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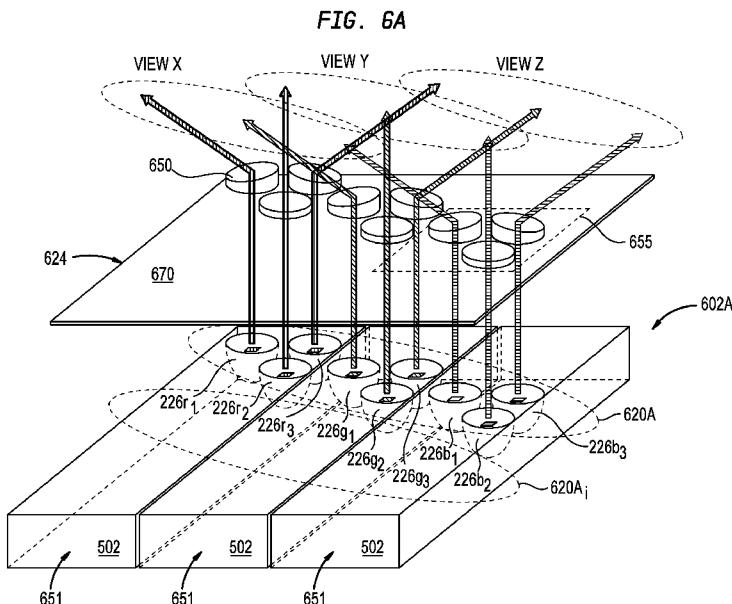
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(57) Abstract: The present disclosure generally relates to light field displays and methods of displaying images with light field arrays. In one example, the present disclosure relates to pixel arrangements for use in light field displays. Each pixel includes a plurality of LEDs, such as micro LEDs, positioned adjacent respective micro-lenses of each pixel.



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## COLLIMATED LED LIGHT FIELD DISPLAY

### BACKGROUND

#### **Field**

**[0001]** Embodiments of the present disclosure generally relate to a light field displays and methods of displaying images with a light field array.

#### **Description of the Related Art**

**[0002]** Long held beliefs that our three dimensional (3D) perception of the world around us is primarily related to stereoscopic vision (where the convergence and/or divergence of two dimensional images viewed separately by the left and right eye combine in the brain to give the perception of depth) have largely been proven untrue. We now know that, in addition to convergence/divergence, visual cues from head and eye movements substantially influence a person's ability to perceive the world about them in three dimensions. For example, if the viewer in Figure 1 moves her head from side to side she will perceive a relative motion between the bird and the mountain that is more than the relative motion she perceives between the bird and the tree, thereby indicating the mountain is the furthest away, which is generally known as motion parallax. Similarly, if she focuses her eye on the bird, the mountain will appear to be more blurry than the tree, another indication of the relative distances of the tree and the mountain compared to the bird, which is generally known as blur cue interpretation. Both motion parallax and blur cue interpretation, as well as other visual cues, require angular information which includes both the intensity of light rays reflected off a surface of an object and the angle of those light rays with respect to a focal plane of the viewer as the light rays travel from the object to the viewer. Light rays of different angles, with respect to a focal plane of the viewer, reflected off the same surface of an object will have different intensities. Advances in the area of light field technology have provided light field cameras capable of capturing tremendous amounts of angular information, however, current display technologies are unable to capture and use all of the angular

information captured by a light field camera for the display of the image without user input.

**[0003]** Accordingly, what is needed in the art are high angular resolution light field displays.

## **SUMMARY**

**[0004]** In one example, a pixel comprises a plurality of micro-lenses; and a plurality of collimated light emitting diodes (LEDs) positioned beneath each micro-lens, wherein LEDs under a respective micro-lens of the plurality of micro-lenses are configured to generate light of the same color.

**[0005]** In another example, a light-field display comprises a plurality of pixels, each pixel of the plurality of pixels comprising: a plurality of micro-lenses; and a plurality of collimated light emitting diodes (LEDs) positioned beneath each micro-lens, wherein LEDs under a respective micro-lens of the plurality of micro-lenses are configured to generate light of the same color.

