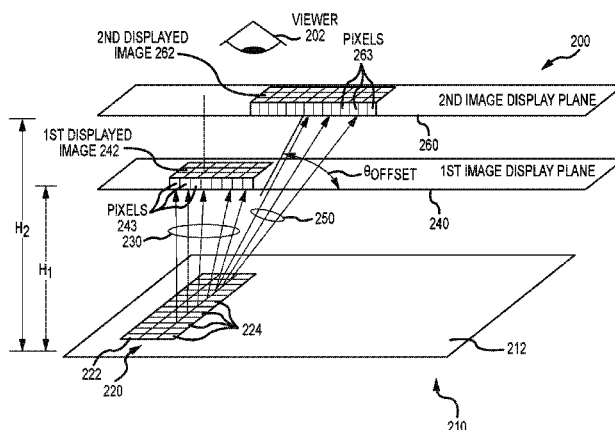
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(57) **ABSTRACT**

A visual display assembly useful as an authentication or anti-counterfeiting element. The assembly includes a substrate and, on a surface of the substrate, an array of micro mirrors receiving ambient light. Each mirror includes a reflective surface to reflect the ambient light so as to display an image that appears to float in a plane, which is spaced a distance apart from the surface of the substrate. The image includes a plurality of pixels, and the array of micro mirrors includes for each of the pixels a set of the micro mirrors each having a reflective surface oriented to reflect the ambient light toward a point on the plane corresponding to one of the pixels. Each of the sets of the micro mirrors includes a plurality of the micro mirrors, and the reflected ambient light each set of micro mirrors intersects to illuminate or write a pixel of an image.

13 Claims, 31 Drawing Sheets



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(58) Field of Classification Search CPC B42D 25/29; B42D 25/378; G02B 17/002; G02B 27/0012; G02B 27/2292; G03B 25/00 USPC 359/851, 852, 853, 855 See application file for complete search history.	WO 2012048847 A1 4/2012 WO 2012000669 A1 5/2012 WO 2013056825 A1 4/2013	OTHER PUBLICATIONS
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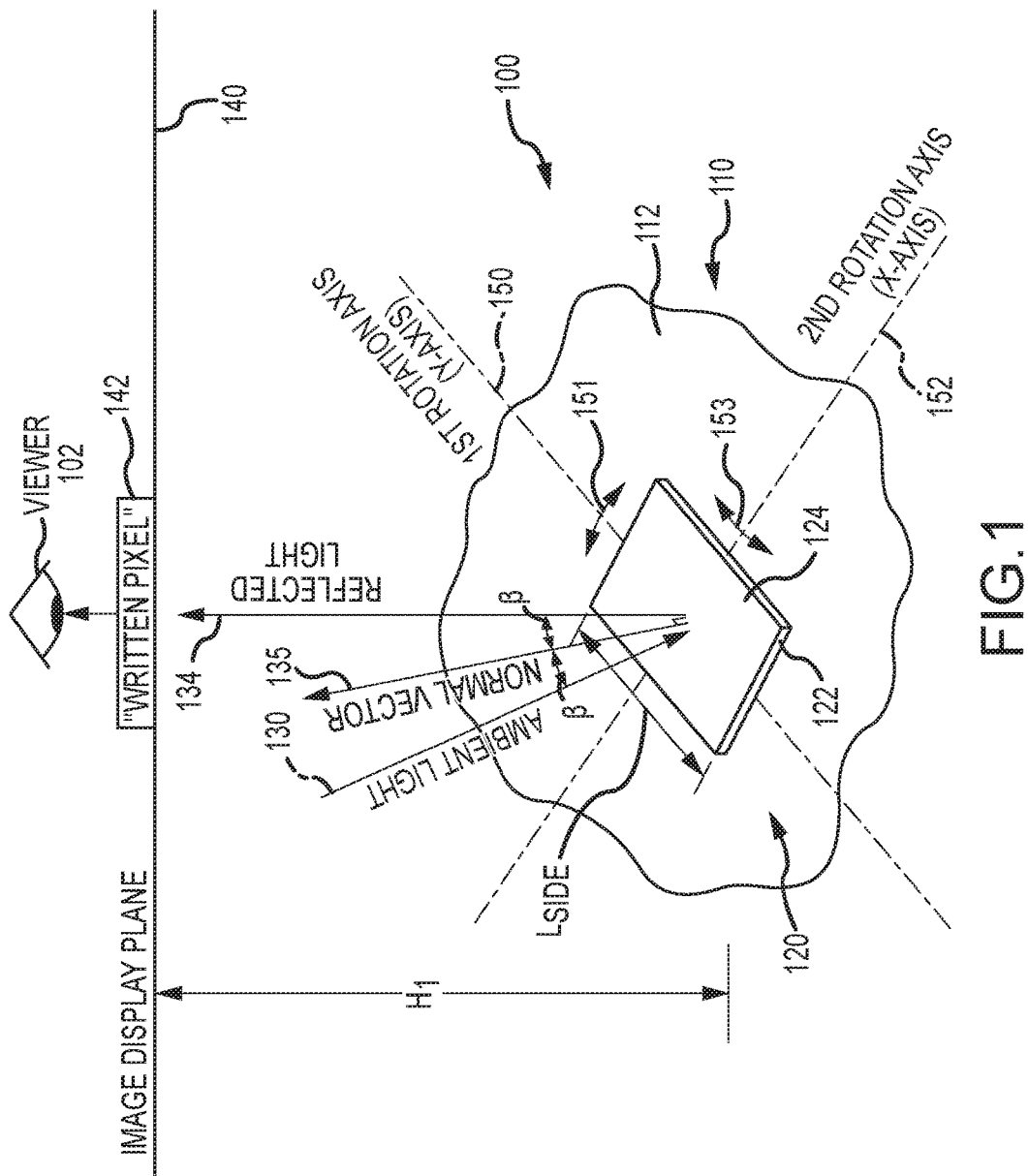
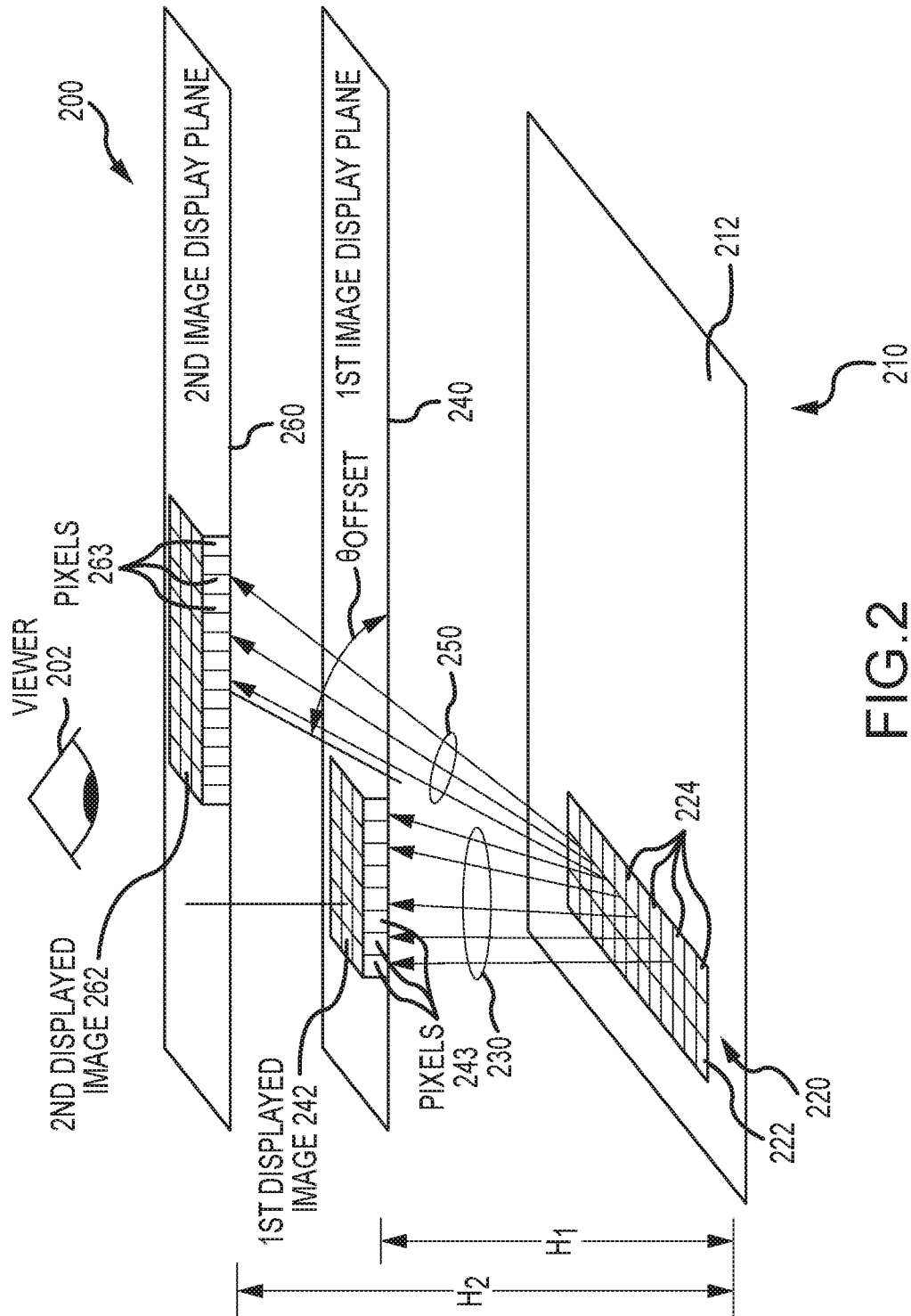


FIG.1



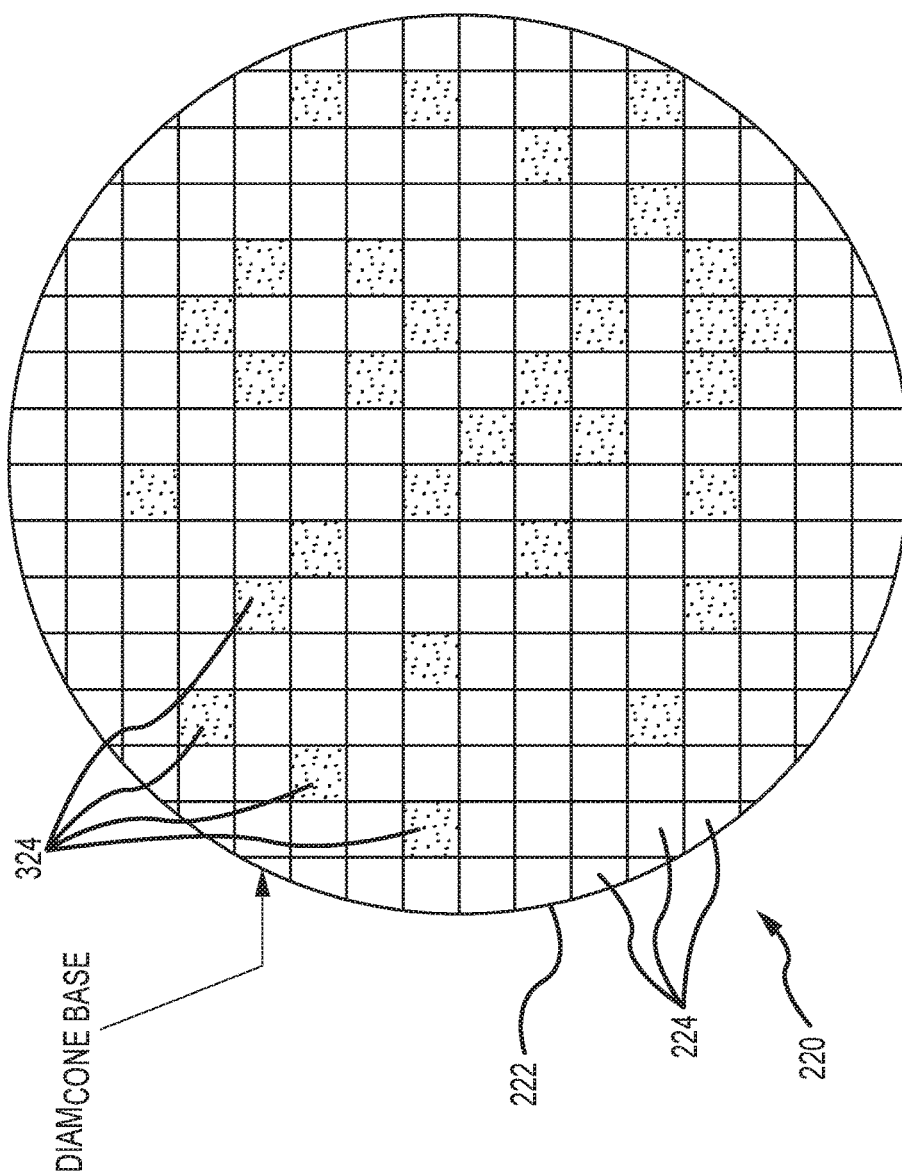
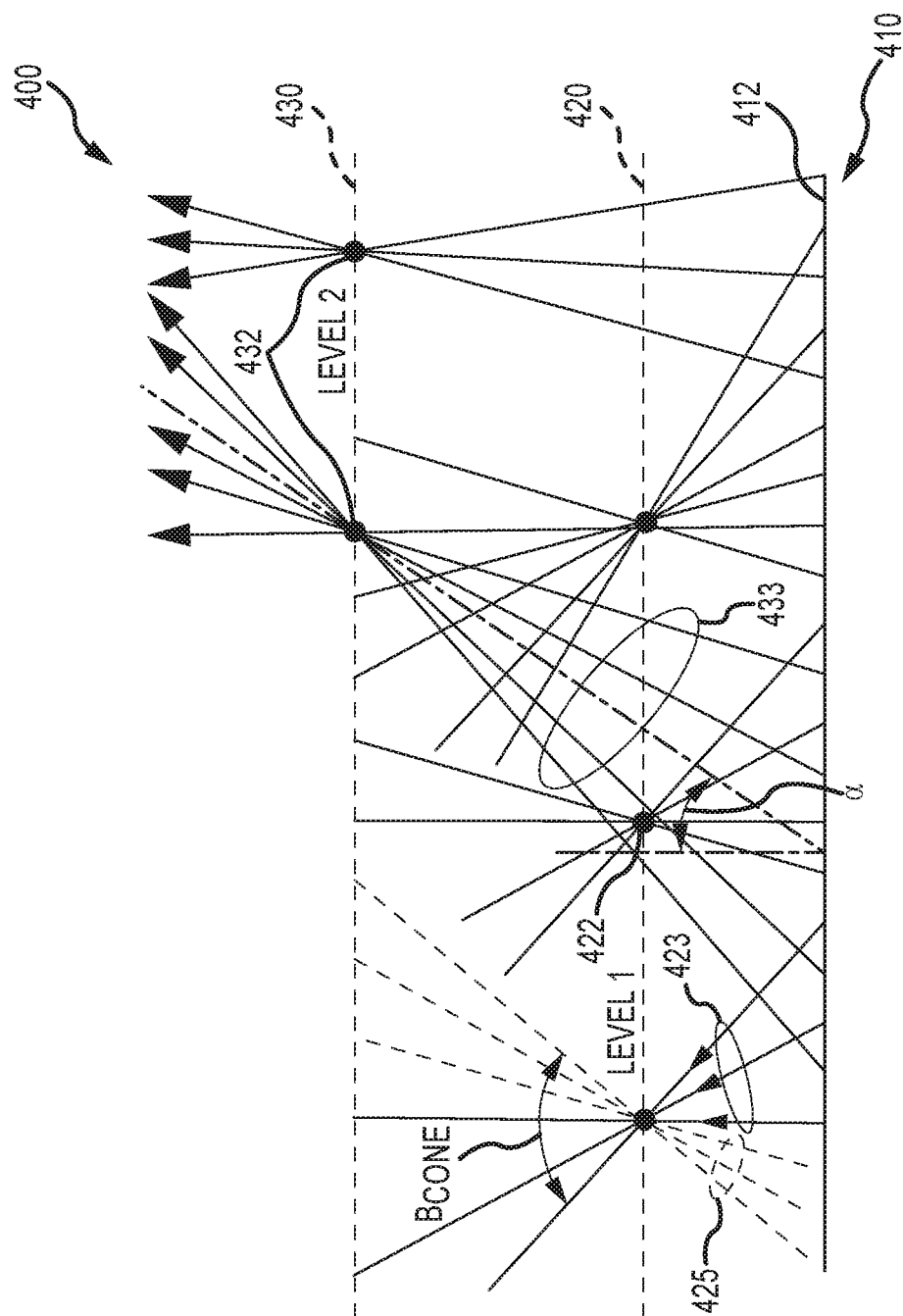


FIG. 3



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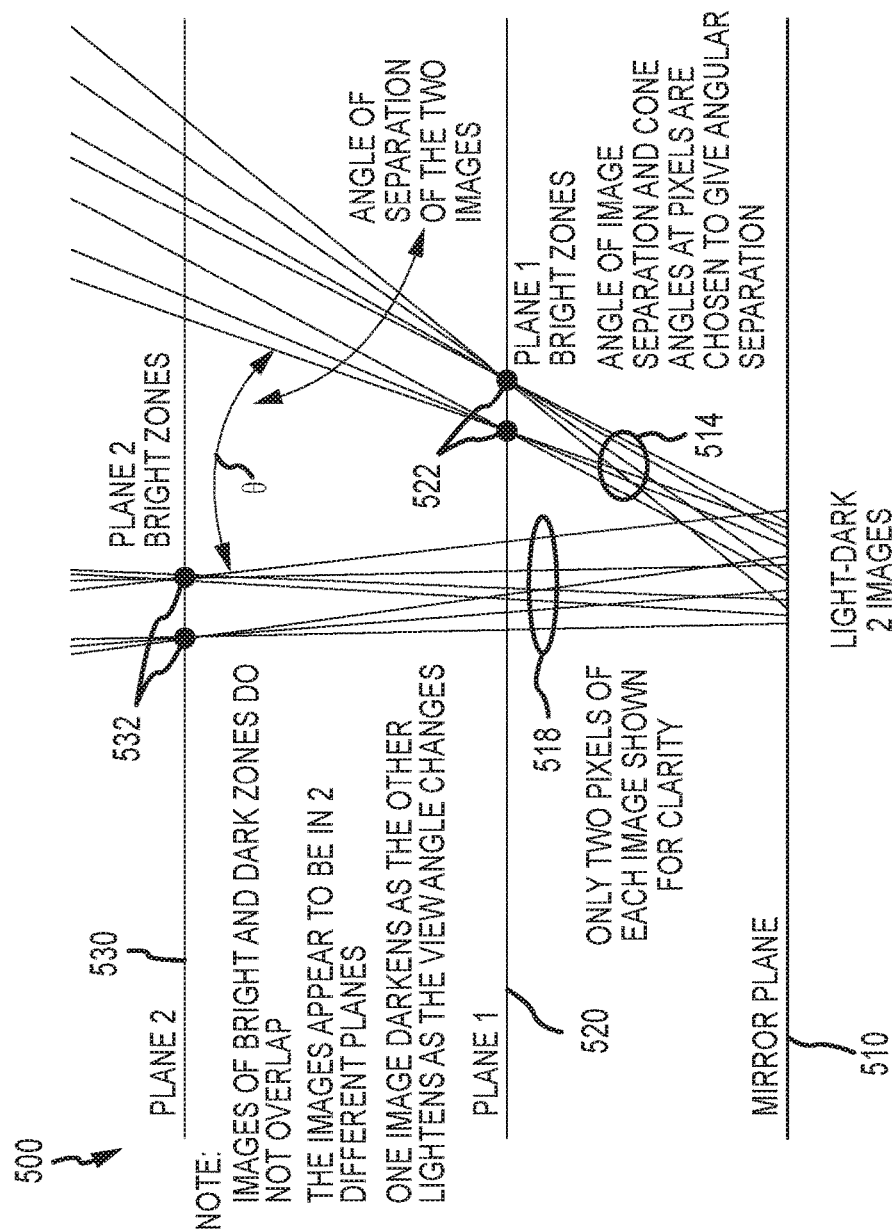