**[0006]** In another example, a light-field display comprises a plurality of pixels, each pixel of the plurality of pixels comprising: a plurality of light-directing features formed on a substrate panel; and a plurality of collimated light emitting diodes (LEDs) positioned beneath respective light-directing features, the plurality of collimated LEDs arranged in linear strips according to a color of light generated thereby.

## **BRIEF DESCRIPTION OF THE DRAWINGS**

**[0007]** So that the manner in which the above recited features of the present disclosure can be understood in detail, a more particular description of the disclosure, briefly summarized above, may be had by reference to embodiments, some of which are illustrated in the appended drawings. It is to be noted, however, that the appended drawings illustrate only exemplary embodiments and are therefore not to be considered limiting of scope, as the disclosure may admit to other equally effective embodiments.

**[0008]** Figure 1 illustrates angular light information from the perspective of a viewer.

**[0009]** Figures 2A-2C schematically illustrate a pixel arrangement of a display according to one aspect of the disclosure.

**[0010]** Figure 2D schematically illustrates the directing of light rays from a pixel arrangement, according to one aspect of the disclosure.

**[0011]** Figure 3A is a schematic cross-sectional view of an LED, according to one embodiment.

**[0012]** Figure 3B is a sectional view of a portion of the LED described in Figure 3A taken along line 3B-3B of Figure 3A.

**[0013]** Figure 4 is a flow diagram illustrating a method of forming an LED, according to one embodiment.

**[0014]** Figures 5A-5H schematically illustrate formation of an LED according to the method described in Figure 4.

**[0015]** Figures 6A and 6B are schematic illustrations of pixel arrangements, according to other embodiments.

**[0016]** To facilitate understanding, identical reference numerals have been used, where possible, to designate identical elements that are common to the figures. It is contemplated that elements and features of one embodiment may be beneficially incorporated in other embodiments without further recitation.

### **DETAILED DESCRIPTION**

**[0017]** The present disclosure generally relates to light field displays and methods of displaying images with light field arrays. In one example, the present disclosure relates to pixel arrangements for use in light field displays. Each pixel includes a plurality of LEDs, such as micro LEDs, positioned adjacent respective micro-lenses of each pixel.

**[0018]** Figures 2A-2C schematically illustrate a pixel arrangement 202 of a light field display 200 according to one aspect of the disclosure. Figure 2A illustrates an enlarged partial view of a pixel arrangement 202 having pixels 220 of a light field display 200. Figure 2B schematically illustrates a plan view of a single pixel 220 of the pixel arrangement 202. Figure 2C schematically illustrates a plan view of a micro-lens and collimated light emitting diodes (LEDs).

**[0019]** The light field display 200 is configured to produce a viewable image, and includes a plurality of pixels 220 controlled by a processor 204 to generate light, thus forming the viewable image. The plurality of pixels 220 is arranged in a pixel arrangement 202, such as a two dimensional hexagonal array or other planar configuration. Each pixel 220 includes a plurality of micro-lenses 224r, 224b, 224g, under which a plurality of plurality of collimated (LEDs), such as collimated micro-LEDs, 226 are positioned. In the example shown, the micro-lenses 224r, 224b, 224g of each pixel 220 are arranged in a triangular configuration with respect to one another, which facilitates a dense configuration of the pixels 220 in the light field display 200. The plurality of pixels 220 within the pixel arrangement 202 results in offset rows of micro-lenses (e.g., aligned in a horizontal direction but misaligned in a vertical direction, or vice versa) in the pixel arrangement 202. This dense configuration improves perceived resolution by a viewer.

**[0020]** Beneath each micro-lenses 224r, 224b, 224g is a plurality of collimated LEDs 226 (two are labeled in Figure 2C) configured to emit light of a desired wavelength. While only micro-lens 224r is shown in Figure 2C, it is to be understood that micro-lenses 224b and 224g are similarly configured. In one example, the LEDs 226 beneath the micro-lens 224r are configured to emit red light, the LEDs 226 beneath micro-lens 224b are configured to emit green light, and the LEDs 226 beneath micro-lens 224b are configured to emit blue light. Stated otherwise, each group of LEDs 226 under a respective micro-lens 224r, 224b, 224g, is monochromatic. Typically, red LEDs 206 generate light having a wavelength in the range between about 620 nm and about 780 nm, green LEDs 226 generate light having a wavelength in the

range between about 495 nm and about 580 nm, and blue LEDs 203b generate light having wavelengths in the range between about 450 nm and about 495 nm.

**[0021]** For purposes of this disclosure, each group of three or more micro-lenses 224r, 224b, 224g, and the LEDs 226 associated therewith, constitute a pixel 220, configured to emit RGB light. Each micro-lens 224r, 224b, 224g may be tailored to collimate and/or transmit light of one color (or light within a specific wavelength range), corresponding to respective LEDs 226 disposed adjacent thereto. In one example, 24 LEDs 226 are positioned beneath each micro-lens 224r, 224b, 224g. In such an example, each pixel 220 is a single pixel of spatial resolution that has a plurality of angular (e.g., directional) resolutions. Specifically, each angular resolution corresponds to one of the LEDs 226 under a single micro-lens, and thus, the 24 LEDs 226 positioned beneath each micro-lens 224r, 224b, 224g each correspond to one of 24 angular resolutions. Thus, the number of pixels 220, and specifically the number of angular resolutions produced thereby, determine the effective resolution of the light field display 200.

**[0022]** In one example, the light field display 200 includes 1920x1080 pixels 220. Each pixel 220 includes micro-lenses 224r, 224b, 224g, each having 24 LEDs 226 corresponding thereto. Thus, each pixel 220 has an angular resolution of 24, generating an effective light field resolution of 46080x25920 for the light field display 200. It is contemplated that more or less than 24 LEDs 226 may be positioned beneath each micro-lens 224r, 224b, 224g, or that more or less than 1902x1080 pixels 220 may be utilized in the light field display 200.

**[0023]** The LEDs 226 are positioned in a “stepped diamond” configuration beneath each micro-lens 224r, 224b, 224g. The “stepped diamond” configuration maximizes the usable landscape under each micro-lens, further facilitating densification of the light field display 200 and thereby improving perceptible resolution. However, it is to be noted that other arrangements of the LEDs 226 are also contemplated, such as hexagonal, rectangular, “cross-

shaped" or "plus sign". In one aspect, the configuration of LEDs 226 is selected to maximize the number of LEDs 226 under a respective micro-lens.

**[0024]** The micro-lenses 224r, 224b, 224g have a concave shape or surface for directing light from the LEDs 226 in a desired directions to provide a desired angular resolution. While the micro-lenses 224r, 224b, 224g are described as being concave, it is contemplated that other lens shapes, such as convex lenses, flat lenses (e.g., meta lenses), or Fresnel lenses, may be utilized. In one example, each LED 226 directs light upward, orthogonal to a plane of the pixel arrangement 202, e.g., orthogonal to a plane of the pixels 220 and a plane of the LEDs 226. The upward-directed light from each LED 226 is then directed in a predetermined direction by respective micro-lenses 224r, 224b, 224g, as described with respect to Figure 2D.

**[0025]** Figure 2D illustrates the directional components of light exiting micro-lenses 224r, 224b, 224g of a pixel 220. To facilitate explanation, only nine LEDs 226 are shown adjacent each micro-lens 224r, 224b, 224g (corresponding to an angular resolution of nine per pixel 220), however, it is to be appreciated that more or less than nine LEDs 226 may be utilized to generate a higher or lower angular resolution.

**[0026]** During operation, each LED 226 generates collimated light in a direction perpendicular to a surface of light field display 200, e.g., the z-axis. As the generated light passes through a respective micro-lens 224r, 224b, 224g, the light from each LED is directed in one of a plurality of predetermined directions, corresponding to angular resolutions of the pixel 220. The LEDs 226 of adjacent each micro-lens 224r, 224b, 224g are configured to direct light (indicated by 212, two are marked) in a direction measured with respect to the deviation, here angle  $\theta$ , of the primary emission direction (the z-axis), and a directional component based on the North (N), east (E), south(S) and west (W) directions in the plane of the display surface 210. Thus, the primary light emission direction of each LED can be notated as (direction, angle  $\theta$ ) for explanation purposes, with the exception of a perpendicular (Z-direction) light ray, annotated as 0,0. Herein, the directional components N, S, E, and W

respectively correspond to the upward, downward, rightward, and leftward directions of a display surface of the light field display 200.