FIG. 5

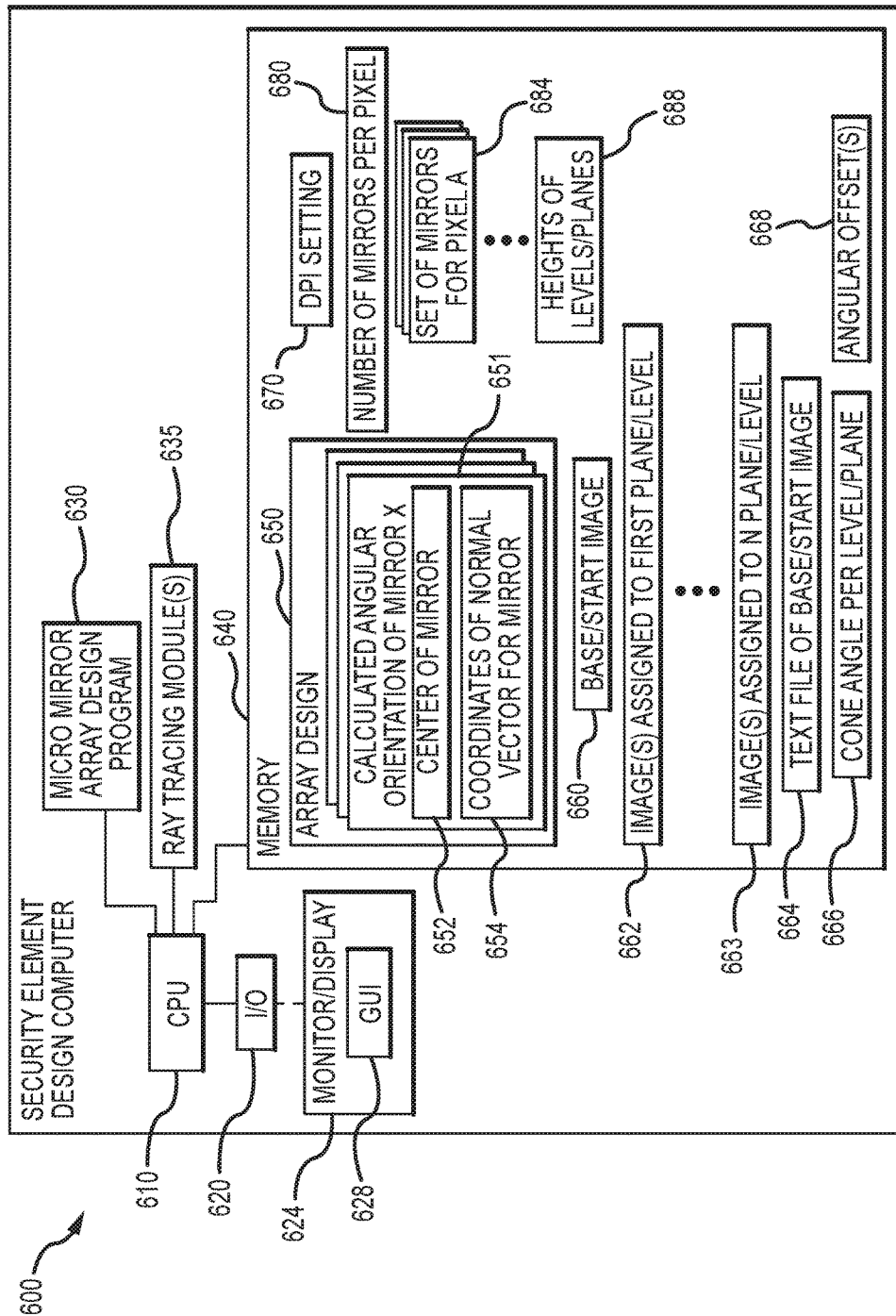


FIG.6

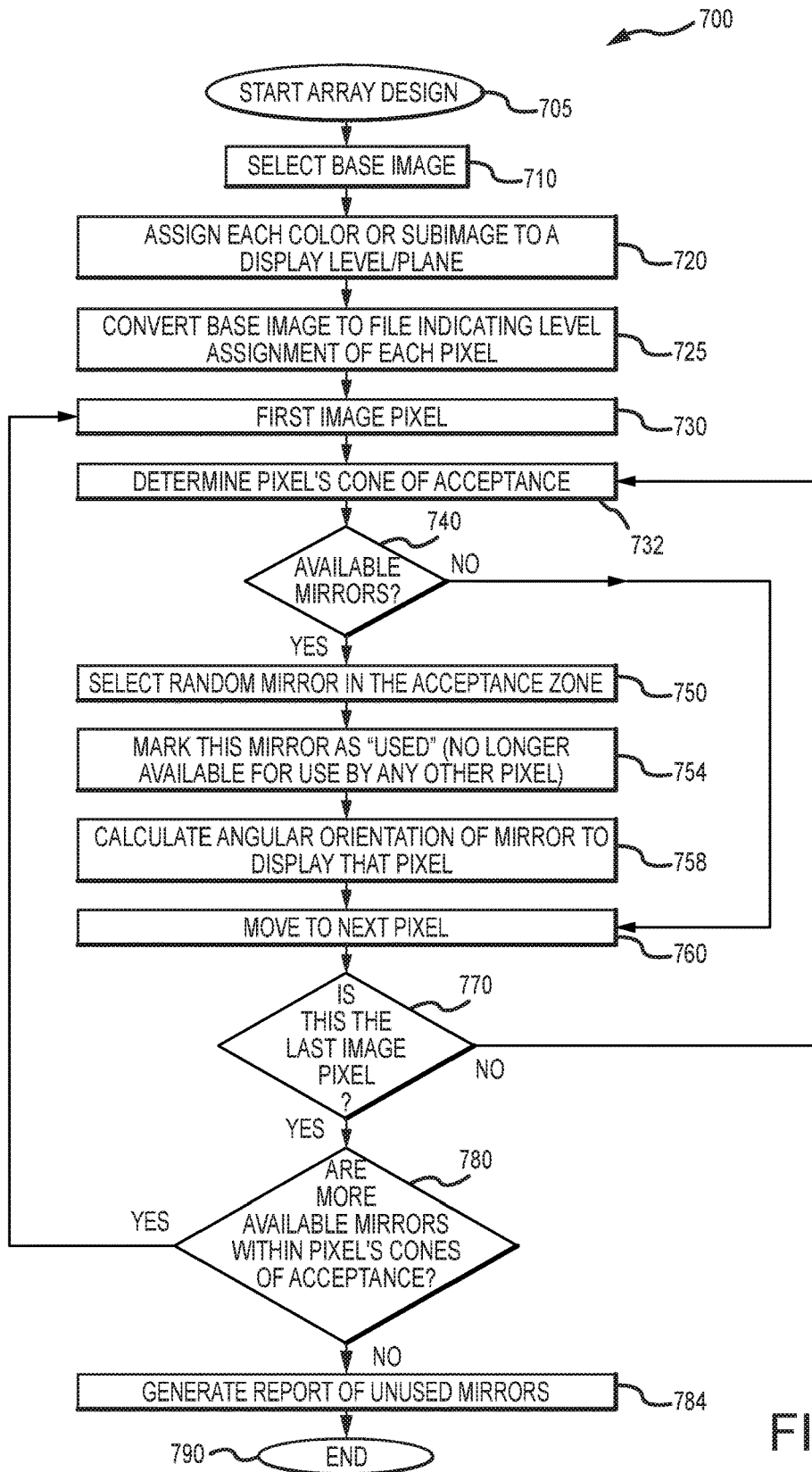


FIG. 7

800

ICE DATA		USER INPUTS	
SAVE ICE DATA		MICRONS	NUMBER OF PIXELS IN X
ICE UNITS (MICRONS) (MM) ETC		2	NUMBER OF PIXELS IN Y
NUMBER OF LEVELS TO USE >0 AND <= 3		10000	TOTAL NUMBER OF PIXELS
LEVEL 1 HEIGHT		80	NUMBER OF MIRRORS IN X
LEVEL 1 CONE ANG DEG		0	NUMBER OF MIRRORS IN Y
LEVEL 1 ANGLE OFFSET		20000	TOTAL NUMBER OF MIRRORS
LEVEL 2 HEIGHT		15	SIZE OVERALL PIXELS X
LEVEL 2 CONE ANG DEG		0	SIZE OVERALL PIXELS Y
LEVEL 2 ANGLE OFFSET		30000	MIRRORS OVERALL SIZE X
LEVEL 3 HEIGHT		20	MIRRORS OVERALL SIZE Y
LEVEL 3 CONE ANG DEG		0	AVG NUM PIXELS IN RANGE OF MIRROR
LEVEL 3 ANGLE OFFSET		50	AVG NUM MIRRORS AVAILABLE PER PIXEL
MIRROR SIZE X		50	AVG NUM MIRRORS USED IN DC PER PIXEL
MIRROR SIZE Y		254	TOTAL NUM MIRRORS
IMAGE FOCAL POINTS X PITCH		254	TOTAL N OF MIRRORS DC CALCULATED
IMAGE FOCAL POINTS Y PITCH		50	MIRRORS NOT USED
NUMBER OF TEST PIXELS IN X		50	CALCULATION TIME (SEC)
NUMBER OF TEST PIXELS IN Y		2	DC GENERATOR USED
TEXT X.0 NONE.1 W2 HALF W.3 ONE PIXEL		0	IMAGE FILE NAME
FUTURE			COMPILED VER #

☐ USE POSITIVE IMAGE

MAIN MENU

FIG. 8A

CALCULATED RESULTS		
50	N DARK PIXELS	1400
50	N WHITE PIXELS	3650
2500	N MISSING PIXELS	-2550
254	N DARK MIRRORS GENERATED	31814
254	N WHITE MIRRORS GENERATED	32702
64516	N UNUSED MIRRORS	0
12700	FUTURE	FUTURE
12700	FUTURE	FUTURE
12700	PIXEL N IN X	25
12700	PIXEL N IN Y	25
0	NUM OF MIRRORS FOR ABOVE PIXEL	9019
25.8064	MIRROR N IN X	127
13.0808	MIRROR N IN Y	127
64516	NUM OF PIXELS FOR ABOVE MIRROR	349
32702		
31814		
27.928		
GEN 3D MAS		
#2 TEST X HALF WHITE LEVEL 2		
1		

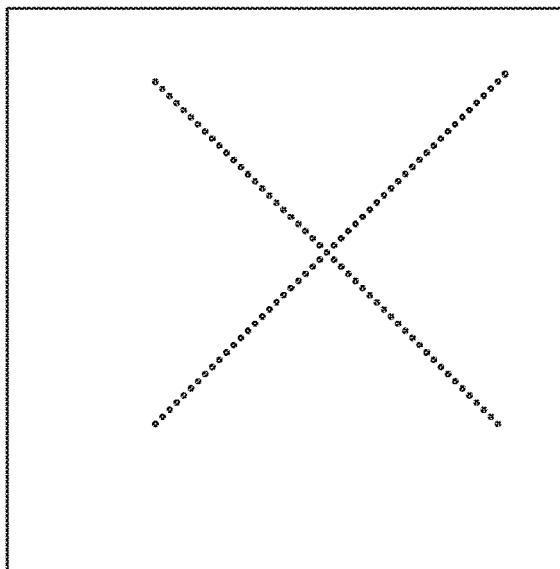
910


FIG. 9A

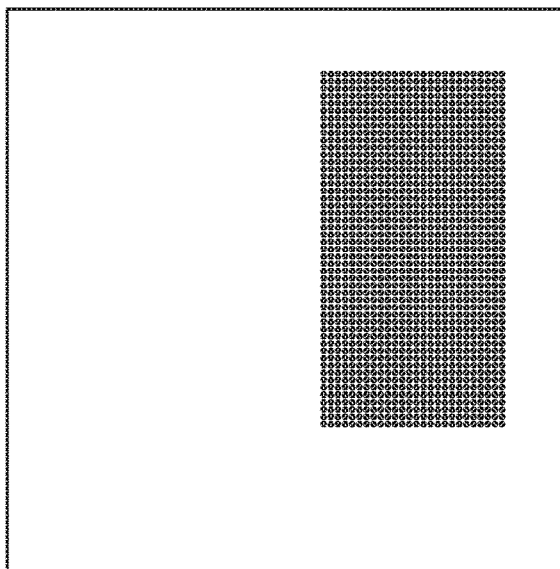
920


FIG. 9B

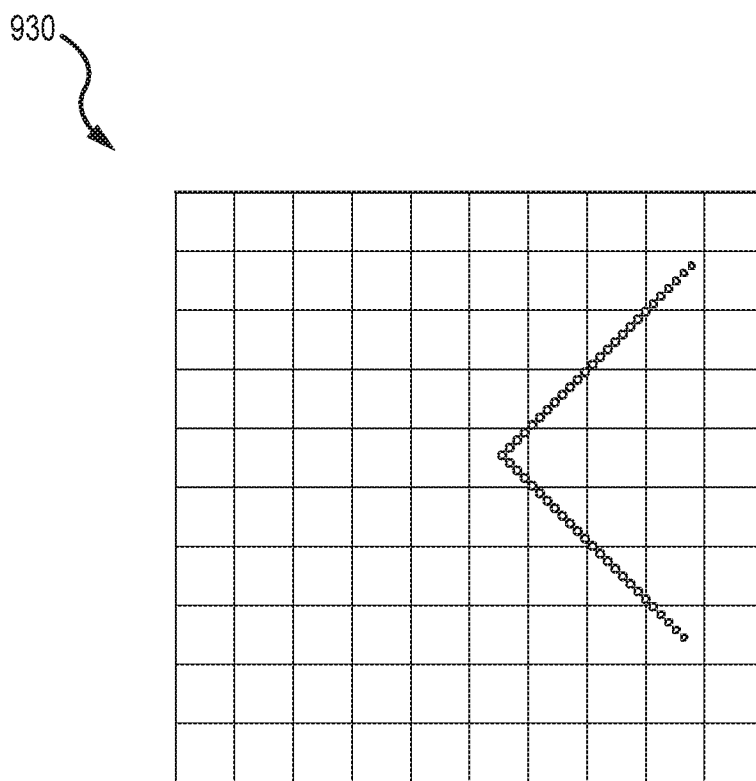


FIG. 9C

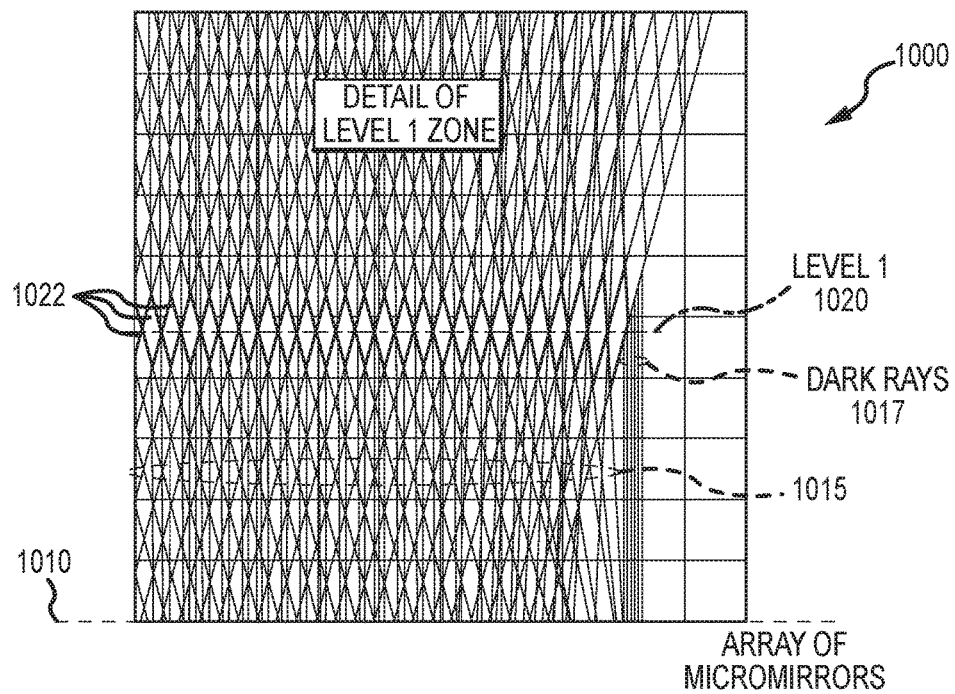


FIG. 10

1100

☐ PLOT PARAMETERS FOR 3D VIEW			
SAVE PLOT DATA			
CROSS SECTION SELECTIONS ☐ NOT USED ☐ XY PLANE RAYS ☒ XZ PLANE RAYS ☐ YZ PLANE RAYS			
EYE LOCATION XYZ (z=18 INCH 457200 MICRONS)	19350	6450	457200
EYE FOCAL LENGTH (22MM 22000 MICRONS)	21200		
EYE INDEX OF REFRACTION (1.333)	1.333		
EYE APERTURE (6.5 MM 6500 MICRONS)	6500		
EYE LENS RADIUS (5.55MM 5550 MICRONS)	5550		
NUMBER OF RAYS TO TRACE PER MIRROR (<10,000)	15		
CONE ANGLE OF MIRROR TRACE (DEG)	0.2		
RETINA PLOT SELECTIONS		EYE CROSS SECTION	
3D X WIDTH 20000	☐ USE PLOT 1	EYE PLOT L 1 -15000	☐ EYE PLOT 1
3D Y HEIGHT 20000	☐ USE PLOT 2	EYE PLOT R 15000	
3D X WIDTH 90000	☒ USE PLOT 3	EYE PLOT B 450000	
3D Y HEIGHT 90000		EYE PLOT T 480000	
3D X WIDTH 1000		EYE PLOT L 2 -3000	☐ EYE PLOT 2
3D Y HEIGHT 1000		EYE PLOT R 3000	
		EYE PLOT B 7000	
		EYE PLOT T 13000	
☒ PLOT TRACED RAY INTERSECTIONS ☒ PLOT CAPTIONS ☐ PLOT MIRRORS ☐ PLOT PIXEL CONES ☐ PLOT MIRROR BOUNDARY ☐ PLOT GRID			

FIG.11

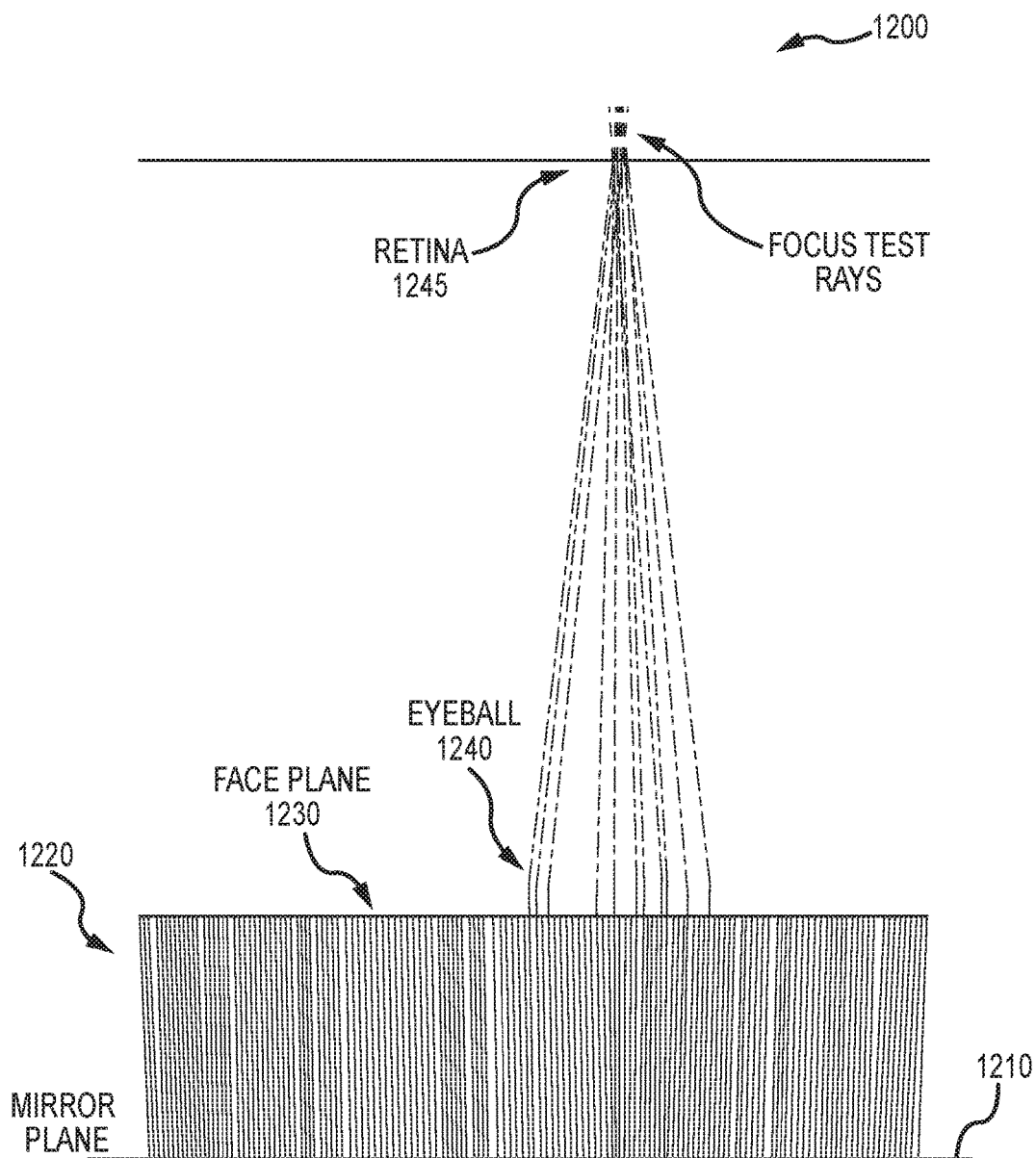


FIG. 12

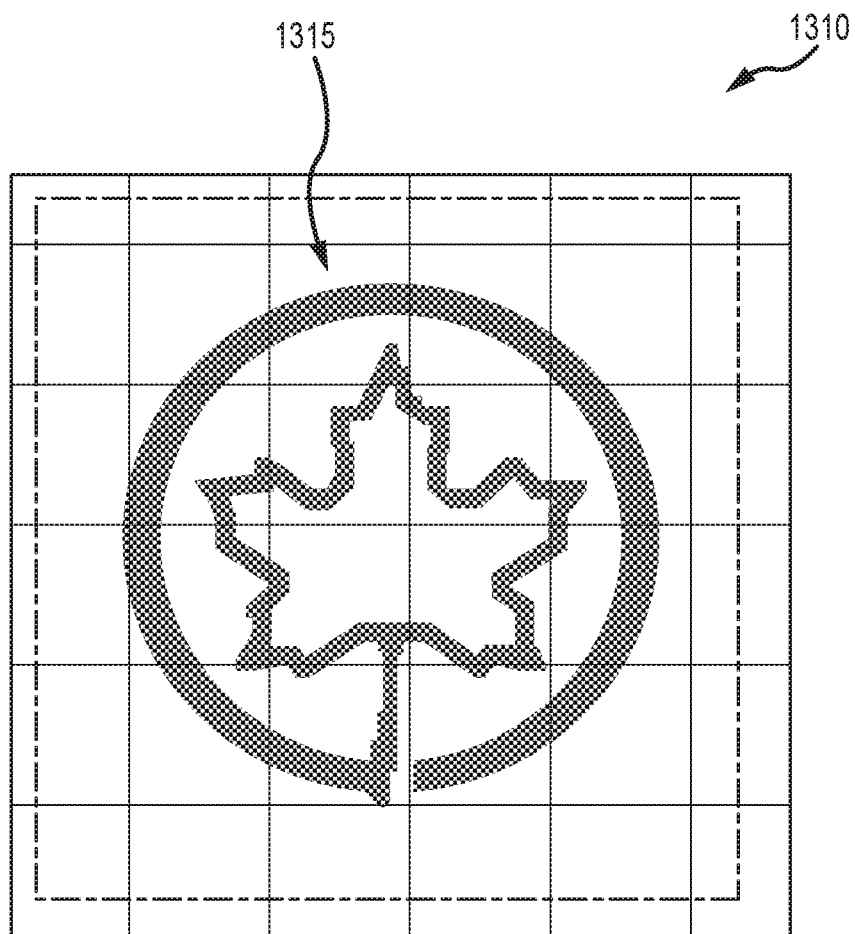


FIG. 13A

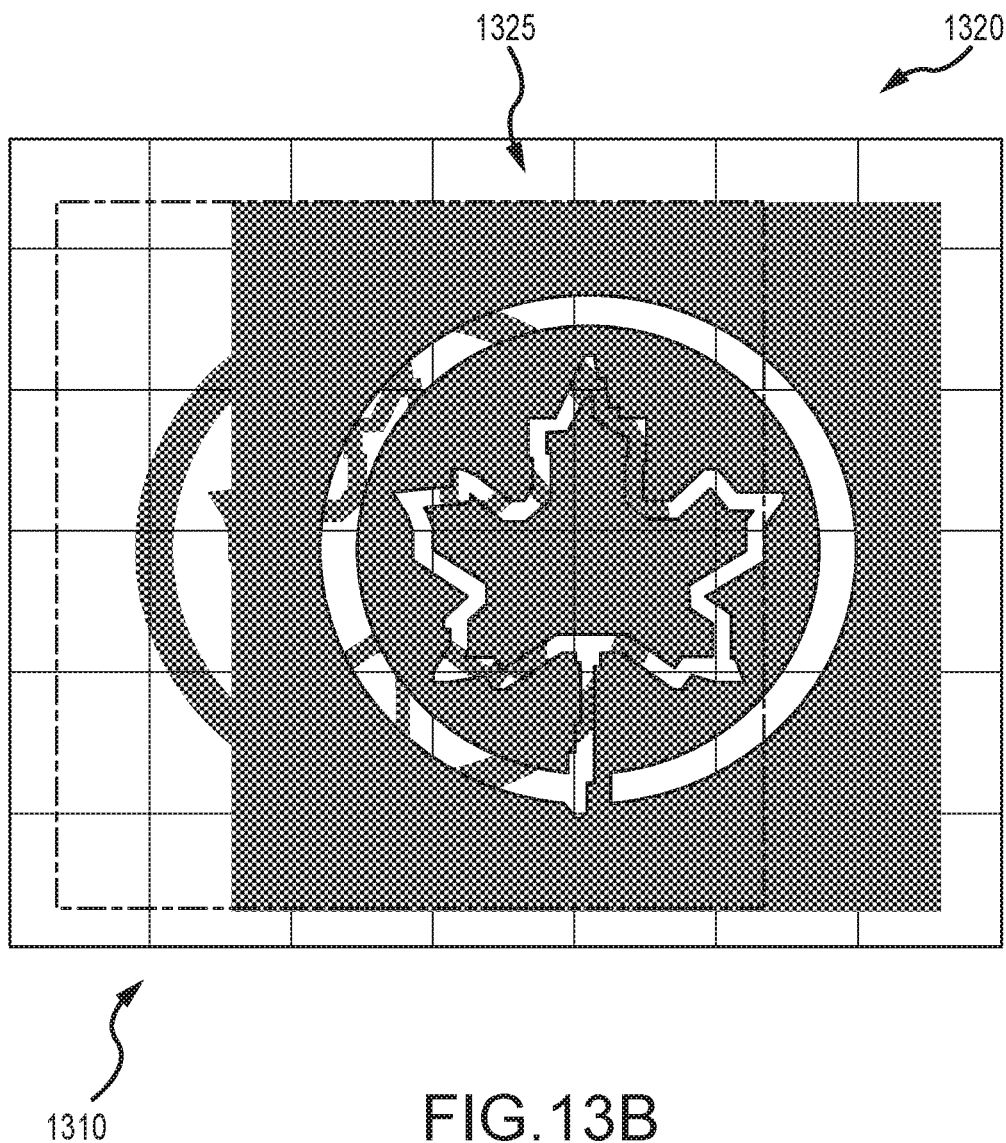


FIG. 13B

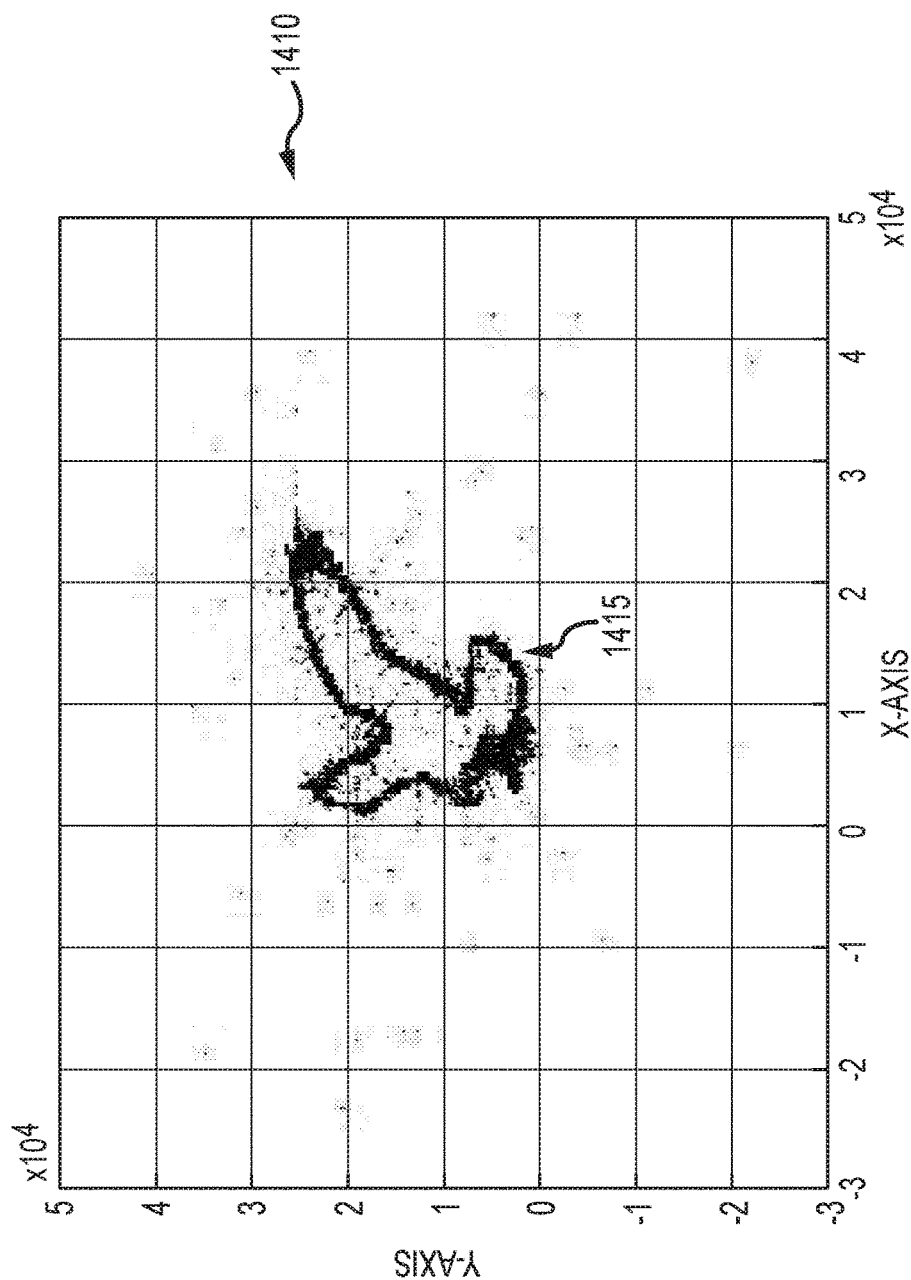


FIG.14A

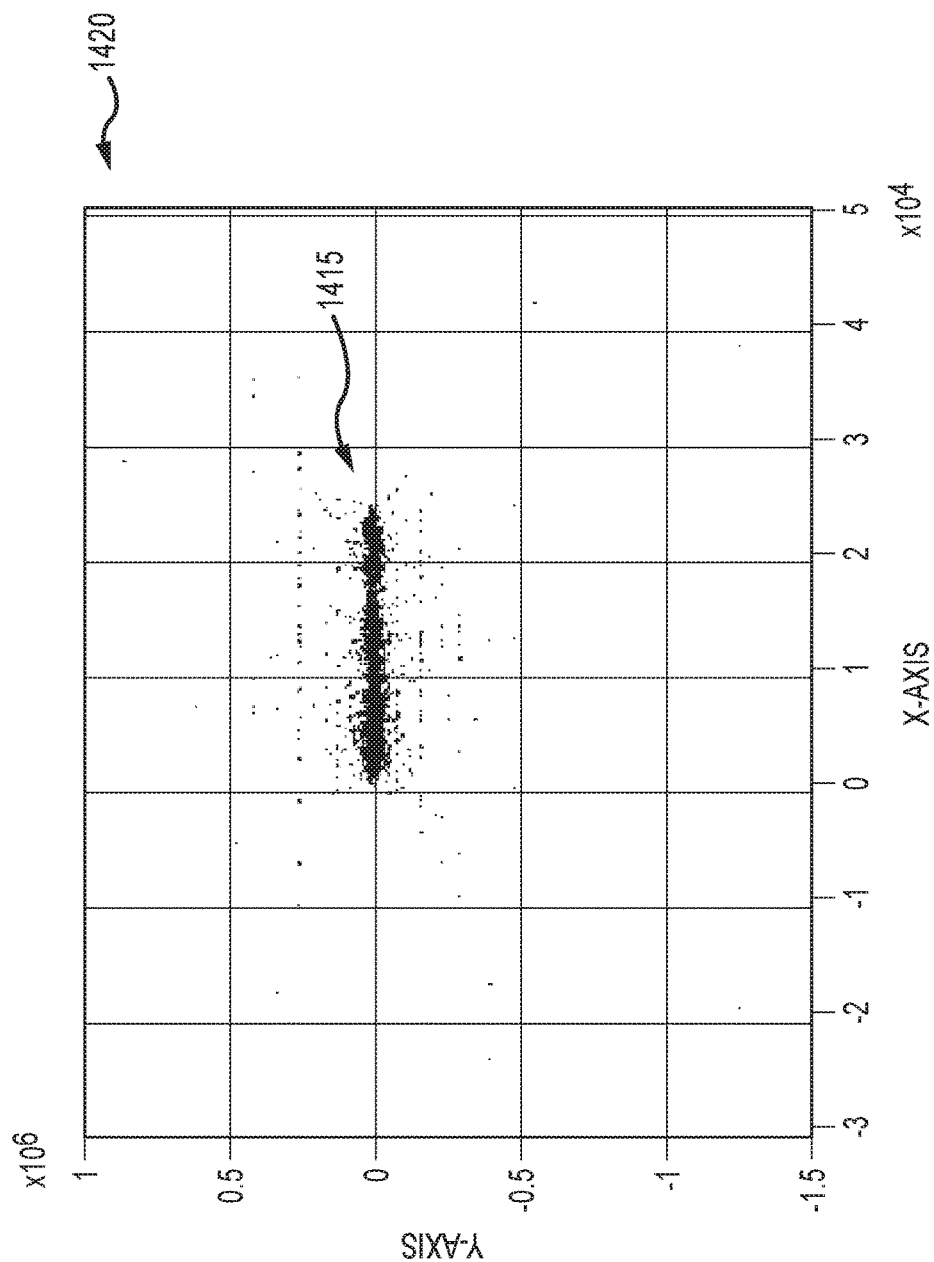


FIG.14B

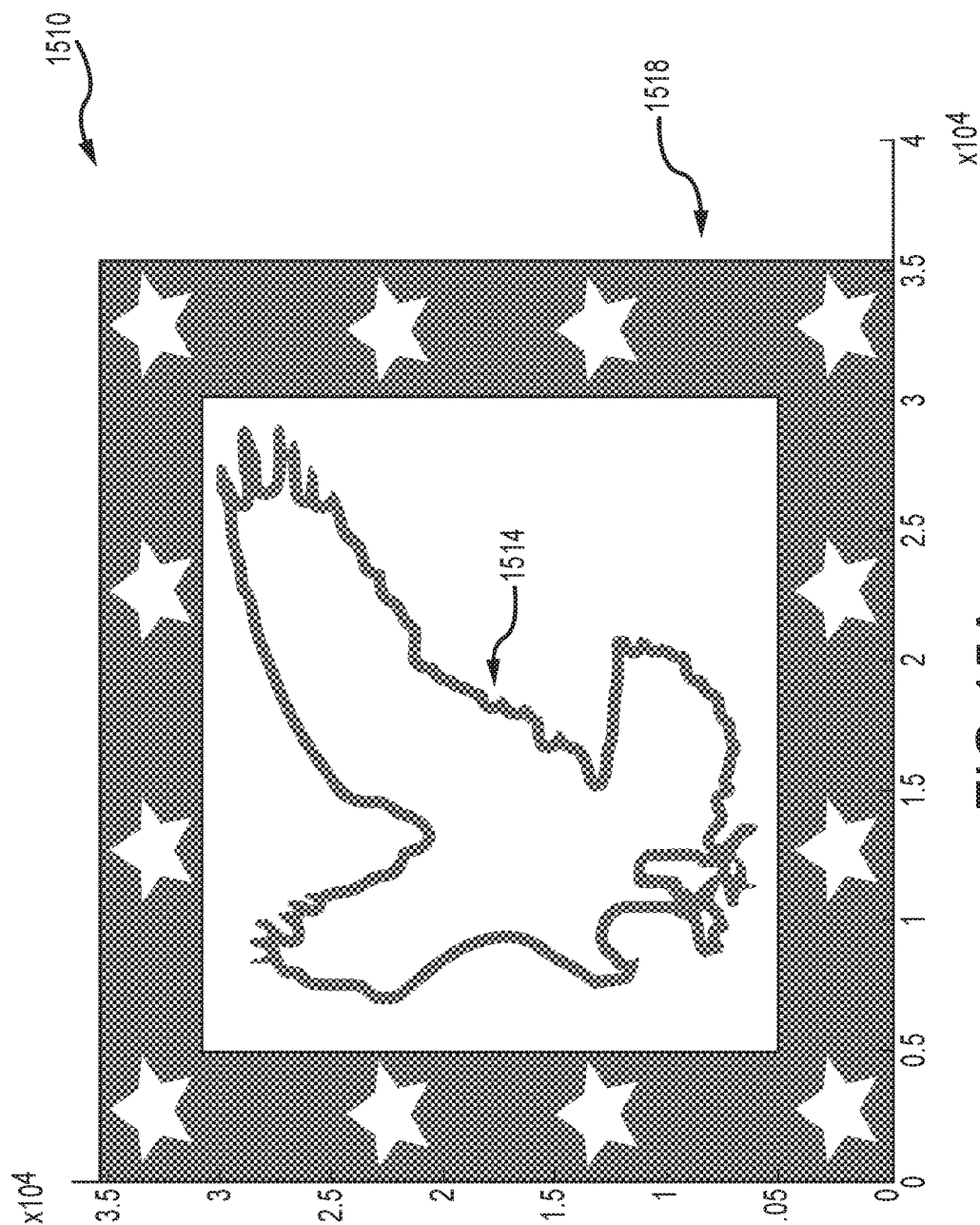


FIG. 15A

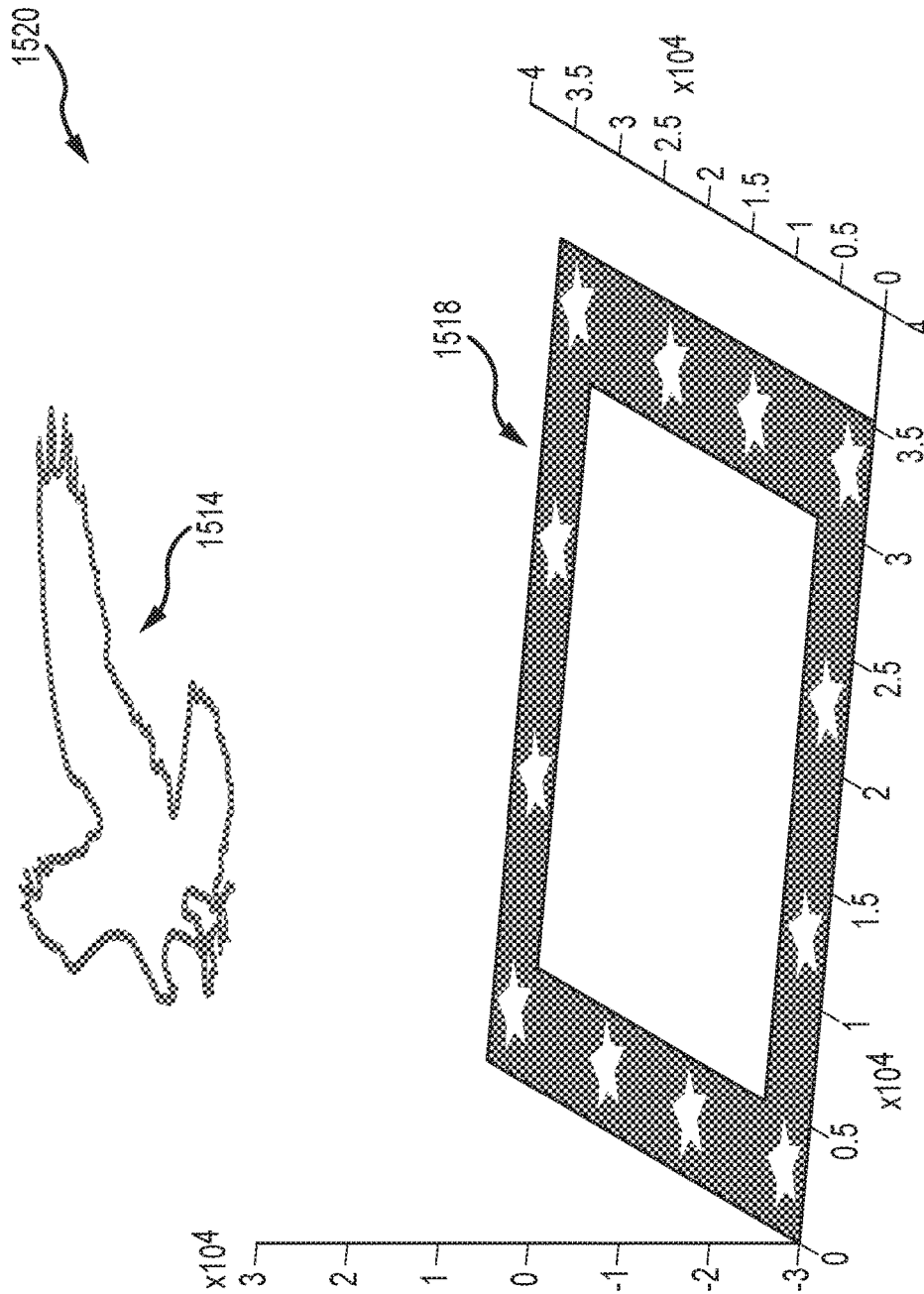
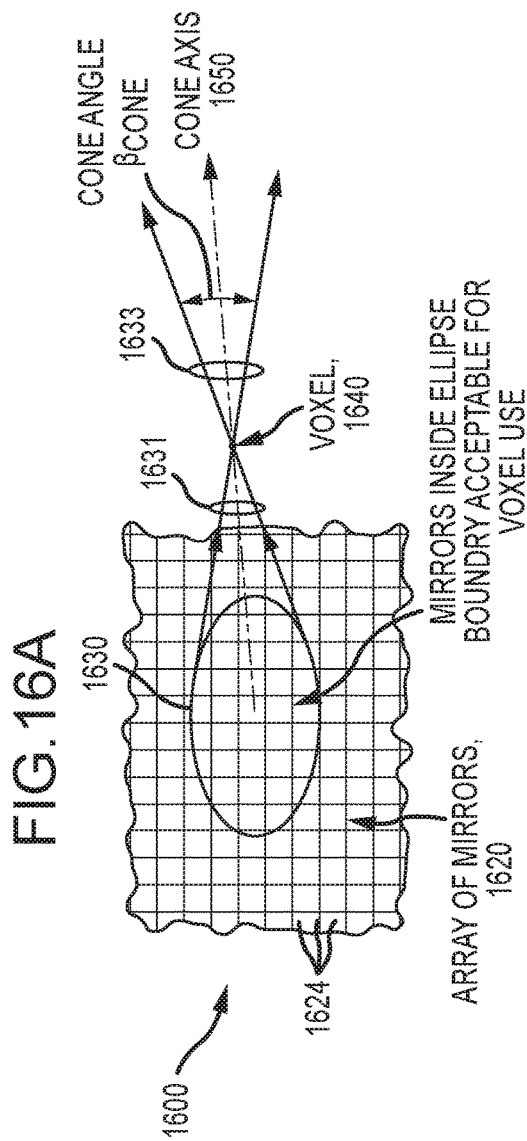
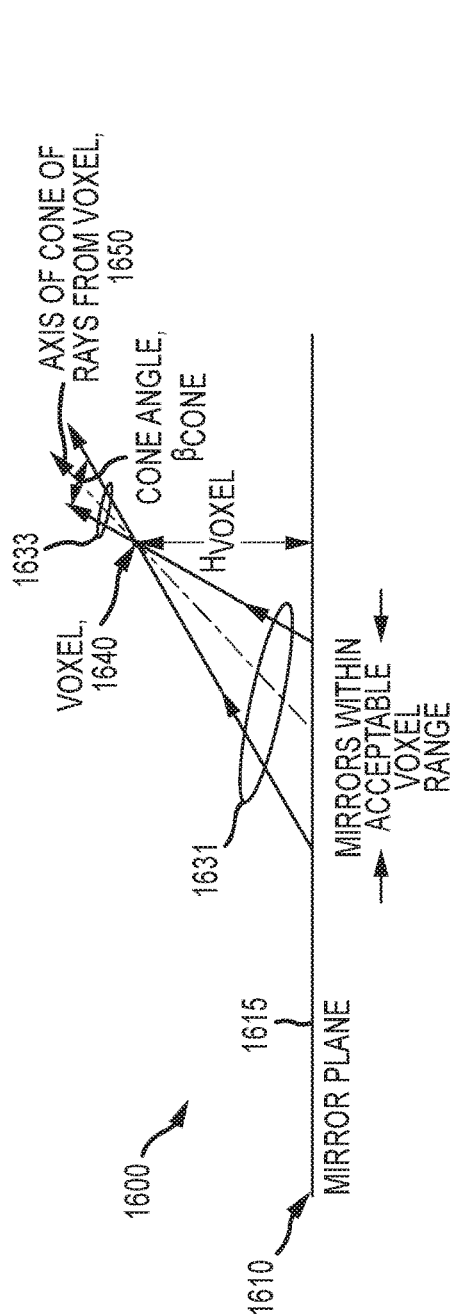