**[0027]** In one example, the LEDs 226 disposed equidistant from a central LED 226 may each direct a light ray 212 which deviates from the Z direction by an angle  $\theta$  (in a respective directional component). It is contemplated, however, that in some instances, angle  $\theta$  may not be equal for each of the LEDs 226, depending on the desired angular resolution. Moreover, it is contemplated that additional LEDs 226 may be included, which direct light rays at an angle  $\theta_1$ , different than angle  $\theta$ , in order to provide additional angular resolution. In such an example, the LEDs 226 having light directed at angle  $\theta_1$  may be positioned radially outward of the LEDs 226 having light directed at angle  $\theta$ . In such an example, angle  $\theta_1$  is greater than angle  $\theta$ . It is to be noted that additional LEDs 226 having light directed at angle  $\theta_2$ , angle  $\theta_3$ , and so forth, may be further included, to increase angular resolution. As noted above, each of the LEDs 226 generate light in a direction perpendicular to a display surface of the light field display 200, however, the particular angle  $\theta$  (or angle  $\theta_1$ , angle  $\theta_2$ , etc.) is determined by the characteristics of a respective micro-lens 224r, 224b, 224g.

**[0028]** In a specific example of the above embodiment, a first LED 226 positioned centrally beneath a respective micro-lens 224r, 224b, 224g has light directed in the Z direction by a respective micro-lens 224r, 224b, 224g. A plurality of LEDs 226, spaced equidistant and radially outward from the first LED 226, have light directed by a respective micro-lens 224r, 224b, 224g at angle  $\theta$  (in a corresponding compass direction). A second plurality of LEDs 226, disposed outward of the LEDs of the first plurality of LEDs 226 and equidistant from the first LED 226, have light directed by a respective micro-lens 224r, 224b, 224g at angle  $\theta_1$  (in a corresponding compass direction). Additional LEDs 226, having light directed at additional angles  $\theta_i$ , may be further included to provide additional angular resolution.

**[0029]** Returning to Figure 2D, to facilitate generation of an image, each LED 226 under the micro-lens 224r is operable with and corresponds to an

LED 226 at a corresponding location under micro-lens 224b and micro-lens 224g. For example, the LED 226 under micro-lens 224r which directs a light ray 212 toward (NW,  $\theta$ ) corresponds to the LEDs 226 under micro-lens 224b and micro-lens 224g which also direct a light ray 212 toward (NW,  $\theta$ ), thereby resulting in RGB light rays 212 for a particular display angle of the angular resolution. Stated otherwise, each LED 226 under one of the micro-lens 224r, 224b, 224g, also has a corresponding LED 226 (of angular direction) under the remaining micro-lenses of the pixel 220, in order to direct RGB light to a particular angular location, facilitating display of an image.

**[0030]** While Figure 2D is described with respect to compass directions, it is to be noted that such directions are only used to facilitate explanation, and that angular directions are not limited to intervals of 90 degrees or 45 degrees from one another.

**[0031]** Figure 3A is a schematic cross-sectional view of an LED 226 disposed on a portion of a display panel 310, according to one embodiment. Figure 3B is a sectional view of a portion of the LED 226 described in Figure 3A, taken along line 3B-3B of Figure 3A.