FIG. 15B



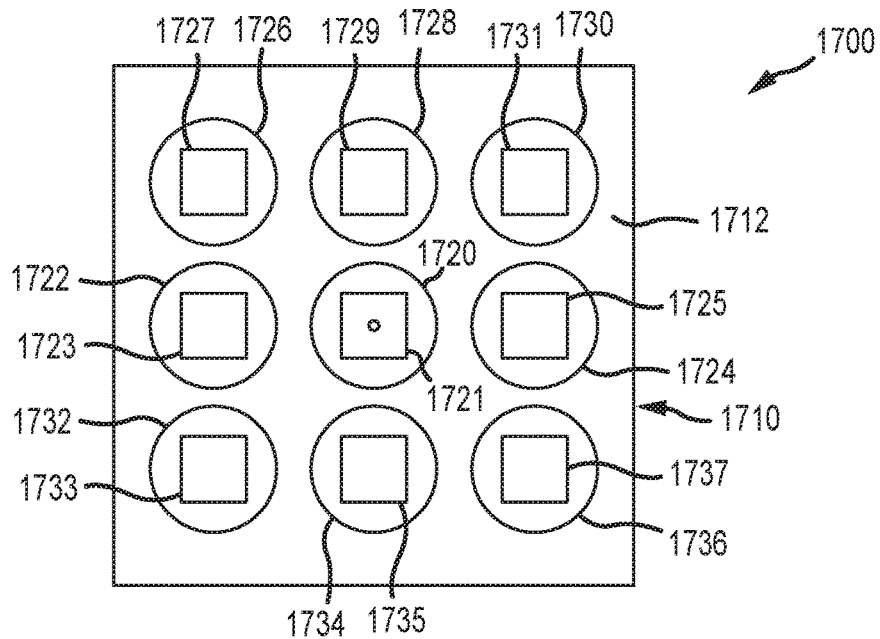


FIG. 17

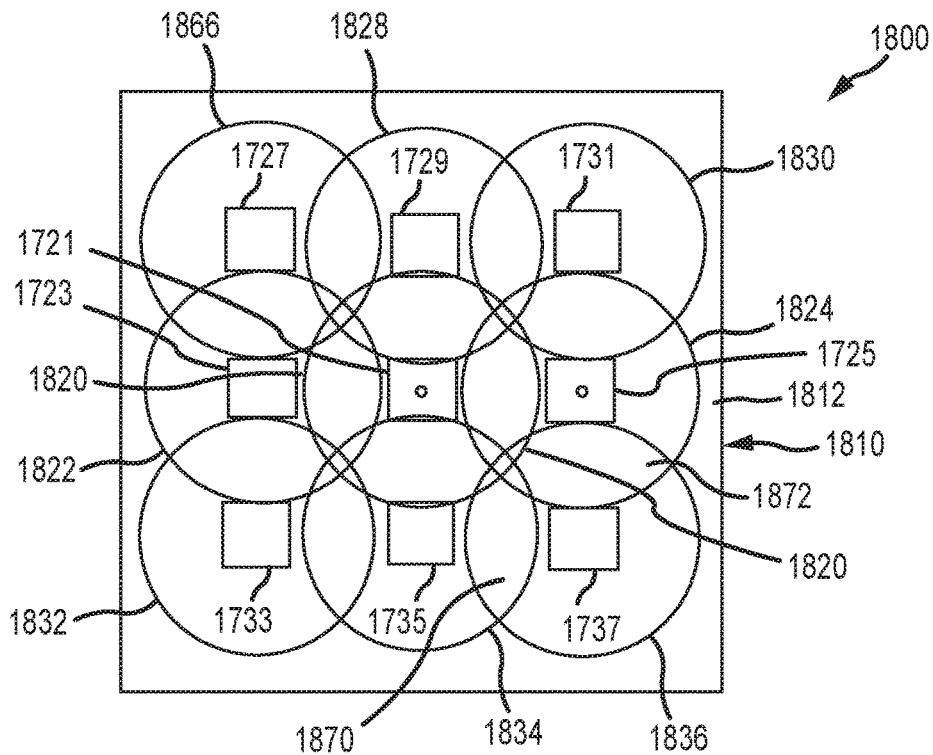


FIG. 18

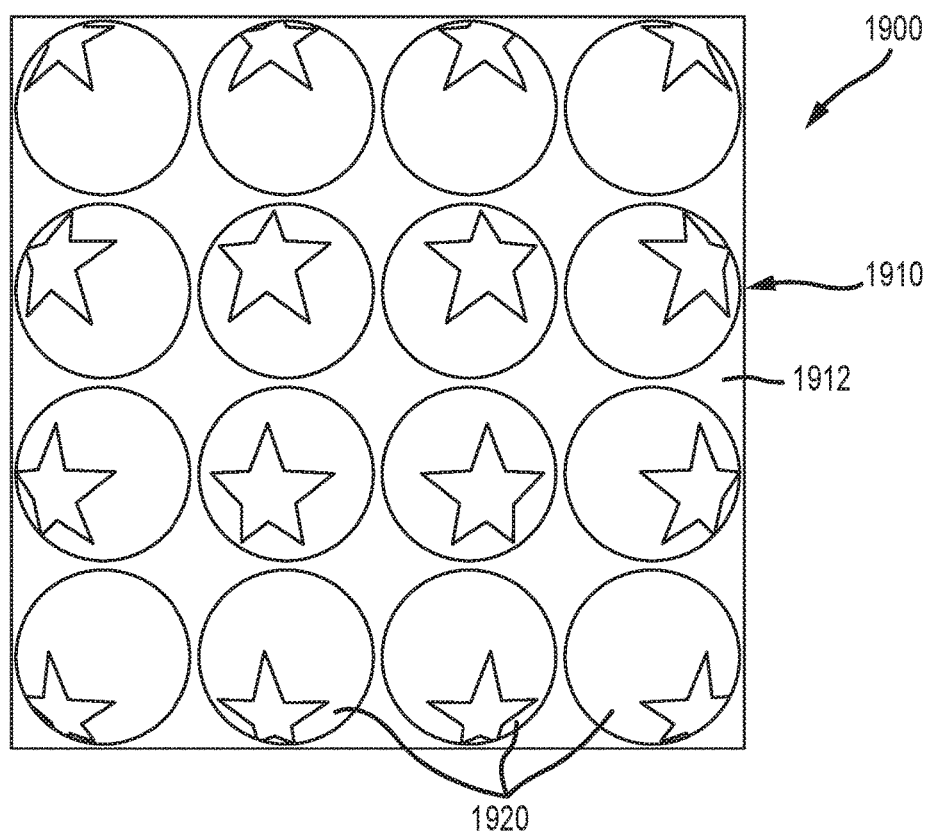


FIG. 19

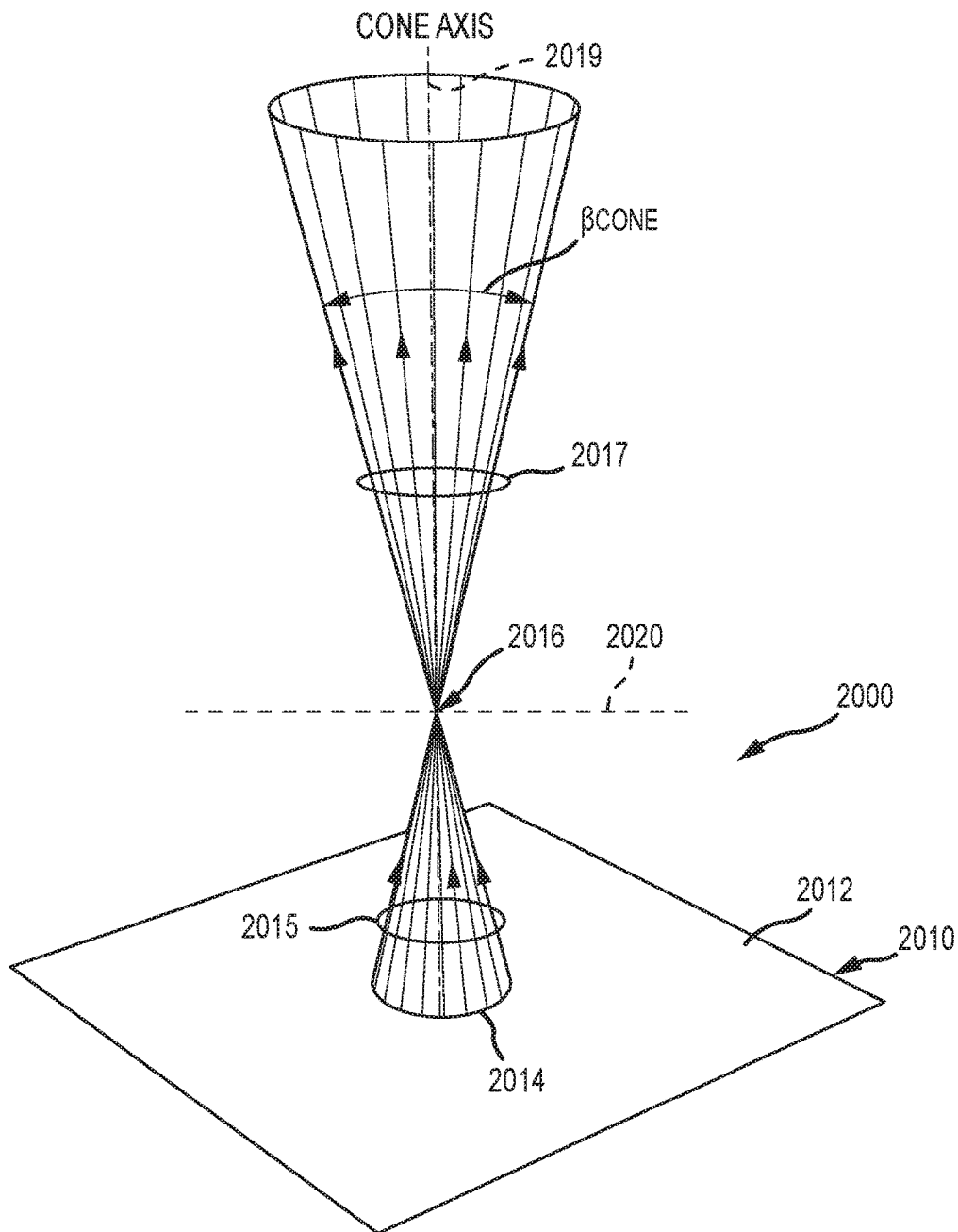


FIG. 20

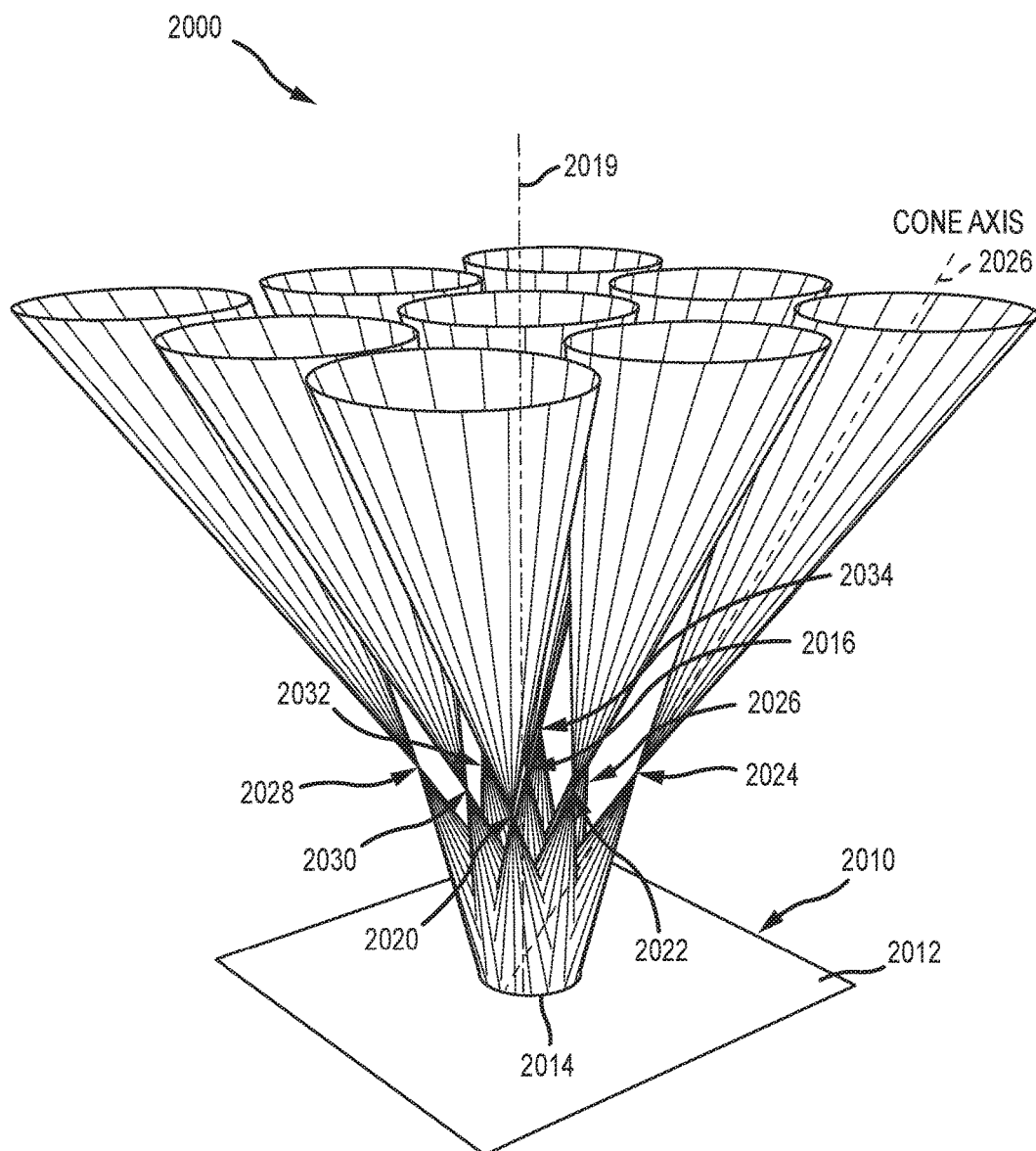


FIG. 21

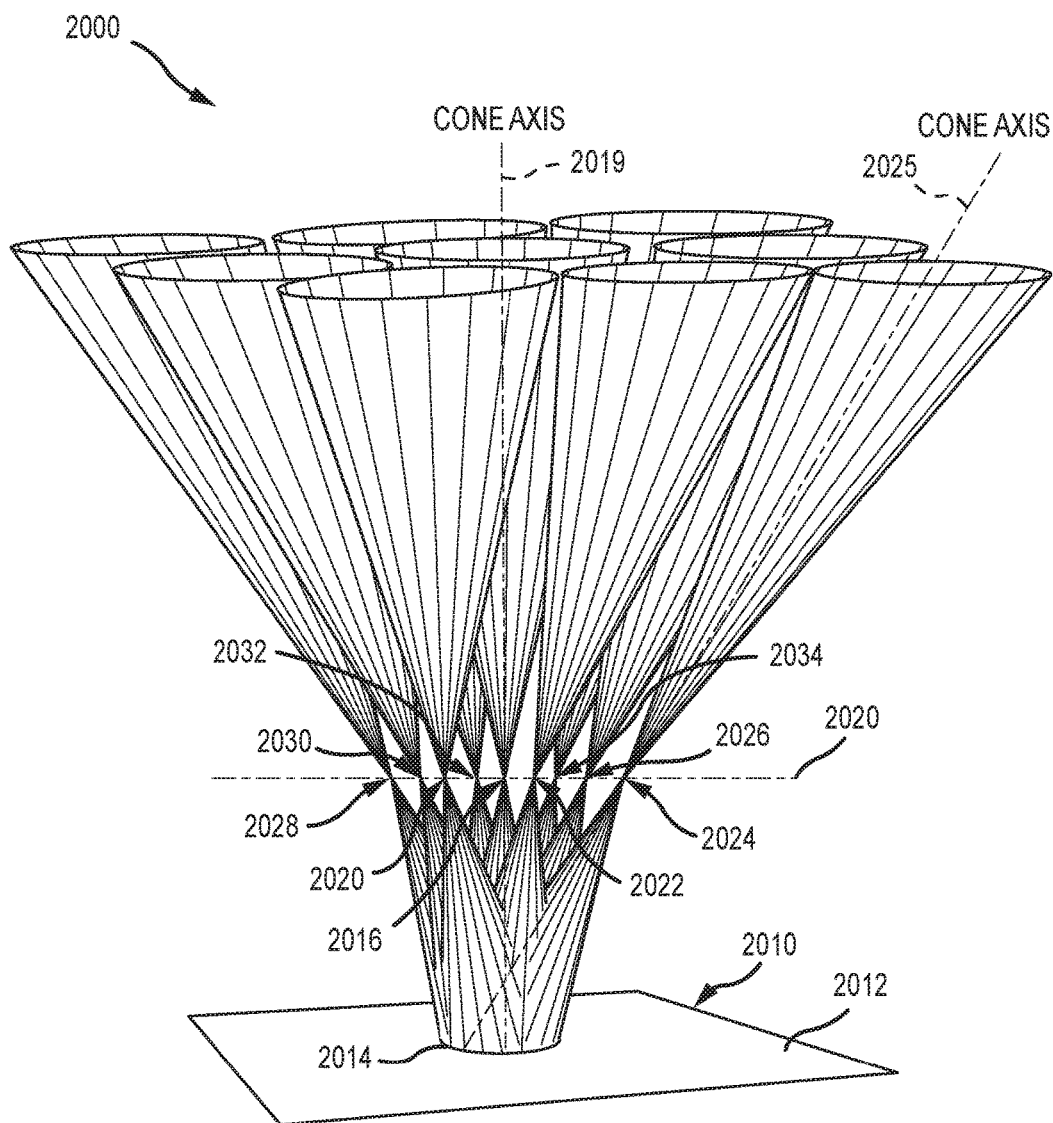


FIG. 22

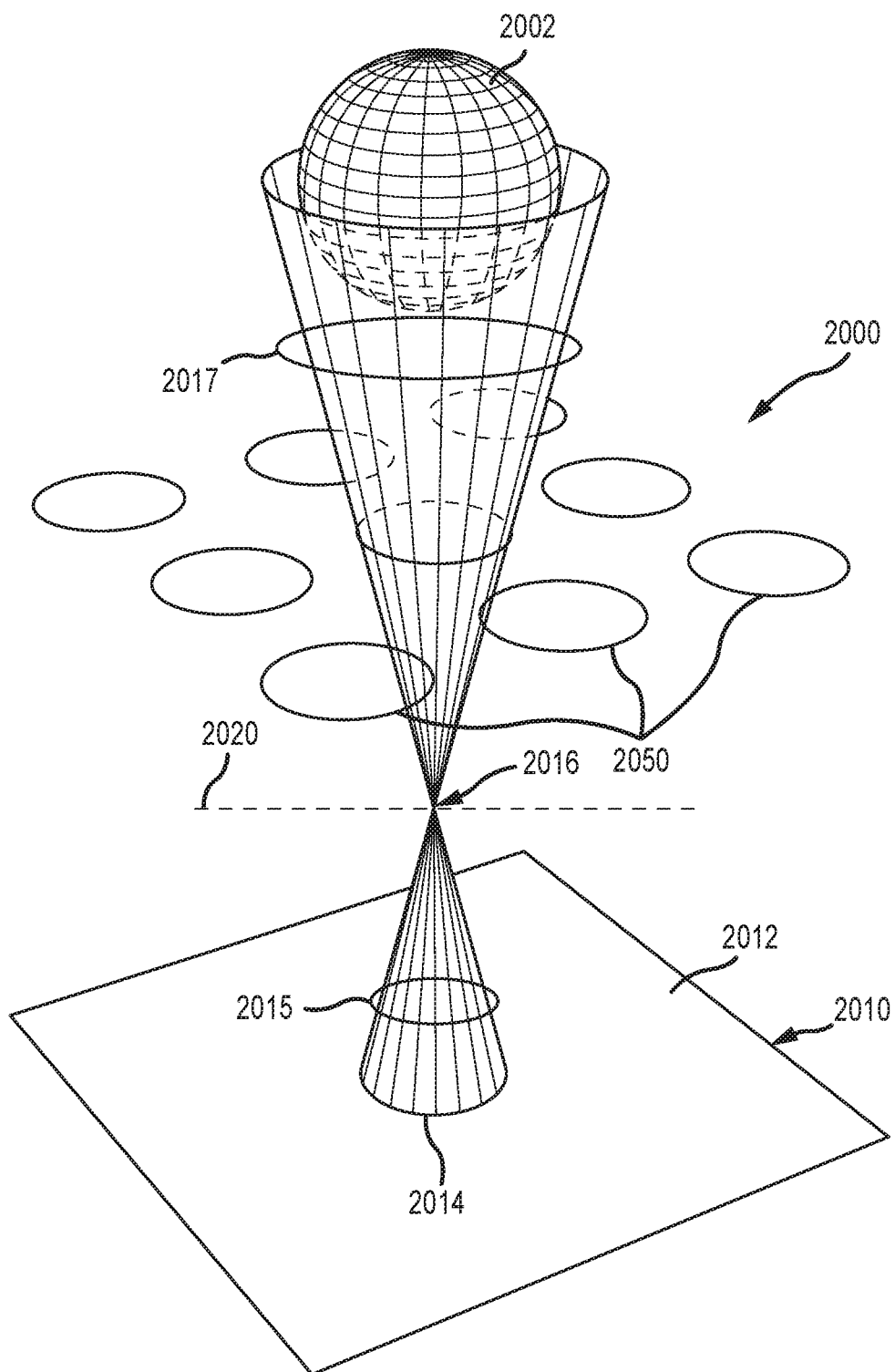


FIG. 23

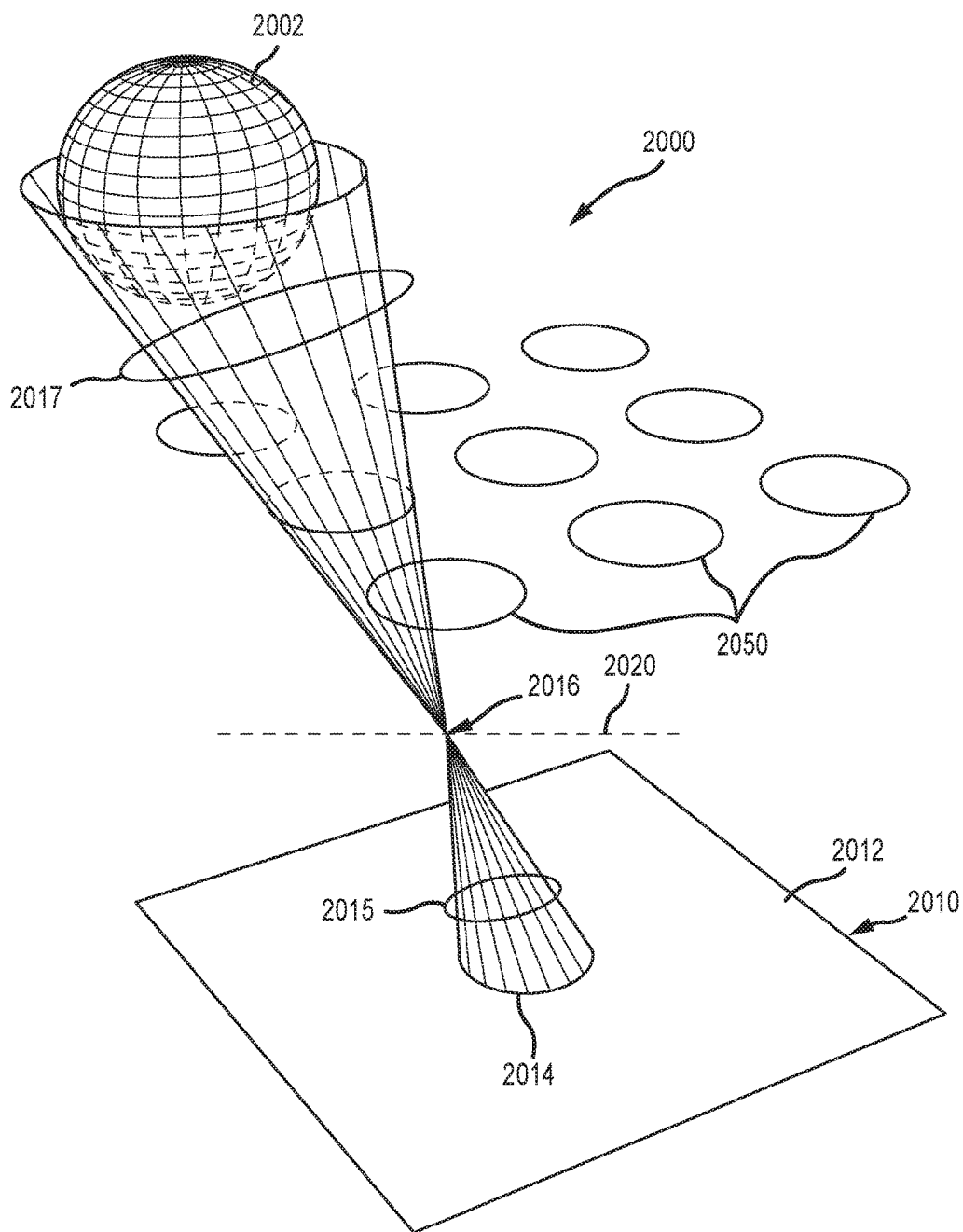


FIG. 24

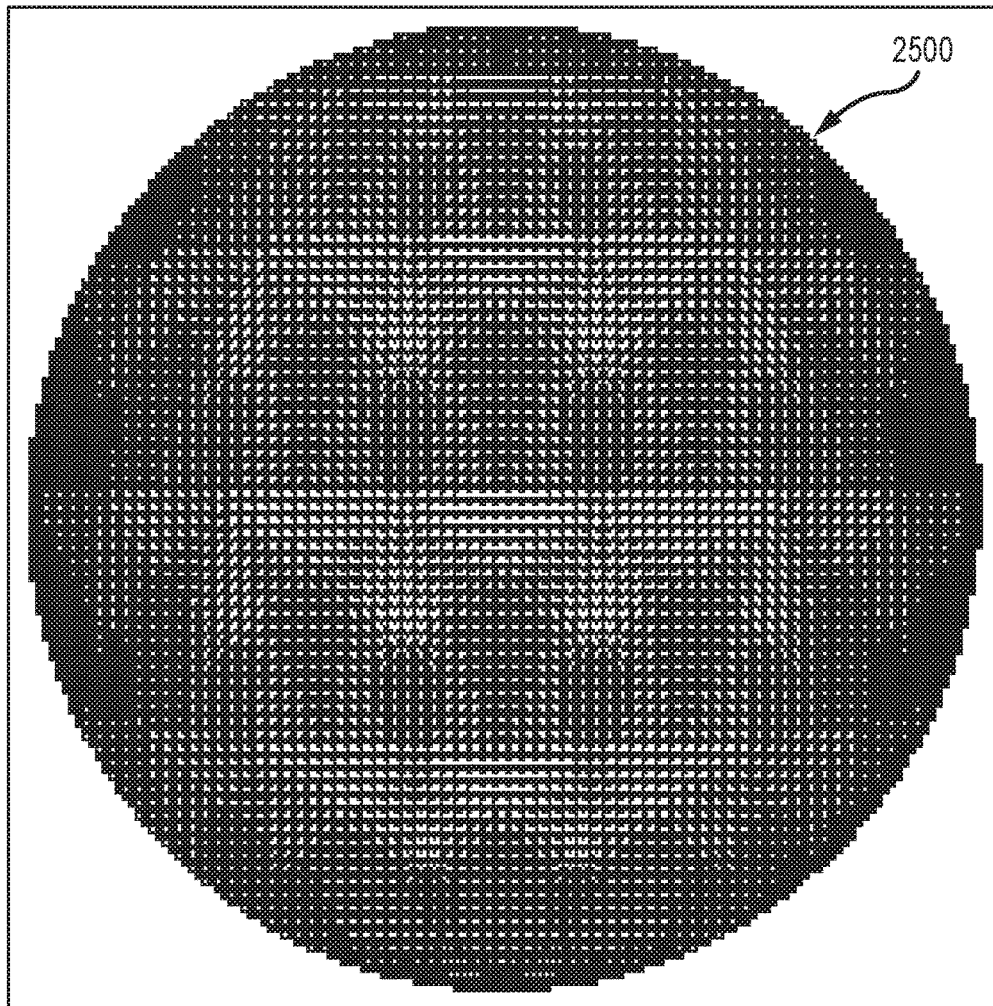


FIG. 25

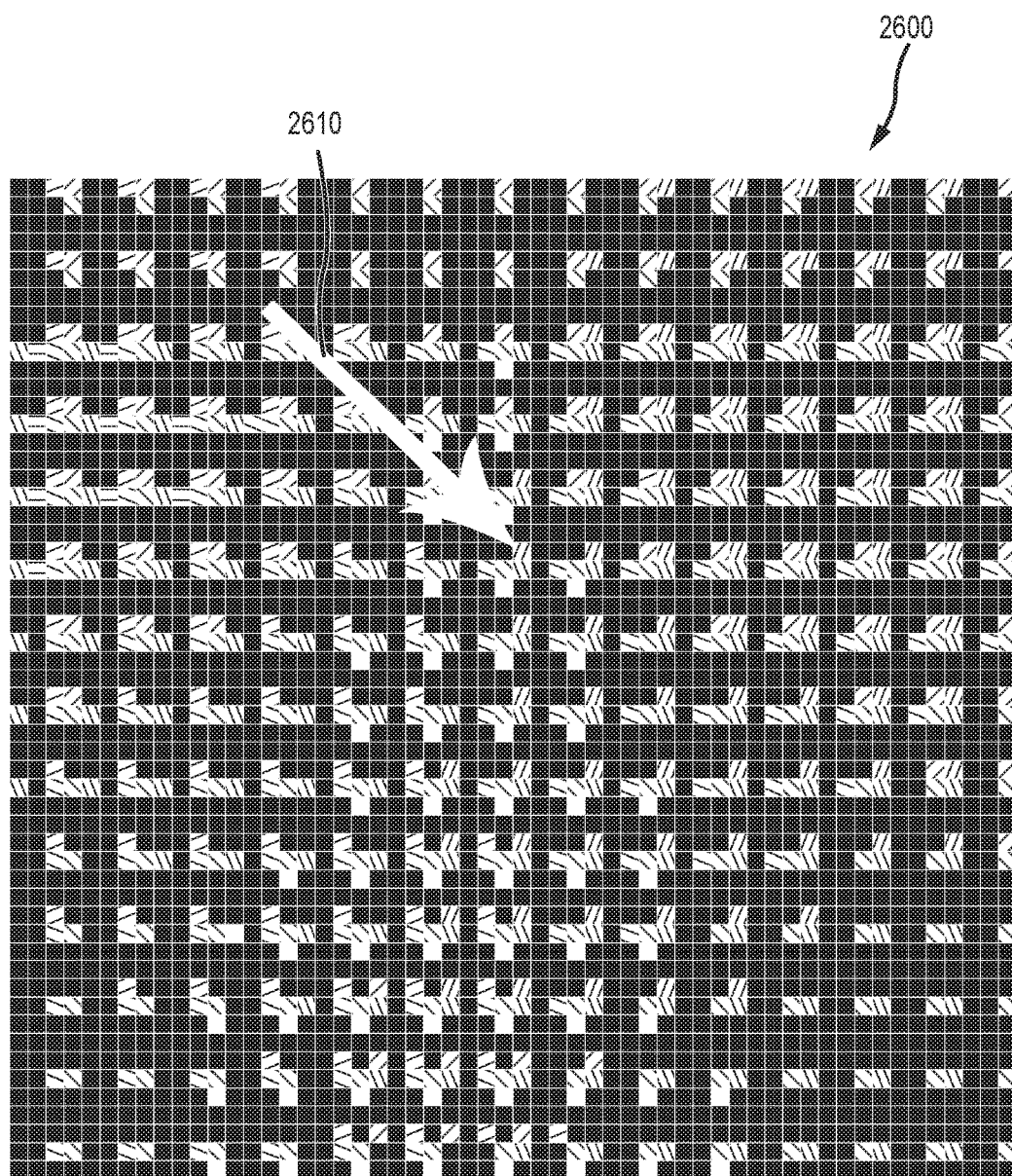


FIG. 26

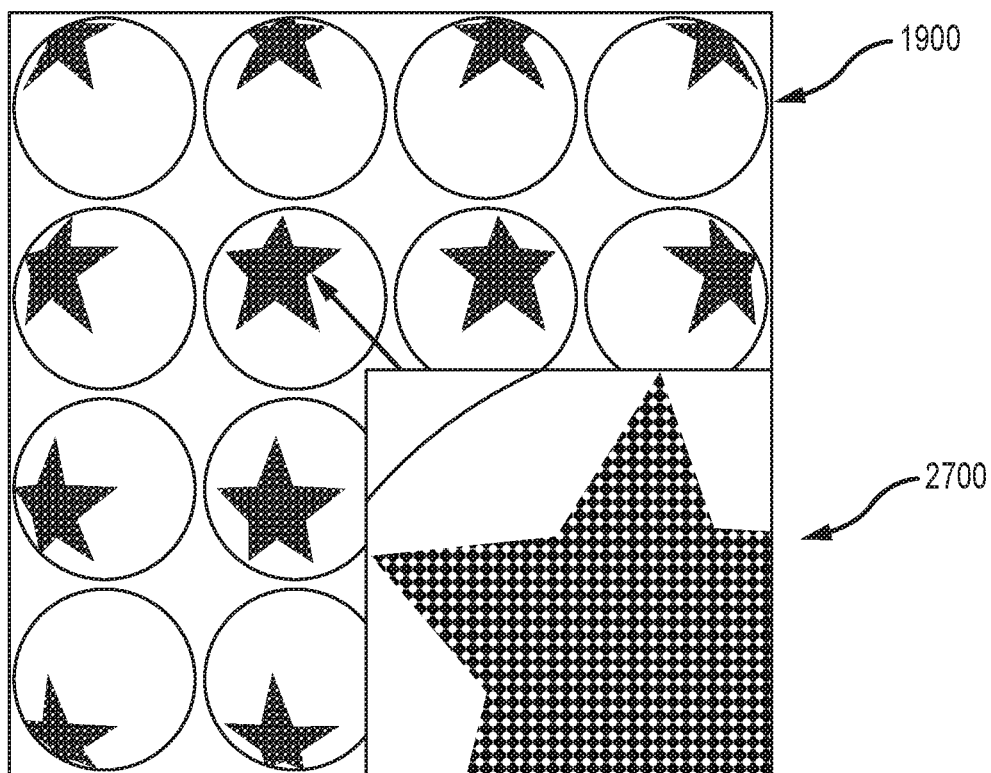


FIG.27

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ARRAYS OF INDIVIDUALLY ORIENTED MICRO MIRRORS PROVIDING INFINITE AXIS ACTIVATION IMAGING FOR IMAGING SECURITY DEVICES

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is continuation-in-part application of U.S. patent application Ser. No. 15/162,113, filed May 23, 2016, which claims the benefit of U.S. Provisional Application No. 62/262,767, filed Dec. 3, 2015, and both of these applications are incorporated herein by reference in their entireties.

BACKGROUND

1. Field of the Description

The present invention relates, in general, to anti-counterfeiting devices for currency and brand authentication, and, more particularly, to currency and brand authentication elements, and methods of designing and manufacturing such authentication elements, that are configured to provide a multi-planar image that is viewable without special eyewear and that is difficult, if not nearly impossible, to replicate or copy.

2. Relevant Background

Anti-counterfeiting efforts often involve use of an anti-counterfeiting device or element that is made up of an array of lenses and an image printed onto the back of the lens array or onto an underlying substrate or surface (e.g., a sheet of paper or plastic). The anti-counterfeiting element may be used to display an image that is chosen to be unique and be an indicator that the item carrying the anti-counterfeiting element is not a counterfeit. The anti-counterfeiting market is rapidly growing worldwide with anti-counterfeiting elements placed on a wide range of items such as upon currency (e.g., on a surface of a paper bill to help prevent copying) and on labels for retail products (e.g., labels on clothing showing authenticity).

In this regard, moiré patterns have been used for years in anti-counterfeiting elements with arrays of round lenses and with arrays of hexagonal lenses (or round and hexagonal lens arrays). Typically, the printed images provided in an ink layer under these lens arrays are small, fine images relative to the size of the lenses. A moiré pattern is provided in the printed images in the form of a secondary and visually evident superimposed pattern that is created when two identical patterns on a surface are overlaid while being displaced or rotated a small amount from each other.

In such moiré pattern-based anti-counterfeiting elements, some of the images may be printed in a frequency slightly more or less frequent than the one-to-one dimension of the lenses in two axes, and some of the images may be printed slightly differently relative to each other. While helpful to reduce counterfeiting, use of moiré patterns with round lens arrays has not been wholly satisfactory for the anti-counterfeiting market. One reason is that the effects that can be achieved with moiré patterns are limited, and the effect is often relatively easy to reverse engineer, which limits its usefulness as an anti-counterfeiting element. For example, printing the underlying image is becoming easier to accomplish due to high resolution lasers and setters and other printing advances. Typically, for an element, the micro-lenses are printed using an emboss and fill technology, which limits the printing to one color due to the fact that the process tends to be self-contaminating after one color and

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also due to the fact that the process is difficult to control from a relative color-to-color pitch in the emboss-and-fill printing process.

In other cases, holograms and lens features are used for security devices in currency, brand authentication, and brand protection as well as on high security documents. Holograms are becoming increasingly less secure, in part, due to the rise in technology, programming, and general availability of programs that allow one to easily create holograms. In many applications, the cheaper dot matrix holograms are “good enough” to simulate many of the effects of the more expensive elaborate holograms used in anti-counterfeiting elements. While lens features done properly can be more secure than hologram elements, there is a need for a new technology to combat the currency and product counterfeiting. Ideally, the new technology would have attributes that are not possible with holography or micro lenses.

Hence, there remains a need for advancements in the design and fabrication of assemblies or elements that display imagery useful for anti-counterfeiting and/or product/document authentication. For example, such improvements may allow new anti-counterfeiting devices or elements to be produced for use with currency, labels, credit/debit cards, and other items, and these anti-counterfeiting devices preferably would be much more difficult if not nearly impossible to duplicate or copy. Further, there is a growing demand for such anti-counterfeiting devices to provide a surprising visual effect or “wow factor” with their displayed imagery such as images that float above and/or below a focal plane (e.g., more true 3D displays) rather than merely laterally reflecting back light such as with a sequence of mirrors or mirrored surfaces or using reproducible holograms.

SUMMARY

Briefly, the inventors recognized that an anti-counterfeiting or security device can be provided that is configured to “write” images with light in one, two, or more spatial planes above and below the surface of an array of micro mirrors. Each of the micro mirrors is oriented (or “programmed”) to act with a number of other such micro mirrors (e.g., a “set of pixel-providing micro mirrors”) to write or produce one pixel in the written image(s) as each micro mirror in the set of micro mirrors directs its reflected light to a particular location in the image(s) display plane(s) (e.g., an apex of a cone with each of the micro mirrors in the set of pixel-providing micro mirrors being within the base of the cone) that when viewed with a number of other such pixels (each provided by a different set of pixel-providing micro mirrors) makes up a written image in one or more spaced-apart image display planes.

In other words, text, imagery, and so forth can be written with ambient light by focusing the micro-mirrors to different spatial planes above the plane of the security device (which is typically provided on a surface of a document (e.g., currency) or product being authenticated with the security device). Conversely, the technology can then “reverse” to the viewer by having the “bright” pixels go to “dark” and the backgrounds reverse from “light” to “dark” with a change of perspective (e.g., occurring when the viewer changes their viewing angle or rotates the document/product containing the security device).

Also, since the technology is made of mirrors (which may be made from thin aluminum, silver, or gold depositions on an upper surface of the document/product on which the security element is provided (e.g., any supporting substrate)), the anti-counterfeiting or security device will work

from two sides in a film process (e.g., when the supporting substrate is transparent). This type of two-sided or two-view image cannot be done with holography or other presently available anti-counterfeiting technologies. The technology can be embossed into films, metallized, and then processed into currency threads, foil stamps, labels, and packaging. It can also be directly stamped onto coins or other metallic surfaces (e.g., provided on nearly any supporting substrate). Color can also be added to the displayed or "written" image(s) by using a reflective ink printing method or with the use of dielectric nanostructures (e.g., with plasmonic resonance and/or other techniques).

More particularly, a visual display assembly is provided that is useful as a security element on paper and coin currency, product labels, and other objects. The assembly includes a substrate (which may be part of the object upon which the security element is provided such as a piece of currency or a product label). The assembly also includes, on a surface of the substrate, an array of micro mirrors receiving ambient light and, in response, displaying an image in a plane spaced a distance apart from the surface of the substrate. The image includes or is "written" with a plurality of pixels, and the array of micro mirrors includes for each of the pixels a set of the micro mirrors each having a reflective surface oriented to reflect the ambient light toward a point on the plane corresponding to one of the pixels.

In some embodiments, each of the sets of the micro mirrors includes at least twenty of the micro mirrors (e.g., a number in the range of 20 to 40 such as about 30 mirrors). To provide a "bright" or light pixel, the reflected ambient light from the twenty or more micro mirrors intersects at, crosses at, or passes near to the point corresponding to the one of the pixels (e.g., each pixel is displayed or lit by beams/rays from reflective surfaces of the micro mirrors crossing at a common point on the image display plane). The point on the plane may correspond to an apex of a cone, and the twenty or more micro mirrors can be located within a base of the cone coplanar with the surface of the substrate. The micro mirrors within the base of the cone but excluded from (or not included in or used for) the set of the micro mirrors displaying the pixel are oriented to reflect the ambient light away from the point on the plane corresponding to the pixel so as to generate or provide a dark background for the "written" image.

The assembly may be configured to display images in more than one image display plane or in two or more levels/layers. In this regard, the array of mirrors may be configured to behave further in response to the receiving of the ambient light to display a second image in a second plane spaced a distance apart from the first plane displaying the first image. The second image may be provided or "written" with a plurality of pixels (as was the case with the first image). The array of micro mirrors includes, for each of the pixels of the second image, a set of the micro mirrors each having a reflective surface oriented to reflect the ambient light toward a point on the second plane corresponding to one of the pixels of the second image. The first image has a first viewing angle and the second image has a second viewing angle offset from the first viewing angle by at least 10 degrees (such as an offset angle in the range of 10 to 45 degrees with offset angles of 20 to 30 degrees being useful in some embodiments).

In some particular implementations, the substrate is transparent, whereby the image is displayed to be spaced apart the distance from a first side of the substrate and further whereby a second image including a second set of pixels is displayed by the array of micro mirrors to be spaced apart a

second distance from a second side of the substrate opposite the first side. In this manner, the array of micro mirrors can be said to be completely functional on the reverse side of the substrate (or film) to present a mirror image or a reverse image (in the image plane) to the viewer on the opposite side of the substrate.

In the same or other embodiments, the micro mirrors are rectangular (e.g., square) with a smallest side having a length of at least 31 microns such as 50 microns or more while other embodiments use mirrors that are circular with a diameter of at least 31 microns (e.g., 50 microns or larger in diameter). In practice, the plane in which the image is displayed may be above, below, or coinciding with the focal plane for the array of the micro mirrors. Also, the image may be displayed using only (or mostly) white light (and off or dark pixels) or the micro mirrors may be configured to display the image with colors (in addition to white). This may be achieved with at least one of ink, plasmonic resonance, or dielectric material being used to configure the micro mirrors to display the image with the desired colors.

In some embodiments, the assembly is configured to provide infinite axes animation using cone angle offsets to display two or more images on an image plane above (or below) the substrates. Specifically, the micro mirror array may be configured for displaying a plurality of images in a plane spaced a distance apart from the surface of the substrate. Each of the sets of the micro mirrors is configured to provide or "write" (with reflected light at pixel locations) the pixels for each of the differing ones of the images with a differing cone angle offset. In this regard, the cone angle offset is defined based upon a relative position of a cone axis for a cone of rays projected by the sets of the micro mirrors through each of the pixels.

In some cases, the cone may have a cone angle in the range of 10 to 45 degrees, and the cone angle offsets are selected whereby the cones do not overlap at a predefined height above the substrate (e.g., to leave spacing at an expected viewing distance such as in the range of 6 to 18 inches to avoid ghosting or the like). The images may include two or more frames of an animated clip, whereby a viewer observes animation when viewing two or more of the images associated with the two or more frames, and the animation is sometimes in both the X axis and in the Y axis. In the same or other embodiments, one or more additional images may be provided in a second image plane spaced apart a distance from the first image plane to create 3D imagery or effects using cone angle offset techniques, e.g., two or more 3D images are visible based on the particular viewing angle of the viewer.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a top perspective, partial view of a visual display assembly for use as an anti-counterfeiting element or device showing a single micro mirror that would be provided in an array of such micro mirrors;

FIG. 2 is a side view (e.g., a functional schematic) of an object (such as currency, a document, a financial card, or the like) including an anti-counterfeiting or authentication (or security) element/device of the present description;

FIG. 3 is an enlarged view of a subset of the micro mirrors of the security element of FIG. 2 corresponding to micro mirrors in an area of one cone base associated with one cone apex or written pixel in one of the displayed/written images provided by the security element of FIG. 2;

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FIG. 4 is a schematic or graphic side view or diagram of a security element during its use to provide a two-layer or level image;

FIG. 5 is a side schematic view or diagram of a security element during its use to provide a display that combines a light image and a dark image;

FIG. 6 is a functional block diagram of a computer or computing device configured to run an array design program to allow an operator to generate a design of an array of micro mirrors for displaying a particular image(s) when provided in a security element;

FIG. 7 is a flow diagram of an exemplary design method for an array of micro mirrors for use in a security element, such as may be carried out by operation of the system of FIG. 6;

FIGS. 8A and 8B illustrate a micro mirror design GUI that can be displayed on a monitor or display by the design program;

FIGS. 9A-9C are graphs illustrating images that can be displayed on various levels or image display planes by an array of micro mirrors of the present description;

FIG. 10 is a plot illustrating a ray tracing near a first image display plane or first level/layer for one modeled array of micro mirrors;

FIG. 11 illustrates a representative GUI or ray tracing menu that allows a user to specify parameters to utilize in performing the ray tracing;

FIG. 12 is a plot of a representative ray tracing showing beams/rays reflected from micro mirrors in a mirror plane and converging on a viewer's retina;

FIGS. 13A and 13B illustrate written or displayed images provided by an array of micro mirrors with an angular offset between image display planes or levels/layers of the imagery;

FIGS. 14A and 14B illustrate plots of floating pixels in a space above an array of micro mirrors;

FIGS. 15A and 15B illustrate plots generated and displayed by a preview program (which may be a subroutine of the design program described herein) for previewing likely or predicted results of a design of an array of micro mirrors;

FIGS. 16A and 16B illustrate schematically side and top views, respectfully, of a security element or visual display assembly during its use to display a single voxel, such as from a particular image/frame visible at a particular height/level and associated with a particular offset value or angle;

FIG. 17 illustrates a schematic top view of a security element/visual display assembly of the present description that is configured to use nine different cone angle offset values for sets of micro mirrors used to display nine different images/frames with no (or minimal) cone overlap;

FIG. 18 illustrates a view of another security element similar to that of FIG. 17 but with cone overlap being provided with a differing configuration of the micro mirrors used to display/write voxels of the nine images;

FIG. 19 illustrates a top view similar to FIGS. 17 and 18 of a security element with its micro mirror array configured for sixteen cone offset angles to display sixteen differing frames of an animation clip;

FIG. 20 illustrates a side perspective view of a security element of the present description showing a single voxel of an image (such as a frame of an animation clip or an image a 3D model) being displayed at a particular height and at a particular cone angle offset;

FIGS. 21 and 22 are top and side perspective views of the security element of FIG. 20 as it is being used to display nine

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voxels/pixels from nine different images/frames via sets of micro mirrors configured with nine different cone offset angles;

FIGS. 23 and 24 illustrate the security element of FIGS. 20-22 during its use by a viewer showing that configuring differing sets of micro mirrors to differing cone angle offsets allows the viewer to view on frame/image in differing viewing positions or angles;

FIG. 25 illustrates an interlaced image comprising pixels from sixteen differing frames/images for display via sets of micro mirrors using pixel mapping;

FIG. 26 illustrates an enlarged portion of the image of FIG. 25 showing differing colored pixels; and

FIG. 27 illustrates the images of FIG. 19 showing an exploded view of one of the sixteen images to illustrate this images pixels in found in the interlaced image of FIG. 25.