**[0032]** The LED 226 includes an active layer stack 304, a transparent conductive oxide (TCO) layer 306 disposed on the active layer stack 304, an electrically insulating layer 312, such as dielectric layer, disposed on the active layer stack 304, and an electrically conductive reflective layer 316, such as a metal layer, disposed on the electrically insulating layer 312. Typically, the active layer stack 304 of the LED 226 described herein is formed of one or more III-V materials, such as GaAs, GaN, InGaN, AlGaNp, or combinations thereof, and includes a p-type layer 304a, an n-type layer 304c, and one or more quantum well (QW) layers 304b interposed between the p-type layer 304a and the n-type layer 304c. In some embodiments, the blue and green LEDs 226 are formed using an active layer stack 304 that includes a InGaN layer interposed between a p-type GaN layer and n-type GaN layer, where the wavelength of light emitted by the active layer stack 304, and thus the color of light provided by the LED 226, is determined by relative concentrations of

indium and gallium in the InGaN layer. Alternatively, dopants, or color filter layers, may be used to provide the different output colors of the LED 226. In some embodiments, red LED 226 are formed using an active layer stack 304 that includes an AlGaInP layer interposed between a p-type GaP layer and an n-type GaAs layer.

**[0033]** The LED 226 is mounted to a display panel 310 of a light field display 200 (shown in Figure 2A), in a desired pixel arrangement 202 (shown in Figure 2A), using a transparent conductive adhesive (TCA) layer 318 disposed therebetween. When mounted, a major surface of the active layer stack 304 is substantially parallel to a plane of the display panel 310. Typically, the active layer stack 304 has a thickness T(1) between about 10 nm and about 100nm, such as about 30 nm and forms an ohmic contact with the TCO layer 306 at the surfaces therebetween. The TCO layer 306 is formed of a transparent conductive oxide material such as indium tin oxide (ITO) or doped conductive zinc-oxide, such as aluminum doped zinc oxide (AZO) or gallium doped zinc oxide (GZO). The TCO layer 306 and at least a portion of the active layer stack 304 form a circular or elliptical paraboloid shape, such as a substantially circular paraboloid shape at surfaces proximate to the electrically insulating layer 312.

**[0034]** The electrically insulating layer 312 is typically formed of a transparent dielectric material, such as silicon oxide, silicon nitride, or combinations thereof. The electrically insulating layer 312 is conformal to the circular paraboloid shape of surfaces of the TCO layer 306 and at least portions of the surfaces of the active layer stack 304 disposed therebeneath. In such a configuration, a reflective surface 316a of the reflective layer 316 disposed on the electrically insulating layer 312 forms an parabolic mirror, such as a circular or elliptical parabolic mirror, having a focal point F at or proximate to a surface of the p-type layer 304a. An opening 314 formed in the electrically insulating layer 312 enables a p-contact between the reflective layer 316, disposed through the opening 314, and the TCO layer 306. In some embodiments, the TCA layer 318 provides an n-type contact to the

active layer stack 304. In other embodiments, the LED 226 is mounted to the display panel 310 using a transparent non-conductive adhesive.

**[0035]** In some embodiments, the LED 226 further includes a sapphire layer (not shown) disposed between the active layer stack 304 and the display panel 310, where the sapphire layer of the LED 226 is bonded to the display panel 310 using a non-electrically conductive transparent adhesive layer (not shown). In other embodiments, the LED 226 is mounted to a back panel (not shown).

**[0036]** Typically, a surface of the active layer stack 304 proximate to the TCO layer has a diameter D along the major axis thereof. In some embodiments, the diameter D is less than about 100  $\mu\text{m}$ , such as less than about 50  $\mu\text{m}$ , less than about 20  $\mu\text{m}$ , less than about 10  $\mu\text{m}$ , for example less than about 5  $\mu\text{m}$ , or between about 0.1  $\mu\text{m}$  and about 10  $\mu\text{m}$ , such as between about 0.5  $\mu\text{m}$  and about 10  $\mu\text{m}$ , for example between about 0.5  $\mu\text{m}$  and about 5  $\mu\text{m}$ . In some embodiments, a ratio of the diameter D to a height of the LED 226, herein height H, is more than about 0.2, such as more than about 0.3, more than about 0.4, more than about 0.5, more than about 0.8, for example more than about 1.