DETAILED DESCRIPTION

Briefly, the present description is directed toward visual display assemblies that can be used as anti-counterfeiting or authentication elements or devices such as on currency, coins, documents, products, and so on. Each visual display assembly includes an array of a large number of micro mirrors, and this array can be provided on a surface of nearly any supporting substrate (e.g., a surface of a piece of currency, on a coin, on a surface of a product or its sales/identification label, and so on). Sets (or subsets) of the micro mirrors are used to work in unison to "write" the pixels of images in one, two, or more image display planes above the supporting substrate by having each of the micro mirrors in each of the pixel-providing sets direct light striking its first or upper reflective surface to a location of a single one of the pixels in one of the image display planes. The sets of pixels may be configured to provide angular offset viewing (e.g., by an offset angle in the range of 15 to 35 degrees or the like with 20 degrees used in some cases between the viewing angles of the written images of each adjacent image display plane) in the different image display planes such that a viewer typically only observes or perceives the written pixels of one image display plane at a time (or at a single viewing angle or perspective) and switching occurs as the viewer changes their viewing angle or rotates the substrate supporting the visual display assembly and its many micro mirrors.

The visual display assembly (or security element/device) is designed to create a floating image(s) made up of many pixels, and the pixel-providing sets of micro mirrors are chosen to have a large enough number to effectively display a great enough quantity of light to allow a viewer to perceive each separate, floating pixel in the written or displayed image. The number of micro mirrors used in each set may vary due to a large number of parameters such as the material used to provide the reflective upper surface, the size of each micro mirror (e.g., with 35 to 100 micron mirrors used in some implementations and 50 micron mirrors used in one prototype of the present invention), and the like. Each of these micro mirrors in each pixel-providing set is oriented to try to have all of the micro mirrors direct their reflected light to intersect at a point (i.e., to display or produce the written pixel of the displayed image) in an image display plane a distance above (or below) the supporting substrate, and each pixel of the written image is either on or off (or providing light or no light) at various viewing angles.

A basic or underlying idea of the micro mirror-based visual display assembly is to use ambient light and a plane (an upper surface of a supporting substrate) containing

many, small mirrors. The ambient light that is reflected off the mirrors is aimed or targeted toward desired points (or pixels) above the plane that contains the mirrors. The image displayed by all the pixel-providing sets of micro mirrors targeting a first image display plane above the supporting substrate may be considered a first layer image. The first layer image can be defined by artwork that has light or dark pixels to be produced in this first layer (or a multi-layer image) or first image display plane. To this end, the mirrors in a pixel-providing set of micro mirrors are carefully selected from the micro mirror array as being within a circle (or cone base) defined by the intersection of the cone defined by an apex angle and a pixel from the desired image display plane/layer (e.g., the first image display plane) that is chosen to coincide with the apex of the cone. Each of these mirrors (which are in the base of the cone) is fabricated so as to be aimed or targeted (or "oriented") toward the cone apex (image's pixel) so that the resulting effect is a point source of light floating a height or distance above (or below in some cases) the plane of the supporting surface containing the array of micro mirrors at the location of the pixel in the displayed or written image.

Prior to explaining a design or configuration of an entire array of micro mirrors in a visual display assembly, it may be useful to first look at a single one of these mirrors. FIG. 1 illustrates a portion of a visual display assembly 100 (or a substrate with a security element or device) according to the present description. As shown, a supporting substrate 110 with a surface 112 is provided that receives and supports a micro mirror 120. For example, the substrate 110 may be a piece of currency, a coin, a product label, a document, a credit/debit/bank card, or the like for which it is desired to provide anti-counterfeiting or authentication functionality with the visual display assembly or security element 100. The micro mirror 120 is shown to include a body (or lower layer/surface) 122 that is affixed to or integrally formed with the surface 112 of the substrate 110. The view in FIG. 1 is only "partial" as it will be understood that the assembly 100 typically would include many (e.g., hundreds to many thousands) of the micro mirrors 120 (i.e., an array of micro mirrors 120). Each of such micro mirrors 120 is individually oriented or "programmed" as discussed below such that the micro mirrors 120 of the array act together to display one or more floating images made up of a plurality of pixels in one or more image display planes above the substrate surface 112.

The micro mirror 120 also includes an upper (or exposed) reflective surface 124 facing away from the surface 112 of the supporting substrate 110. This surface 124 is reflective as the micro mirror 120 typically will be formed of a metal or metallic compound or other material chosen for its reflective properties. For example, the micro mirror 120 may be a thin layer of aluminum, silver, gold, or the like provided by deposition upon the surface 112 of the substrate 110. When the image display assembly 100 is in use, ambient light 130 strikes the reflective upper surface 124 of the micro mirror 120 and is reflected as shown at 134 from the upper surface 124. Particularly, the micro mirror's upper surface 124 is to have a normal vector 135 (e.g., as may be defined as output of a design program with X, Y, and Z coordinates), and the incoming ray 130 and the normal vector 135 form the same angle, β , as is formed between the normal vector 135 and the reflected light 134.

The reflected light 134 is preferably directed or aimed so as to cross an image display plane 140, which is spaced apart a height, H_1 , above or away from the substrate surface 112 (and reflective surface 124 which may be substantially

coplanar due to the small thickness of the body 122), at a location (X-Y-Z coordinates may define this location relative to the surfaces 112 and 124) coinciding with or defining one of a plurality of written pixels 142 of an image displayed by the assembly 100 in the plane 140. While not shown, a plurality of other micro mirrors configured similar to mirror 120 would also reflect their received ambient light to the point/pixel 142 in the plane 140 (a plurality of reflected light beams from micro mirrors would intersect at the point/pixel 142) so as to provide a point source of light at 142 viewable by a viewer 102.

To provide this desired reflection of light 134, the micro mirror 120 is oriented or has its reflective surface 124 oriented in a particular, predefined manner (e.g., by a visual display assembly configuration computer program or algorithm). Particularly, each micro mirror 120 may be individually oriented by rotating its body 122 (or surface 124) about one or both of first and second rotation axes 150, 152 as shown with arrows 151, 153 during design processes (prior to fabrication). Then, the micro mirror 120 may be formed with these design parameters so that the reflective upper surface 124 (with its known location in the array of micro mirrors defined or designated by X-Y coordinates of its center) is oriented (at first and second angles) relative to the two axes 150, 152 to have its normal vector 135 aimed or targeted in a particular manner (X-Y-Z coordinates of the normal vector for the mirror 120), e.g., to have ambient light 130 reflected as shown at 134 to cross the image display plane 140 at the location of the pixel 142. As noted above, the size (and shape) of each micro mirror 120 may be varied to practice the invention with some embodiments utilizing square-shaped bodies 122 that have sides with a length, L_{side} , that is typically greater than about 35 microns (such as 50 microns) and often in the range of 40 to 60 microns while some embodiments may use larger micro mirrors.

FIG. 2 is a side view (e.g., a functional schematic) 200 of an object (such as currency, a document, a financial card, or the like) 210 including an anti-counterfeiting or authentication (or security) element/device 220 of the present description. The object or substrate 210 includes an upper or first surface 212 upon which is provided or formed the security device 220 (which may take the form of the visual display assembly 100 of FIG. 1). The security device 220 has an exposed or upper surface 222 that is configured to provide an array of micro mirrors 224, which may be individually oriented to provide reflection of ambient light striking the surface 222 of the security element 220 so as to display one or more floating images that can be observed by a viewer 202 to authenticate the object 210.

To this end, a first number of the micro mirrors 224 may be configured to provide sets of pixel-providing micro mirrors that reflect ambient light as shown with arrows 230 to "write" or display a first displayed image 242 made up of a plurality of pixels 243 (with each of these pixels 243 associated with one of the sets of pixel-providing micro mirrors 224). A second number of the micro mirrors 224 is configured to provide sets of pixel-providing micro mirrors that reflect ambient light as shown with arrows 250 to "write" or display a second displayed image 262 made up of a plurality of pixels 263 (with each of these pixels 263 being associated or written by one of the sets of pixel-providing micro mirrors 224). As discussed with reference to FIG. 1, each of the micro mirrors 224 in the same set of pixel-providing micro mirrors 224 used to create/write a particular pixel 243, 263 in one of the images 242, 262 is configured or oriented with its reflective surface oriented (with rotation relative to one and/or two rotation axes) targeted or directed

at a point/location on the plane **240** or **260** coinciding with the pixel **243**, **263**. This point/location, in most embodiments, coincides with an apex of a cone with each of the pixels **243**, **263** written or produced by a set of micro mirrors **224** that are in the base of the cone (e.g., within the circular area on the surface **222** defined by the cone base). Note, each of these micro mirrors **224**, though, is oriented uniquely and differently so as to provide the reflected light **230**, **250** along a normal vector to its reflective surface.

To the viewer **202**, the first displayed image **242** appears to float in the first image display plane **240** that is a height, H_1 , above the surface **212** of the object/substrate **210** while the second displayed image **262** appears to float in the second image display plane **260** that is at a different (typically greater) height, H_2 , above the surface **212**. The micro mirrors **224** are oriented so that the pixels **243** of the first image **242** are at a viewing angle offset, θ_{Offset} (e.g., 10 to 30 degrees or the like) from the pixels **263** of the second image **262** so that the viewer **202** typically only views one of the floating images **242**, **262** at a time (at a range of viewing angles).

As discussed above, micro mirrors for each set of pixel-providing micro mirrors are chosen from a set of available micro mirrors located within an area on the security element surface (or substrate surface) that corresponds with a base of the cone with an apex coinciding with the pixel being created by these micro mirrors. FIG. 3 is an enlarged view of a subset of the micro mirrors **224** on the surface **222** of the security element **220** of FIG. 2, which correspond to micro mirrors **224** in an area of one cone base with diameter, $\text{Diam}_{\text{Cone Base}}$, associated with one cone apex or written pixel **243** or **263** in one of the displayed/written images **242** or **262** provided by the security element **220**.

FIG. 3 illustrates all the available micro mirrors in the cone base, but the security element **220** typically is designed so that only a subset of these available mirrors **224** (such as 20 to 40 or more with 30 shown in use in FIG. 3 at **324**) is used to write or display a particular pixel. The unused mirrors (shown without shading) of the available mirrors **224** typically are oriented to reflect received ambient light away from the location of the pixel being written/created by the chosen mirrors **324**, which may be considered as providing a mask with the unused mirrors. The chosen mirrors **324** (or mirrors in the set of pixel-providing micro mirrors) are shown with shading/patterning that would not be actually present in a security element but that is useful for differentiating these mirrors **324** from the other/unused ones of the available mirrors **224**, which are shown without shading in FIG. 3.

As will be explained below, the micro mirrors **324** in the set of pixel-providing micro mirrors are randomly chosen (by software or a program as discussed below) such that the mirrors **324** do not provide an obvious, regular pattern, and each pixel's set of micro mirrors **224** likely will have a very different pattern within a cone base or circular area of the surface **222** of the security element **220** (i.e., will not repeat the pattern shown in FIG. 3). Also, each of the micro mirrors **324** in the set used to provide a particular pixel **243** or **263** will be differently oriented so as to have the reflected light of all the mirrors **324** intersect at the X-Y-Z coordinates of the same pixel **243** or **263** in the appropriate one of the image display planes **240** or **260**.

Significantly, the mirrors **324** are not pointing toward a viewer but, instead, are aimed or targeted to direct the reflected light toward the intersection point (or pixel coordinates) in the image display plane or layer. The use of sets of micro mirrors to provide or create floating pixels that in

combination can write or display an image in one, two, or more layers is effective in providing a displayed image with depth and with high contrast. Further, the image appears to switch from light to dark with rotation of the object/substrate with the security element (or with movement of the viewer's eyes to change their viewing angle or perspective).

FIG. 4 is a schematic or graphic side view or diagram **400** of a security element **410** during its use to provide a two-layer or two-level image. The security element **410** includes a micro mirror array **412** made up of numerous (e.g., thousands) of micro mirrors (e.g., 50 micron diameter mirrored surfaces). As shown, three sets of micro mirrors in the array **412** have been oriented or configured to display pixels **422** in a first plane or at a first level **420** above the security element **410** (or its surface containing the array **412**). As shown with arrows **423**, light is reflected so that beams from a set of the micro mirrors intersect to create a pixel **422** in the first level **420**. These are provided within a cone angle, β_{Cone} . Further, as shown with arrows **425**, a mask or mask image may be defined to block some rays by having the mirrors that would provide this light directed outside of the conical angle, β_{Cone} , region (e.g., the arrows **425** are associated with light that is not actually reflected for viewing with the light **423** but is, instead, directed elsewhere).

Also, as shown, two sets of micro mirrors in the array **412** have been oriented or configured to display pixels **432** in a second plane or at a second level **430** spaced apart from level **420**. Arrows **433** represent beams of reflected light that are directed from these sets of mirrors to intersect or cross at the locations of the pixels **432**. Also, as shown, the pixels are displayed to the viewer at viewing angles that are offset by an angle (pixel offset angle), α (such as 10 to 30 degrees or the like). The basic angle direction of the pixels **432** is chosen to offset the image in the plane/level **430** for the viewer (or at the viewer) from the image in the plane/level **420**.

FIG. 5 is a schematic or diagram **500** similar to that of FIG. 4 but showing an embodiment of a security element **510** with an array of mirrors adapted specifically to provide two light and dark images. The diagram **500** illustrates that the sets of pixel-providing micro mirrors on the security element **510** (or in a mirror planar surface) can be oriented to provide a light image (with bright pixels) with a dark background that when going in reverse provides a dark image with a light background as the viewer rotates the element **510** or otherwise changes their perspective.

As shown, the security element **510** has a planar mirror surface with an array of micro mirrors adapted to reflect light in directed beams **514** and **518**. The beams/rays **514** are directed so as to display/create pixels **522** on a first plane **520** that is more proximate to the mirror plane of security element **510** (with only two pixels **522** shown in each image plane **520** and **530** (in each displayed image) for clarity with it being understood that any number of pixels (1 or more and typically many (e.g., a few hundred to several thousand or the like)) may be used to create each image with the size of the mirrors and overall array provided in security element **510** being the only limitations. The beams/rays **518** provided by the other sets of pixel-providing mirrors in element **510** are directed/aimed to cross/intersect on the second image displaying plane **530** (which is spaced apart from the first plane **520** some distance such 0.25 to 1 inch to several inches or more) to display/create pixels **532**.

To make the images provided by the pixels **522**, **532** appear light and dark, the beams **514** and **518** are separated by an angle, θ , (e.g., 15 to 30 degrees or more) as may be

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measured between proximate ones of the beams in each group **514** and **518** (e.g., after the beams cross proximate to the mirror plane of security element **510** such as at or after the first image display plane **520**). The angle of image separation, θ , and the cone angles at pixels **522**, **532** are chosen to give this angular separation. Images of bright and dark zones do not overlap, and images provided by pixels **522** and **532** appear to the viewer to be in the two spaced apart or different planes **520**, **530**. One image darkens as the other lightens as the view angle changes.

FIG. **6** is a functional block diagram of a computer or computing device **600** configured to run an array design program to allow an operator to generate a design of an array of micro mirrors for displaying a particular image(s) when provided in a security element (e.g., to perform steps of the method of manufacturing a security element with an array of micro mirrors according to the present description). The computer **600** includes a processor(s) **610** that executes code/instructions in computer readable media to run or provide the functionality of the micro mirror array design program **630** as well as those of the ray tracing module(s) **635**. The processor **610** also manages operation of input/output (I/O) devices **620** such as a keyboard, a mouse, a touch pad or screen, voice recognition software, and the like configured to allow a user to provide input such as to select design parameters for a particular security element. The I/O devices **620** may include a monitor/display **624** and the design program **630** may be configured to generate one or more graphical user interfaces (GUIs) **628** displayed on the monitor/display device **624** to facilitate a user to provide input and to display calculated results (such as the calculated angular orientations of each mirror in the array).

The processor **610** during the running of the design program **630** may access and manage memory (or data storage device) **640**, which may be onboard as shown or offboard but accessible by the processor **610**. The output of the design program **630** is stored at **650** in memory **640** and provides a design for an array of micro mirrors for a particular security element to be manufactured. The design **650** is shown at **651** to include a calculated angular orientation for each mirror in the array. This may be defined with a center location of the mirror (e.g., X-Y coordinates) **652** combined with coordinates of a normal vector (e.g., X-Y-Z coordinates) **654** for the mirror. This information **652**, **654** can be used in the manufacture (e.g., deposition or other processes) of a security element for an object (such as for currency, coins, product labels, documents, and the like).

To allow the design program **630** to generate the array design **650**, a user typically initially chooses a digital image **660** as a base or starting image for creating an anti-counterfeit or authentication image to be displayed in one or more planes or levels relative to the array of micro mirrors. The user/operator then may use the GUI **628** or other I/O devices **620** to identify one or more images to be displayed on each level of the image displayed by the security element being designed as shown at **662**, **663**. For example, images in the first plane or level **662** may be foreground images in the base/start image **660** while images in the second (or later) plane or level **663** may be background (or intermediate) images of the base/start image **660**. The design program **630** or another program on the computer **600** or available to the processor **610** may then be used to convert the digital base/start image **660** into a text or other file that identifies each pixel in the base/start image as being assigned to a particular one of the levels/planes (e.g., a text file with a plurality of numbers replacing the pixels of the image **660**

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representing one of the planes/levels of the image to be displayed by the security element being designed using the design program **630**).

At this stage of operations, the design program **630** may function to generate a GUI **628** with a number of data entry boxes/fields prompting the user to accept default design parameter values or to enter/modify such values. The design program **630** may then operate to calculate the array design **650** including the angular orientations of each of the micro mirrors in an array. For example, the user may set or define a cone angle, as shown at **666** in memory **640**, for use for generating the pixels of images in each level/plane used to display a security image. The cone angle often will differ for each level such as with larger values assigned to earlier/lower levels/planes (but this is not required), and exemplary cone angles for image pixels may be in the range of 10 to 30 degrees or the like.

The user may also be asked to provide or select an angular offset between each pair of image levels/planes as shown at **668** in memory **640**, and this offset may range from 0 to 30 or more degrees to achieve a desired effect for a displayed image. Other parameters that may be entered or set by the user of the system **600** may include the dots per inch (DPI) **670** that defines the spacing of the pixels in each image display level or plane (the cone apex planes). The user may also be allowed to set the number of mirrors to be used to create or display each pixel as shown in memory **640** at **680** (with 20 to 40 mirrors likely to be useful in some implementations). Further, the user may define heights of the image display levels or planes as shown at **688** (such as a first plane at 10000 microns, a second plane at 20000 microns, a third plane at 30000 microns or other useful spacings/heights).

With the parameters defined, the user may instruct the design program **630** to run to first choose, for each pixel in each image to be displayed in the levels/planes, a set of micro mirrors to be used to display or create the pixel. The other pixels may be considered unused pixels or pixels that can be used in a mask, and these pixels may be angularly oriented to direct light outside of the cone angle. The design program **630** may then continue with determining an array design **650** with these sets of pixel-providing mirrors **684** by calculating for each of the micro mirrors of the array its angular orientation **651**, which may be provided by the coordinates (e.g., X-Y coordinates or the like) of the center of each mirror and the coordinates (e.g., X-Y-Z coordinates or the like) of the normal vector for the mirror with such center coordinates. This determination of the design **650** is carried out such that the micro mirrors in each set of pixel-providing mirrors is oriented to direct its reflected ambient light (a reflected light stream or beam or ray) onto the same image display plane at the same location (e.g., at a location of a pixel). The ray tracing module **635** may be configured to test the effectiveness of the array design **650** as explained below to ray trace reflected light providing images to a viewer's eye (or expected viewing positions relative to a security element with the array of micro mirrors having angular orientations as called out in the array design **650**).

FIG. **7** is a flow diagram of an exemplary design method **700** for an array of micro mirrors for use in a security element, such as may be carried out by operation of the system **600** of FIG. **6**. The method **700** starts at **705** such as with loading a design program onto a computing device and initiating or running the program. The method **700** continues at **710** with selecting a base or start image such as selecting a file in memory of a computing device providing a digital

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image of objects that may be useful for providing a multi-layer display for use in authenticating an object (e.g., an image with one or more components that can be presented as foreground images and one or more components that can be presented as background and/or intermediate images or on layers that appear behind the foreground images).

In step 720, the method 700 involves a user indicating which portions/components of the base/start image from step 710 should be presented in the image(s) displayed on each of the one, two, or more image display layers for this security element. Hence, step 720 may be thought of as including first deciding how many display layers/planes to use with this array of micro mirrors (and this value can be affirmed/set in later step 730 as one of the design parameters). Step 720 may involve assigning differing colors of a colored base/start image to differing image display planes/levels. In other cases, a component/object in the image may be chosen as a foreground image and one or more of the other components/objects in the image may be selected to be background images to be on different levels/planes. At step 725, the method 700 continues with converting the base image into a file (such as a text document or file with each pixel replaced with 0's and 1's when two levels/planes are used and so on) that indicates for each pixel in the base image which level/plane that pixel is assigned for display by the array of micro mirrors.

The method 700 continues at 730 with selecting or identifying a first image pixel to be generated by configuration of a set of micro mirrors. Then, at 732, the method 700 continues for this pixel determining the pixel's cone of acceptance. At 740, the method 700 includes determining whether or not there remain or exists mirrors in this cone of acceptance that are available for use in generating the pixel. If not, the method 700 continues at 760 with a second/next pixel in the image. If micro mirrors are available at 740, the method 700 continues at 750 with randomly selecting a mirror from the set of presently available micro mirrors in the acceptance zone. Then, at 754, the method continues with marking this randomly selected micro mirror as no longer available or as "used" in generating a pixel in the image. At 758, the angular orientation of the micro mirror is calculated for displaying the pixel of the image. Then, at 760, the method continues at 760 with a next pixel in the image.

If the pixel is not the last image pixel, the method 700 continues again at step 732 for this next pixel. If the pixel is the last image pixel at 770, the method 700 continues at 780 with determining whether or not there are more micro mirrors available within the pixel's cone of acceptance. If yes, the method 700 continues with repeating step 730. If no at 780, the method 700 continues at 784 with generating a report of the unused mirrors, and then the method 700 ends at 790.

As discussed previously, an underlying idea of the security elements of the present description is to use ambient light and a planar surface containing many small mirrors and to aim the ambient light reflected off the mirrors toward a desired point in space above the planar surface that contains the mirrors. This is called the first layer image and is defined by artwork that has light or dark pixels to be produced in a layer or level (or first image display plane). By carefully selecting the mirrors within a circle defined by the intersection of the cone defined by an apex angle and a pixel from the first layer/level as the apex of the cone, the cone apex from various mirrors in the circular base of the cone provides a point source of light floating above the level of the mirror plane, at the location of a pixel, containing the

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mirrors. A computer algorithm (as shown with the program 630 in FIG. 6) completes this process on a pixel-by-pixel basis. If the pixel in the first layer/level is a dark pixel (e.g., a pixel not associated with the image or image component/portion from a base/start image chosen for display in the first image display plane), no rays will be aimed toward it by the mirrors.

In addition, the program has the capability of using a second layer of pixels that acts as a mask for the first layer of pixels so that various portions of the pixel image at level one are "hidden" or visible depending on the viewing angle. The algorithm that generates the first layer of floating pixels looks at the rays aimed to the pixel in the first layer and the continuation of the rays to the second layer. The intersection location in the second layer is calculated and is searched for nearby dark pixels of the second layer/level (mask layer and/or second image display plane). If dark pixels are found in the intersection area on the second layer, the mirror that reflected that ray to the first layer is not used to aim the ray at that pixel to the first layer (e.g., this additional processing can be used to modify or originally select the mirrors to be used to display the pixel of the first image display plane).

Thus, there is a masking effect of the mask layer as is desired. To form a mask that appears to "float" over the pixels in the first layer (or first image display plane), some pixels of the first layer will have partial cones of pixels depending on the mask geometry defined by the pixels on/off of the second layer and on the angle the pixels are viewed (as can be seen with reference to the diagram 400 of FIG. 4). As the viewer's eye is moved (or the mirror assembly tilted to the viewer), pixels of the first layer will change brightness and appear or disappear from view in a way that causes the mask to appear to move.

To insure uniform illumination across pixels, during the aiming process as described above, only one of the available mirrors is used in each pixel's cone of acceptance by the design program, and the mirror is selected at random from the available mirrors in the cone of acceptance. After the direction cosines of the selected mirror are calculated, the mirror is marked by the design program as "no longer available for use by any other pixel." The design program moves on to the next pixel, and the same sequence of events or design steps are repeated until all the mirrors are used (or oriented for desired light reflection). At that point in the design algorithm, the entire sequence of pixels is again used to pick up one of the available mirrors for each pixel. After a number of cycles of the pixels, all the mirrors are used depending on the image and mask patterns. If some mirrors cannot be used because of the geometry of the image layer and mask layer, they will be aimed out of the viewing zone.

The design program allows the user to choose the values of the spacing of image levels from the mirror plane, as well as pixel cone angles, mirror sizes, and pixel pitches. These all can be optimized or selected by the user to make (or try to make) the best image to present to the viewer. The inputs to the design program in some embodiments are pixel image files for the first layer image and for the mask for the second image display plane or layer/level. However, there are also capabilities for the program to make its own test input layers. The output of the program is a data file containing mirror locations and the coordinates of the normal vector to each mirror in a format suitable to make the mirrors or to form an array of micro mirrors on a supporting substrate (such as a piece of currency, a coin, a product label, a document, or the like).

In some embodiments, the design program allows the user to see the input files, ray traces to different levels (e.g., via

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operation of the ray tracking module **635** shown in FIG. **6**, and the expected image seen on the retina of a viewer. Tracings can be done using input cones of light on the mirrors to see the effects ambient light distributions have on the viewer's retina. As an example of the GUI **628** of FIG. **6** that can be generated by the design program **630**, FIG. **8** illustrates a micro mirror design GUI **800** that is displayed on a monitor of a display device in one prototype of the design program created and used in prototyping by the inventors.

The main GUI or menu **800** shows an exemplary set of inputs (design parameters, for example) that can be chosen, input, or modified by the user. These include pixel pitch, level/image display plane values, and cone angles for pixels, mirror size, and selection of test patterns. The right side of the GUI/menu **800** shows some of the details or results of the calculations performed by the design algorithm based on the user's input or selected (or default) design parameters provided on the left side. These include the number of mirrors that are dark (aimed away from pixels of images chosen for display on level or image display plane), numbers of mirrors used, algorithm used, and time required to calculate direction cosines of mirrors.

The level height parameter can be used to define or set how far above or below the mirror plane, in microns, that the image designated will appear for a mirror array design. The level cone angle degree parameter sets the angle at the floating pixel of the cone in which specific mirrors can be selected. A narrower angle means that there will be fewer potential mirrors for each pixel, and the opposite for a larger angle. The level angle offset parameter defines or sets the angle of offset that a designer would like the image level to appear, in respect to the Z axis. The "Assign Image (1,2) color (0,1,3,4) to level" input box allows the user to place the various image colors to the specified levels. The "Border Edge Width Add" input box allows the user to expand or shrink the canvas to allow for movement of the images.

As noted earlier, the design process begins with inputting or providing an image file for the design program to process to create or calculate the design for the micro mirrors. One significant parameter in such design calculations is the resolution (DPI), and, in some applications, it may be useful to input or use lower resolution files (or digital images). For instance, an image that is 100 DPI is equivalent to having a pixel every 254 microns. In the GUI **800** in FIG. **8**, this is the input shown under "image focal points X pitch=254" (and the same value for Y pitch). Based on this resolution or how many pixels you need floating to represent that specific image along with the mirror size (in the attached menu **800** this is 50 microns), the design program calculates "avg Num Mirrors available per pixel," which in this example is 25.7685291. In other words, a little over 25 mirrors can be used to represent one pixel from the original or base/starting image file.

FIGS. **9A-9C** illustrate with graphs **910**, **920**, **930** images that can be displayed on various levels or image display planes by an array of micro mirrors of the present description. Graph **910** of FIG. **9A** shows a first layer image, with the light on or on pixels providing an "X" pattern that would be displayed by a number of sets of pixel-providing mirrors to be floating in a first image display plane. In FIG. **9B**, graph **920** shows a second layer image, with the light on or on pixels providing a rectangular background pattern or object that would be displayed by a number of sets of pixel-providing mirrors so as to be floating in a second image display plane. The graph **930** of FIG. **9C** shows a partial "X" of light on

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pixels displayed with micro mirrors of an array and shows the effect of a mask blocking part of the image.

FIG. **10** is a plot **1000** illustrating a ray tracing of light rays **1015** and dark rays **1017** near a first image display plane or first level/layer **1020** for one modeled array of micro mirrors **1010**. As can be seen, the array of micro mirrors **1010** provides converging rays of reflected ambient light meeting or intersecting at a number of pixels **1022** at the floating pixel level or image display plane **1020** (or a first level as discussed above). It can also be seen that dark rays **1017** are directed away from the converging points/pixels **1022** and do not converge at the first level **1020**.

One useful analysis tool of the design program and/or the ray tracing module is that a designer of an array of micro mirrors for a security element is able to evaluate the image as seen by a viewer. To this end, a ray tracing part of the design module (or a separate module as shown in FIG. **6**) is used to view the image on a simulated retina. Thus, the effectiveness of array design including a mask can be analyzed by putting the viewer's eye in various locations, which is equivalent to tilting the mirror plane, and plotting the ray traced image on the simulated retina. FIG. **11** illustrates a representative GUI or ray tracing menu **1100** that allows a user to specify parameters to utilize in performing the ray tracing. FIG. **12** illustrates a plot **1200** of a representative ray tracing showing the mirror plane **1210**, traced reflected rays/beams **1220**, a face plane **1230**, location of a viewer's eyeball at **1240**, and a corresponding retina at **1245** upon which rays converge indicating display of a set or number of pixels of a "written" or displayed image by the mirrors oriented in a desired manner at the plane **1210**.

A number of manufacturing approaches may be used to fabricate an array of micro mirrors for attachments to or upon a surface of a substrate (such as currency, coins, product labels, and so on). In some embodiments, a photo resist process has been implemented by the inventors in creating security elements or devices as taught herein. As discussed earlier, the design program or software generates an output file (as explained in more detail below). To form the micro mirrors according to this output file, a laser system is used to expose the photo resist material, usually on a quartz or lime glass master. The photo resist material is normally at least 25 microns thick. The laser or laser system may expose the material in steps such as in about 0.5μ steps. The exposure settings correspond to the amount of material that will be washed away and not hardened, and this exposure creates a "Z" axis or height of the feature. The resulting micro mirrors (which may be flat or may be concaved for better focus depending upon design) are made in the photo resist material. The photo resist is generally still light sensitive and will "melt" in white light. In some cases, the photo resist is chrome plated in house before processing. The photo resist is then placed in an electroforming tank. The resist is charged and attracts nickel (or other metallic) particles, and nickel is "grown" on the photo resist as a nickel "shim." This nickel shim can be "turned" as needed from negative to positive and back again for tooling. The nickel shim is then used in the cast and cure process to form the array of micro mirrors oriented as indicated by the output file of the design program or software.

In other fabrication processes, a UV (ultraviolet light) or energy-cured polymer is used, and the process includes metallizing the mirrors to form an array as taught herein. In other cases, the fabrication process involves stamping or forming the micro mirrors into surfaces such as chrome or aluminum containers.

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In general, the inventors teach a method of fabricating a security or branding element. The method includes providing a substrate and forming an array of micro mirrors on a surface of the substrate. The array of micro mirrors is configured for receiving ambient light and, in response, displaying an image in a plane spaced a distance apart from the surface of the substrate. The image comprises a plurality of pixels, and the array of micro mirrors includes for each of the pixels a set of the micro mirrors each having a reflective surface oriented to reflect the ambient light toward a point on the plane corresponding to one of the pixels.

In some embodiments of the fabrication method, the forming the array of micro mirrors step includes casting the micro mirrors with a mirror tool in contact with the surface of the substrate. In these embodiments, the substrate may be a clear, energy-cured polymer, and the mirror tool can be formed of nickel or a polymer.

In some cases, the step of forming the array of micro mirrors includes metallization of surfaces of the micro mirrors. This may be performed so as to apply a thin layer of aluminum, gold, or silver to form reflective surfaces or form the mirror structures of the array. The metallization may be performed in a vacuum chamber using a deposition system or the like. Further, the forming step may include, prior to the metallization of the surfaces of the micro mirrors, embossing the surface of the substrate to form the surfaces of the micro mirrors. In this regard, it may be useful for the surface of the substrate to include or be made up of an embossable coating or layer.

In performing the fabrication method, the substrate may be (or include or be provided on) a coin, an automobile part, a computer part, a bumper, or a container, and the displayed image provides branding or authentication for the component that includes the array of micro mirrors. In such cases, the array forming step may include stamping the micro mirrors into the surface of the substrate.

In the same or other embodiments, the step of forming the array of micro mirrors may involve filling in recessed surfaces associated with the micro mirrors with a filler so as to make duplication (e.g., by molding) more difficult if not impossible. The filler may take the form of an ultraviolet (UV) varnish, an e-beam solvent, a water-based varnish, or the like. In some cases, it may be desirable for the filler to have a higher refractive index such as an index of at least 1.55, such that at least a portion of the received ambient light at extreme angles is reflected to sharpen the displayed image for a viewer.

From the description and figures, it can be seen that there are numerous advantages and unique features of security elements/devices that include or are formed of arrays of micro mirrors. The individual mirrors can be programmed or oriented in two axes to focus to a specific pixel in any visual plane (e.g., in a first image display plane, in a second image display plane, and so on). In this way, the micro mirrors are used to image pixels forming drawings or text that appear to float relative to the planar surface containing the array of micro mirrors. The micro mirrors can be configured or designed to focus above or below the visual plane forming pixels that in combination display images with depth (multi-layered or multi-depth imagery). The program performs a unique design method providing an output file that can be used in fabricating or generating the micro mirrors.

In practice, the shape of the micro mirrors can be round, square, or rectangular with the reflective surface being flat, concave, or convex to provide desired focusing upon a pixel (or location on one of the image display planes). The size of the mirrors may vary to practice the arrays of micro mirrors

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such as from about 1000 microns down to one micron with mirrors in the 35 to 70 micron range likely being desirable (with 50 micron square mirrors being used in a prototype/model).

An array of micro mirrors can be designed to provide a variety of visual effects such as showing images above or below the visual planes and in first, second, third, or more image display planes relative to the mirror-containing planar surface. In other cases, the mirrors are used to provide an effect of light images with dark backgrounds animating to light backgrounds and dark images with a change of perspective. In the same or other cases, an array of micro mirrors can be configured with selective orienting of mirror reflective surfaces to provide a masking effect showing one image receding as it goes across another image. In many cases, the micro mirrors generate more than one level of imagery to the viewer (two or more). Particularly, the micro mirrors can generate one image made up of a set of pixels at one level above the focal plane while also (or separately) generating an image below the focal plane. In the same or other cases, the micro mirrors may be configured to generate an image at the focal plane. In these embodiments, the images are displayed/written either with bright pixels (light) or dark pixels (the absence of light or reflected light from the viewer). Images created by the micro mirrors can provide an animation effect, and, in the same or other embodiments, the images created by the micro mirrors may provide a 3D effect.

The array of micro mirrors can be used in (or provided as part of) a currency thread, which may be about 10 to 50 microns thick. The array of micro mirrors or security element can be used as a foil stamp that may be about 10 to 100 microns thick. The array may be formed by stamping the micro mirrors into any metallic surface, such as a surface of a coin, or by placing the micro mirrors on glass, ceramic, or plastic substrates, which may be clear so as to create a unique visual display or imaging effect that allows a viewer to see images in display planes on two sides of the substrate supporting the array of micro mirrors (or transparent film including such mirrors). In these and other ways, an array of micro mirrors may be successfully used in any high security application including, but not limited to, passports and other high security documents including currency.

In some embodiments, the displayed or written image is colored (e.g., is not simply black and white). In one embodiment, a color display is created by forming the mirrors of the array with plasmonic resonance for color while other fabrication processes use tinting of the reflective mirrors with ink. In other embodiments, diffractive material is added to the reflective surface of the mirrors or diffraction grating may be used to create color with the micro mirrors. In some embodiments, dielectrics are used to provide color with the array of micro mirrors. In still other colored display embodiments, a protective cover layer may be applied to the mirrors that is transparent (to-translucent), and then coloring may be provided by printing on this cover layer with translucent color squares (or other mirror shape-matching coloring filters) aligned over the proper micro mirrors to achieve a desired colored image in one or more of the image display planes or levels/layers.

FIGS. 13A and 13B illustrate plots 1310 and 1320 provided by the design program of images chosen for display on first and second image display planes or levels, respectively, and these are the two images that would be written or displayed by micro mirrors of an array. In FIG. 13A, a user has input an image with a colored or plain background with a circular boarder enclosing a leaf, and the circular boarder

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and the outline of the leaf have been chosen for display or writing on a first level or first image display plane (at a first height such as 10000 microns away from the planar surface containing the mirrors). The offset angle may be set at 0 degrees (or some other value), and FIG. 13A represents an approximation of what a viewer would see when viewing the security element with this design of an array of micro mirrors. Particularly, a plurality of bright or "on" pixels showing the circular boundary and the outer edges/boundary of the leaf.

FIG. 13B shows the first layer imagery 1310, but it also shows with plot 1320 that as the viewer rotates the mirror plane or changes their perspective (e.g., from a 0 degree viewing angle to the offset angle that may be 20 degrees or the like) the original images 1315 are replaced with the new images 1325 at the second level or second image display plane (which may be at 20000 microns or some other height such that the two levels/image display planes are spaced apart some desired distance). As shown, the designer/program user has indicated that the background of the input image, the inner portion of the circle, and the inner portion of the leaf should be written or have their associated pixels "on" in the second layer while the portions chosen for image 1315 of the first layer are "off" or dark. In this manner, the image sees a transition between displaying imagery with light and then with dark pixels as their perspective or viewing angle changes to view the images in the two spaced apart levels/layers or image display planes.

FIGS. 14A and 14B illustrate plots 1410 and 1420 that show the results of programming or orienting an array of micro mirrors to display an object or image 1415 (here an eagle or hawk). The plot 1410 of FIG. 14A may be considered a top view as the intersections of normal vectors from the micro mirrors are shown relative to X and Y axes while the plot 1420 of FIG. 14B may be considered a side view as the same intersections are shown relative to the X and Z axes. FIG. 14A is useful for showing a representation of what a viewer would perceive when looking in an orthogonal direction to the plane containing the mirrors, e.g., the viewer perceives the outline of an eagle (which may be displayed or written with bright or dark pixels). The intersections act to display "pixels" that, as can be seen at 1415, work in combination to display an object/subimage (as may be chosen by a user of the design program from an input image file for display in a particular level or image display plane). FIG. 14B shows that the pixels (or normal vector intersections) are generally planar or provided in a plane coinciding with a preset/defined level or image display plane relative to the planar surface containing the micro mirrors (e.g., a plane spaced apart a predefined distance from the array of micro mirrors), and this acts to provide a floating image 1415 or an image with depth or 3D effects.

As discussed above, the design program or algorithm functions to create an output file that may be used in manufacturing an array of micro mirrors adapted to display one or more floating images above (or below) the planar surface containing the array. Table 1 below provides exemplary data that may be provided in such an output file (with only a small number of mirrors being shown for ease of explanation but with it understood that similar data would be provided for each mirror in the array). The X and Y columns of Table 1 show mirror positions (in microns, e.g., in the second row a mirror is located in the array at 35 microns on the X axis and at 0 microns on the Y axis. In the table, next to each mirror location in the array, the DX, DY, and DZ columns provide the coordinates of the normal vectors for

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each of the mirrors. In this way, each mirror has a defined position in the array and a precise direction its reflective surface is pointing in space.

In creating the exemplary data in Table 1, the following assumptions were made for the design of the array of micro mirrors: (1) units are microns; (2) the array is configured to have flat mirrors with tilted reflective surfaces; (3) the mirrors were square in shape with 35 micron sides; (4) the array was also assumed to be square in shape with 27,930 micron sides; (5) the number of mirrors was calculated to be 798 along the X and Y axes such that the total number of mirrors was 636,804; and (6) the maximum mirror tilt angle was requested to be 30 degrees (e.g., due to vendor/manufacture limitations so may be set at 20 degrees).

TABLE 1

X	Y	DX	DY	DZ
0.00	0.00	-0.061672	0.021122	0.997873
35.00	0.00	-0.020315	0.050724	0.998506
70.00	0.00	-0.063424	0.008449	0.997951
105.00	0.00	-0.064293	0.008449	0.997895
140.00	0.00	-0.056737	0.016904	0.998246
175.00	0.00	-0.053402	0.000000	0.998573
210.00	0.00	-0.058482	0.012677	0.998208
245.00	0.00	-0.025586	0.008464	0.999637
280.00	0.00	-0.051801	0.000000	0.998657
315.00	0.00	-0.061093	0.012675	0.998052
350.00	0.00	-0.061967	0.004225	0.998069
385.00	0.00	-0.058619	0.016902	0.998137
420.00	0.00	-0.046852	0.000000	0.998902
455.00	0.00	-0.018142	0.004233	0.999826
490.00	0.00	-0.016225	0.021122	0.997900
525.00	0.00	-0.062100	0.016898	0.997927
560.00	0.00	-0.062979	0.000000	0.998015
595.00	0.00	-0.063848	0.004225	0.997951

FIGS. 15A and 15B illustrate plots generated and displayed by a preview program (which may be a subroutine of the design program described herein) for previewing likely or predicted results of a design of an array of micro mirrors. Specifically, FIG. 15A illustrates a plot 1510 of a 3D image that may be displayed with a selected image and a particular design of an array of micro mirrors. The plot 1510 illustrates a foreground or first layer image 1514 (e.g., a bird such as a flying eagle) relative to a background or second layer image 1518 (e.g., a colored frame with stars) relative to each other and X and Y coordinates. The plot 1510 previews what a viewer looking directly at or downward at the security device may see via the array of micro mirrors. FIG. 15B illustrates a plot 1520 illustrating the foreground image 1514 and background image 1518 not only relative to the X and Y axes but also relative to the Z axis (e.g., the depth that would be provided by the array of micro mirror design).

The preview program providing the plots 1510 and 1520 takes as input the output file of the design program, with all the mirror positions and normal vector coordinates. The preview program calculates the intersection of the reflected rays (e.g., rays coming straight down and bouncing off of the mirrors to the viewer) with the plane where the image is supposed to (or is designed to) float. With the plots 1510 and 1520 provided by the preview program, the operator or designer can verify the combination of foreground and background images 1514, 1518 provides a desired 3D image or representation as shown in FIGS. 15A and 15B. In this example, an eagle 1514 is floating in a first image plane at +30,000 microns above the mirror plane while the frame 1518 (with stars) is floating in a pushed back second image plane at -30,000 microns (or the two image planes are

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spaced apart 60,000 microns for the viewer providing a desirable 3D effect). Stated differently, the preview program takes the normal vectors corresponding to the eagle's mirrors and plots the intersection to the plane at 30,000 microns (and does a similar processing for the frame/background image's mirrors and the plane at -30,000 microns).

Although the invention has been described and illustrated with a certain degree of particularity, it is understood that the present disclosure has been made only by way of example, and that numerous changes in the combination and arrangement of parts can be resorted to by those skilled in the art without departing from the spirit and scope of the invention, as hereinafter claimed.

As will be appreciated from the above description and FIGS. 1-15B, the arrays of micro mirrors can be effectively configured to display images in one, two, or more planes. In the above examples, the micro mirrors were typically configured, such as with tilting about their X and Y axes, to provide sets of pixels of single images/frames provided in each image plane or level. In other embodiments it may be desirable to select and configure sets of mirrors in the array of micro mirrors for pixel (or "voxel") creation so as to provide animation and 3D effects at different heights (e.g., in differing image planes or levels relative to the surface(s) containing the array of micro mirrors) and with infinite axes activation.

In order to create 3D images that appear to float in air relative to the visual display assembly or security element, light is directed by sets of the micro mirrors to focus at selected points/locations above a plane containing the micro mirrors. Within each set of micro mirrors, the micro mirrors are aimed or tilted so that when incident light within a range of angles is reflected off the micro mirrors the reflected light comes to a focus at the selected point, which is called a pixel of an image in the discussion above and is called a voxel in the following discussion. The reflected light or rays from the micro mirrors to the voxel continue to travel to a viewer (or their eyes) who sees/perceives a point of light that appears to float above (or below) the plane of the array of micro mirrors (e.g., a surface of a substrate such as a surface of currency, a product label, or the like). In most examples herein, the array of mirrors is described as being provided in a single plane, but the array of micro mirrors does not need lie within a single plane or on a planar surface with such differing embodiments being clear to those skilled in the arts.

Voxels, as used herein, are each specified by their position in space (e.g., with X, Y, and Z coordinates), the direction cosines of the cone (as described above and as may be designated by DX, DY, and DZ), and the cone angle of the apex of the cone of rays emitted from the voxel toward the viewer. The color and intensity of light can also be specified as part of the design of the security element and its array of micro mirrors. With regard to color, colored filters may be used on or provided on/over micro mirrors of a set of voxel-providing micro mirrors to color that pixel/voxel. The intensity of the pixel/voxel can be controlled in some cases by specifying the number of micro mirrors to be included in each set of voxel-providing micro mirrors to illuminate a particular voxel within an image (and the light intensity may be varied on an image-by-image basis or even on a voxel-by-voxel basis). Also, during this description, it should be remembered that voxels can be made to appear below the mirror plane, such as shown for voxels 224 in FIG. 2.

Turning to the inputting of image information, the starting point of getting the desired voxel information may be the output of a program or routine that produces pixel images.

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The images can be pixels in frames that are read into the mirror generation program (e.g., an implementation of micro mirror array design program 630 in FIG. 6). The frames can determine or define the voxel information. For example, the images may be read into the mirror generation program and then further processed. The processing may involve reading in a sequence of black and white pixels that describe coordinate values for voxels to be created by an array of micro mirrors. One frame may be designated as an image of voxels to be created at a certain height and at a certain angular offset. The image pixels that are read in may be black and white. The cone angles of the voxels may also be specified for each layer of voxels, e.g., all set to the same angle or set individually for each image layer/level. A second layer may be designated as having voxels at a different height above the micro mirrors and, in some cases, with a different offset angle than the first layer. This process can be repeated for each layer displayed by the array of micro mirrors to define a 3D voxel image.

Another way to enter information for generating the design/configuration of the micro mirrors may involve use of a special program or routine. This special program/routine may be configured to directly generate voxels defined by their position in space (e.g., their X, Y, and Z coordinates or values) along with the direction cosines of the voxel cone of rays (e.g., their DX, DY, and DZ values). The apex angle of the voxel cone is also specified. These parameters are, in this embodiment, directly read into the mirror design program and do not generally require further processing before sets of voxel-producing micro mirrors are generated (e.g., by choosing which mirrors to include in which voxel's set and how to orient each mirrors reflective surface to direct light to the voxel).

FIGS. 16A and 16B illustrate schematically side and top views, respectfully, of a security element or visual display assembly 1600 during its use to display a single voxel 1640, such as a pixel from a particular image/frame that is configured to be visible at a particular height/level, H_{voxel} , and associated with a particular offset value (defining a relative offset angle and direction relative to an orthogonal or "0" offset of the cone axis 1650 such as with the DX, DY, and DZ values). As shown, the security element 1600 includes a substrate 1610 that has an upper planar surface 1615 that defines the mirror plane for the array 1620 of micro mirrors 1624. For a particular voxel 1640 and cone angle, β_{cone} , a cone base 1630, which may be circular or an ellipsis as shown, is defined, and mirrors 1624 inside this ellipsis/cone base 1630 are ones that may be included in a set of micro mirrors useful in generating the voxel 1640. Particularly, reflected light beams or rays 1631 are focused upon and/or cross at the location in space of the voxel 1640, and rays 1633 that continue on past the voxel 1640 would be directed to a viewer's eyes within a cone having the cone angle, β_{cone} , and with a cone axis 1650 (that passes through the voxel 1640 and also through the center point of the cone base 1630). To create an image, numerous voxels are defined for each image/frame that are offset in the X direction from the voxel 1640 but with a like height, H_{voxel} (which may be positive or negative to display an image above/in front of or below/behind the mirror plane) and offset value.

Further, in regard to mirror design/generation, the mirror sizes are in general smaller than the voxel pitches so that a number of micro mirrors are available for each voxel. Depending on the voxel cone angle and height above the mirror plane of two or more voxels, there can be multiple overlapping zones of acceptance or cone bases from which micro mirrors may be chosen to reflect light to write or

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display the voxels of an image. In order to allocate the micro mirrors of an array of micro mirrors properly for each voxel without having some voxels being poor in mirrors (having fewer than the predefined mirror number for each set) and other voxels being rich in mirrors (having many mirrors), the inventors have developed the following algorithm to more evenly distribute the available mirrors among the voxels and, in many cases, to achieve the predefined values (such as 20 micro mirrors per voxel or the like).

According to this mirror choosing algorithm, voxels are taken one at a time, and a zone of acceptable mirrors is determined. The micro mirrors in this zone (e.g., a base of a cone) are able to produce the desired offset angles and, in use, a bundle of rays with a desired apex or cone angle for the cone of rays emitted by/through the voxel presently being considered in the algorithm. For the voxel, an available mirror is randomly selected from the acceptable zone, and the proper tilt angles are calculated for the selected mirror to aim the incident light to the voxel. Generally, the incident light is assumed to arrive normal to the plane of the mirror, but this is not necessarily so or required to practice the algorithm. The micro mirror that is selected and configured with its tilt angles (oriented properly for the voxel) is then recorded in memory as being associated with this voxel and as not being available for any other voxels.

The above procedure is then done for each voxel in turn. When the last voxel is reached in the algorithm, each voxel will have one mirror assigned to it. Then, the whole process is repeated so that each voxel will have a second mirror assigned to it (and the second mirror will have its unique tilt angles determined and assigned for the particular voxel). This whole process is repeatedly carried out until all available mirrors have been used and/or a desired number of mirrors has been assigned to each voxel. As discussed above, this procedure and technique of using sets of micro mirrors of an array to light or create (or "write") voxels can be used to create multiple cone angle offsets to the viewer and different heights/levels for two or more images displayed by sets of voxels.

In some embodiments, it may be desirable to display different images within an overall image or image set to the viewer for each of the cone angle offsets. This approach results in an image that can provide up to about one hundred cone angle offsets totaling up to about 120 degrees of viewing angles to the viewer. The micro mirror array may be configured such that each image of an image set or frame of an animation clip/imagery is displayed by different sets of voxel-providing micro mirrors adapted for different cone angle offsets (and for display at a single display height/level or at two or more such heights/levels).

FIG. 17 illustrates a top view (as may be seen by a viewer) of a security element 1700 as it is reflecting light. The security element 1700 is configured such that each cone angle offset can be seen at one time by the viewer. Particularly, the security element 1700 includes a substrate 1710 upon which an array of micro mirrors 1712 is formed/mounted (as discussed above in more detail). A first number of sets of voxel-providing micro mirrors are configured (e.g., via their positions in the array and tilt angles) to focus on voxels of a first frame/image 1721, and the rays from these micro mirrors are configured with a first cone angle offset (such as with a "0" offset). When a viewer views the security element 1700 straight down or orthogonally, the image 1721 is visible via the reflected light from the micro mirror array 1712.

Additionally, the security element 1700 has its micro mirror array configured to display an additional eight

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frames/images or a total of nine images/frames in this example as shown at 1723, 1725, 1727, 1729, 1731, 1733, 1735, and 1737. To this end, eight different sets of voxel-providing micro mirrors are configured to produce voxels of these other frames/images at eight different cone angle offsets as can be seen with representations of ray or beam cones 1722, 1724, 1726, 1728, 1730, 1732, 1734, and 1736 that would be projected from the voxels of the corresponding images/frames 1723, 1725, 1727, 1729, 1731, 1733, 1735, 1737 (with their circular cross section shown in FIG. 17). A viewer would see each image/frame separately or with overlap when they properly position their eyes at a viewing angle corresponding to the cone angle offset.

FIG. 18 illustrates another security element 1800 that is adapted to display the same nine images/frames. Security element 1800 includes a substrate 1810 and an array of micro mirrors 1812 on a surface of this substrate 1810. Security element 1800 differs from element 1700 in that the sets of voxel-providing micro mirrors adapted to provide the frames/images 1721, 1723, 1725, 1727, 1729, 1731, 1733, 1735, 1737 are configured with nine different cone angle offsets but in a manner such that the rays/beams in their cones 1820, 1822, 1824, 1826, 1828, 1830, 1832, 1834, and 1836 displaying have some overlap. For example, ray/beam cone 1836 displaying image/frame 1737 is allowed to have overlap or overlap regions 1870 with the ray/beam cone 1834 displaying image/frame 1735 and also with the ray/beam cone 1824 displaying image/frame 1725.

In both FIGS. 17 and 18, the resulting image(s) or displayed output/effect of using the security elements 1700, 1800 may be a full animation image with a different view provide to the viewer in each of the cone angle offsets. The full animation image has nine frames/images in this example that can be adapted to provide a continuous image showing dimension or sequences. The sets of voxel-providing micro mirrors in the arrays 1712, 1812 may be configured such that the frames/images 1721, 1723, 1725, 1727, 1729, 1731, 1733, 1735, and 1737 may be written or displayed (via crossing or focusing voxels at particular locations relative to the substrates 1710, 1810) at the same height (e.g., for 2D animation with nine frames or a set of nine different images) or at different heights (e.g., for 3D imagery with or without animation at a particular height/level).

FIG. 19 illustrates an example of a security element 1900 that is adapted for displaying animation using differing cone angle offsets. As shown, the element 1900 includes a substrate 1910 supporting a micro mirror array 1912. Sets of voxel-producing micro mirrors in the array 1912 are configured to write voxels for sixteen different frames of an animation clip at sixteen different cone angle offsets, e.g., at a single level/height, as shown with beam/ray cones 1920. In this example, there is no (or minimal) cone overlap. In this manner, continuous animation (a moving star in this case) is achieved in multiple axes. Hence, the present technique of using multiple cone angle offsets to display different frames/images with sets of micro mirrors allows infinite axis activation of the cone angles to the viewer. The displayed imagery may be provided above or below the visual plane or in combination for animation or each cone angle offset may be used to display completely unique images.

It may be useful at this point in the description to explain further the use of differing cone angle offsets to achieve infinite axis activation. FIG. 20 illustrates a side perspective view of a security element 2000 of the present description showing a single voxel 2016 of an image (such as a frame of an animation clip or an image a 3D model) being displayed or written at a particular height and at a particular

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cone angle offset (e.g., a zero offset with the cone axis being orthogonal to the planar substrate containing the mirrors). As shown, the security element **2000** includes a substrate **2010** that supports a micro mirror array **2012** (mirrors not being shown but understood from the description above of mirrors/facets providing a canvas for generating imagery by writing numerous pixels/voxels with sets of configured to cross/focus at pixel locations above/below the substrate **2010**).

In use, incident light (not shown) strikes the mirror array **2012** and a set of micro mirrors in the array **2012** in the acceptable cone base **2014** is configured to reflect light/rays **2015** in a cone upward to cross or focus at the voxel/pixel **2016** in an image plane **2020** (which is at a predefined height/level above (or below) the substrate **2010**). The rays/beams **2017** continue past the voxel **2016** or are “projected” from the voxel **2016** in a cone with a cone angle, β_{Cone} , and with a cone axis **2019**. For each voxel **2016**, mirrors in array **2012** are selected from an acceptable zone **2014** within the range of the voxel. A set of mirrors/facets (e.g., 10 to 30 or the like) in array **2012** are aimed (e.g., with their tilts/tilt angles) to create a common intersection point where the voxel **2016** will exist. This intersection point is the level **2020** at which the image, which includes the voxel **2016**, will appear to float above or apart from the substrate **2010**. A single voxel **2016** for the image associated with this cone angle offset is shown for ease of explanation, but it will be understood that each image/frame is displayed with numerous (100s to 1000s) of voxels/pixels of the image with like cone angle offsets and at matching (generally) heights (e.g., to display the image from which the voxel **2016** is taken at a particular level/plane **2020**).

FIG. **21** shows the security element **2000** as it is being used to display nine different voxels/pixels **2016**, **2020**, **2022**, **2024**, **2026**, **2028**, **2030**, **2032**, and **2034** with nine different sets of micro mirrors in the array **2012** that are all within the cone/acceptable zone **2014** on the substrate **2010**. Each of the voxels/pixels **2016**, **2020**, **2022**, **2024**, **2026**, **2028**, **2030**, **2032**, and **2034** is from a different frame or image, and each of the nine frames or images is given or assigned a different/unique “offset” value that defines the location and/or direction of the cone of beams/rays being projected from the voxels/pixels **2016**, **2020**, **2022**, **2024**, **2026**, **2028**, **2030**, **2032**, and **2034**. For example, the voxel **2024** has an offset axis assigned to it that differs from the offset value assigned to voxel **2016** such that its cone axis **2025** (and the beams/rays of the associated cone) is offset in angle and direction from the cone axis **2019** associated with voxel **2016** (e.g., each voxel is assigned differing DX, DY, and DZ values). No overlap is shown but other embodiments may allow some overlap between the adjacent/neighborhood cones of beams/rays passing out of the voxels/pixels.

Generally, each of the nine frames/images will include many voxels rather than the single voxels **2016**, **2020**, **2022**, **2024**, **2026**, **2028**, **2030**, **2032**, and **2034** shown in FIG. **21**, and nine frames/images are shown for ease of explanation as a smaller or larger number of frames/images may be displayed by the security element **2000**. FIG. **22** is a side view of the security element **2000** of FIG. **21** that is useful for more clearly showing the image or display plane/level **2020**. As shown, each cone of reflected light from the nine differing sets of micro mirrors in the array **2012** on substrate **2010** has an intersection point (i.e., at or to display/write voxels **2016**, **2020**, **2022**, **2024**, **2026**, **2028**, **2030**, **2032**, and **2034**) that is at the same height (i.e., are in image plane/level **2020**) above the mirror array **2012** as the other cones. This height may be a default value or be set by a user of the

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design program as discussed above. In this way, each of the nine frames/images associated with the voxels/pixels **2016**, **2020**, **2022**, **2024**, **2026**, **2028**, **2030**, **2032**, and **2034** appears to float the same distance above (or below in other embodiments) the substrate **2010**.

FIGS. **23** and **24** are useful for illustrating that during use of the security element **2000** the offset cone angles assigned to the voxels **2016**, **2020**, **2022**, **2024**, **2026**, **2028**, **2030**, **2032**, and **2034** means that a viewer will only see one frame/image at a time. FIGS. **23** and **24** show rings (or cones) **2050** to indicate generally where each of the nine images/frames is viewable due to their differing cone angle offsets. Only one frame's cone as shown at **2050** is visible at one time or from one viewing angle. Particularly, the frame/image that is visible to the viewer is determined by the angle of the user's eye in relation to the substrate **2010** and the micro mirror array **2012**.

FIG. **23** shows the viewer positioning their eye **2002** directly over (or with a line to their eye from the substrate **2010** being orthogonal) the substrate **2010** such that the rays/beams **2017** from voxel **2016** are visible to the viewer (received by user's eye **2002**), and this causes the viewer to perceive the frame/image that is associated with voxel **2016**. In FIG. **24**, the viewer has changed the position of their eye **2002** relative to the substrate **2010** (e.g., to a new viewing angle), and the rays/beams associated with voxel **2030** are received by the user's eye such that they perceive the frame/image associated with voxel **2030** instead of the one associated with voxel **2016**. Hence, by moving their eye or moving the substrate **2010** to new tilt angles, the viewer is able to sequentially and separately view each of the nine frames/images presented by voxels **2016**, **2020**, **2022**, **2024**, **2026**, **2028**, **2030**, **2032**, and **2034** (along with additional voxels for each image/frame from differing cone bases/acceptance zones other than base/zone **2014**), and this may provide an animated clip/image or may provide nine different images in the plane **2020**.

Instead of using cone angle offsets to achieve axes activation, the inventors recognized that the micro mirrors may be configured using interlacing techniques (which may be thought of as using interlaced micro mirrors). Using a matrix of frames to create multiple cone angle offsets to the viewer, such as where light reflected from mirrors set according to each cone angle offset can be seen at one time, can create some challenges at the moment of sharing the acceptable mirror zone for some voxels from different frames. For example, if each original image frame has 200 DPI and is 1-inch by 1-inch in size, the total number of pixels in that image is 40,000. The challenge in designing the micro mirror array is to project voxels equivalent to that number (i.e., 40,000 in this example) times the total number of frames that were used above the plane containing the mirrors. The micro mirror array may handle this challenge using different offset angles as discussed above by distributing the mirrors per voxel.

However, some embodiments of method methods of manufacturing security elements/visual display assemblies and security elements/visual display assemblies instead use interlacing techniques to address this challenge and at the same time optimize the use of mirrors per voxel. As previously explained, the starting point of getting the desired voxel information can come from the input of the matrix of frames to the mirror-generating program/algorithm. Using the example of 200 DPI images, each of these images will input 40,000 pixels to the program/algorithm to generate the mirror design information. The interlacing design method is based on the concept of having the equivalent to a single

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image input to the mirror generating program, which has already combined and pixel mapped the information from all the frames or images into a single one (e.g., an interlaced image).

Using the same example of 200 DPI images, the use of interlacing techniques means that instead of using as an input several 200 DPI images (which may be at 40,000 pixels each) and having the software/algorithm create different offset angles, the mirror design or generating program/algorithm be modified to receive as input a single 200 DPI image that contains selected pixels (pixel mapped) from each original frame/image that is to be displayed by a security element and its micro mirror array. The mirror design or generating program/algorithm then acts to create multiple cone angle offsets to the viewer for each group of pixels that correspond to each frame/image.

For example, interlacing techniques can be used to provide the security element **1900** shown in FIG. **19**. FIG. **19** shows an original set of frames (stars providing animation), and, instead of creating voxels for all the pixels from all of the sixteen images/frames, a single pixel mapped image is first created that has pixels from all the frames. While it is difficult to illustrate, FIG. **25** shows an image **2500** from a digital file where each of the sixteen original frames/images or the original file information is represented by a different color (shown with shading/hashing in FIG. **25**).

FIG. **26** illustrates an enlarged view of a portion **2600** of the image **2500** of FIG. **25**, and the pixel **2610** pointed at with the arrow and all the other pixels with the same color (like the zoom view **2700** shown in FIG. **27** of one of the sixteen images) only belong to a single frame/image from the original set of frames/images. At this point in the design/generation process carried out by the program/algorithm, each specific color pixel can be selected and saved as an individual frame/image. This saved image/frame only contains a fraction of the original pixels, and, more importantly, each of these pixels will not have the same position as any other of the pixels of the other images/frames. In this example, a 4 by 4 set of frames/image is being used. If the interlaced image (and the images/frames used to form it) is assumed to be 200 DPI, instead of trying to project 640,000 voxels (i.e., $4 \times 40 \times 200 \times 200$), only 40,000 voxels will need to be projected with the same number of micro mirrors. This results in each voxel being brighter by having more micro mirrors being assigned to each voxel from each acceptable zone/cone base.

The security elements/visual display assemblies taught herein using cone angle offsets and micro mirror interlacing techniques provide a number of useful advances and advantages relative to prior security elements. These security elements can have their micro mirror arrays designed and fabricated so as to create infinite axes of activation of images using different cone angle offsets (e.g., one, two, three, or more cone angle offset values) using micro mirrors. Animation can be created in X and Y-axes with images using cone angle offsets and micro mirrors. Alternatively or additionally, independent images can be displayed for each cone angle offset in more than one axis using the micro mirrors. Dielectric coatings can be applied to the micro mirrors to provide a color shift for different cone angle offsets in more than one axis.

In some cases, the micro mirror array is configured to create images both below and above the focal plane in each of the cone angle offsets using the micro mirrors. The images displayed using cone angle offsets may be at the same or differing heights or levels relative to the substrate containing/supporting the micro mirror array. In this way, the use of

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voxels created by sets of micro mirrors and differing cone angle offsets can be used to generate or display/write a continuous image in 3D. In some embodiments, it may be desirable to create a matrix grid of cone angle offsets to the viewer with identical numbers of cone angle offsets in the X and Y axes. The micro mirrors may be configured to display separate images/frames or may be configured to display an interlaced image (or the mirrors may be thought of as being an interlaced mirror system to provide multiple cone angle offsets to the viewer with an interlaced image used as input to design and generate/fabricate the mirrors).

We claim:

1. A visual display assembly useful as a security element on paper and coin currency and on product labels, comprising:

a substrate; and

on a surface of the substrate, an array of micro mirrors receiving ambient light and, in response, displaying a plurality of images in a plane spaced a distance apart from the surface of the substrate,

wherein each of the images comprises a plurality of pixels,

wherein the array of micro mirrors includes, for each of the pixels of each of the images, a set of the micro mirrors each having a reflective surface oriented to reflect the ambient light toward a point on the plane corresponding to one of the pixels,

wherein each of the sets of the micro mirrors providing the pixels for each of the differing ones of the images has a differing cone angle offset,

wherein the cone angle offset is defined based upon a relative position of a cone axis for a cone of rays projected by the sets of the micro mirrors through each of the pixels,

wherein the cone has a cone angle in the range of 10 to 45 degrees,

wherein the cone angle offsets are selected whereby the cones do not overlap at a predefined height above the substrate, whereby only one of the images is observable at a time by a viewer,

wherein each of the sets of the micro mirrors includes at least two of the micro mirrors,

wherein the reflected ambient light from the at least two of the micro mirrors intersects at the point corresponding to the one of the pixels,

wherein the point on the plane corresponds to an apex of a cone and the at least two of the micro mirrors are located within a base of the cone coplanar with the surface of the substrate, and

wherein each of the micro mirrors in each of the sets for the micro mirrors is selected randomly from available micro mirrors in the base of the cone coplanar with the surface of the substrate, whereby each of the sets of the micro mirrors is arranged in a random pattern.

2. The assembly of claim **1**, wherein the micro mirrors are rectangular with a smallest side having a length of at least 31 microns.

3. The assembly of claim **1**, wherein the micro mirrors are configured to display the images in at least two colors and wherein at least one of ink, plasmonic resonance, and dielectric coating is used to configure the micro mirrors to display the image with the colors.

4. The assembly of claim **1**, wherein the images comprise two or more frames of an animated clip, whereby a viewer observes animation when viewing two or more of the images associated with the two or more frames.

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5. The assembly of claim 4, wherein the animation is in both the X axis and in the Y axis.

6. A visual display assembly useful as a security element on paper and coin currency and on product labels, comprising:

a substrate; and

on a surface of the substrate, a plurality of micro mirrors receiving light and, in response, displaying a plurality of images in a plane a distance away from the surface of the substrate,

wherein the plurality of micro mirrors includes, for each of displayed pixel of each of the images, a number of the micro mirrors each having a reflective surface oriented, in a rigid manner, to reflect the ambient light toward a point on the plane corresponding to one of the pixels,

wherein each of the sets of the micro mirrors providing the pixels for each of the differing ones of the images has a differing cone angle offset,

wherein the cone angle offset is defined based upon a relative position of a cone axis for a cone of rays projected through each of the pixels,

wherein each of the numbers of the micro mirrors includes at least two of the micro mirrors,

wherein the reflected ambient light from the at least two of the micro mirrors intersects at the point corresponding to the one of the pixels,

wherein the point on the plane corresponds to an apex of a cone and the at least two of the micro mirrors are located within a base of the cone coplanar with the surface of the substrate, and

wherein each of the micro mirrors in each of the sets for the micro mirrors is selected randomly from available micro mirrors in the base of the cone coplanar with the surface of the substrate, whereby each of the sets of the micro mirrors is arranged in a random pattern.

7. The assembly of claim 6, wherein the cone has a cone angle in the range of 10 to 45 degrees and wherein the cone angle offsets are selected whereby the cones do not overlap at a predefined height above the substrate.

8. The assembly of claim 6, wherein the micro mirrors are rectangular with a smallest side having a length of at least 31 microns.

9. The assembly of claim 6, wherein the micro mirrors are configured to display the images in at least two colors and wherein at least one of ink, plasmonic resonance, and dielectric coating is used to configure the micro mirrors to display the image with the colors.

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10. The assembly of claim 6, wherein the images comprise two or more frames of an animated clip, whereby a viewer observes animation when viewing two or more of the images associated with the two or more frames.

11. The assembly of claim 10, wherein the animation is in both the X axis and in the Y axis.

12. A visual display assembly useful as a security element on paper and coin currency and on product labels, comprising:

a substrate; and

on a surface of the substrate, an array of micro mirrors receiving light and, in response, displaying images; wherein each of the images comprises a plurality of pixels,

wherein the array of micro mirrors includes, for each of the pixels of the images, a set of the micro mirrors each having a reflective surface oriented to reflect received light toward a point on a plane corresponding to one of the pixels,

wherein each of the sets of the micro mirrors providing the pixels for each of the images has a differing cone angle offset,

wherein each of the sets of the micro mirrors includes at least two of the micro mirrors,

wherein the reflected received light from the at least two of the micro mirrors intersects at the point corresponding to the one of the pixels,

wherein the point on the plane corresponds to an apex of a cone and the at least two of the micro mirrors are located within a base of the cone coplanar with the surface of the substrate,

wherein the images comprise two or more frames of an animated clip, whereby a viewer observes animation when viewing two or more of the images associated with the two or more frames,

wherein the animation is in both the X axis and in the Y axis, and

wherein each of the micro mirrors in each of the sets for the micro mirrors is selected randomly from available micro mirrors in the base of the cone coplanar with the surface of the substrate, whereby each of the sets of the micro mirrors is arranged in a random pattern.

13. The assembly of claim 12, wherein the micro mirrors are configured to display the images in at least two colors and wherein at least one of ink, plasmonic resonance, and dielectric coating is used to configure the micro mirrors to display the image with the colors.

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