**[0037]** In some embodiments, portions of the surface of the p-type layer 304a are selectively treated, for example plasma treated, to desirably form a non-or-low-light transmission region 304a(2) circumscribing a light transmission region 304a(1). Plasma treating the surface of the p-type layer in the non-or-low-light transmission region 304a(2) desirably increases the resistance of the ohmic contact with the TCO layer 306 disposed thereon to bound an area of effective light transmission from the active layer stack 304 to a light transmission region 304a(1) centered about the focal point F. Bounding the area of light transmission to a region about the focal point F desirably increases the collimation of light provided by the LED 226. The LED 226 generates collimated light rays 212 in a direction that is substantially orthogonal (Z-direction) to the display surface 210 (e.g., X-Y plane). Thus, the

axis of symmetry Z' of the reflective surface 316a is in substantially the same direction as the Z-direction.

**[0038]** Figure 4 is a flow diagram illustrating a method 400 of forming an LED 226, according to one embodiment. Figures 5A-5H schematically illustrate formation of an LED according to the method described in Figure 4.

**[0039]** The method 400 includes depositing a resist layer, such as the resist layer 508 shown in Figure 5B, on the surface of a substrate 500, at activity 410. The substrate 500 includes a structural base 502, an active layer stack 304 disposed on the structural base 502, and a transparent conductive oxide (TCO) layer 306 disposed on the active layer stack 304. Typically, the structural base 502 is formed of a lattice-matching material, such as sapphire or silicon carbide, and one or more layers of the active layer stack 304 are epitaxially formed thereon. The resist layer 508 herein comprises a UV curable resin material deposited and/or dispensed onto the surface of the substrate 500. In some embodiments, the resist layer 508 is formed from a plurality of droplets of the UV curable resin material.

**[0040]** At activity 420, the method 400 further includes physically imprinting a pattern into the resist layer 508 using an imprint lithography (IL) stamp 510. The imprint lithography (IL) stamp 510 includes one or more paraboloid shaped openings 512 formed therein. Physically pressing the IL stamp 520 into the resist layer 508 displaces the resin material about the pattern of the IL stamp. The resin material is cured using electromagnetic radiation provided through the IL stamp to form a patterned resist layer 508b comprising one or more paraboloid shaped features. An axis of symmetry Z' of the surface of the paraboloid shaped openings 512 is parallel to a Z-direction and orthogonal to the X-Y plane. Typically, the IL stamp 510 is formed of a material that is transparent to the electromagnetic radiation 514, such as UV radiation, used to cure the resin material of the resist layer 508. In other embodiments, the patterned resist layer 508b is formed using a thermal imprint lithography process or a grey-scale lithography process. In some other embodiments, the IL stamp 510 and/or the patterned resist layer 508b is formed using a grey-

scale lithography process. In some other embodiments, the patterned resist layer 508b is formed using a combination of grey-scale lithography and imprint lithography. It is contemplated that other maskless direct lithography techniques may also be used.

**[0041]** At activity 430, the method 400 further includes transferring the pattern formed in the patterned resist layer 508b to the TCO layer 306 and the active layer stack 304 disposed therebeneath to form a patterned substrate, such as the patterned substrate 518 of Figure 5F. In Figure 5F, the patterned substrate 518 includes one or more paraboloid shaped features 520 (three are shown). Typically, the pattern is transferred using a dry etch process, such as an inductively coupled plasma (ICP) etch process or a reactive ion etching (RIE) process.

**[0042]** At activities 440, 450, 460 the method 400 further includes depositing an electrically insulating layer 312 onto the patterned substrate 518, forming one or more openings 314 in the electrically insulating layer 312, and depositing a reflective layer 316 over the electrically insulating layer 312 to form one or more LEDs 226, such as the LED 226 described in Figure 3.

**[0043]** In some embodiments, the method 400 includes dicing the one or more LEDs 226 along the dicing lines 522 shown in Figure 5H. Dicing the one or more LEDs 226 is typically done using laser scribing, mechanical sawing, water/solvent knifing, ion beam milling, a multi-layer photolithography etch process, or a combination thereof. The LEDs 226 may be diced into individual LEDs 226, or groups of LEDs 226 in a predetermined configuration, such as in a linear strip or the orientation shown in Figure 2C. In some embodiments, the method 400 further includes removing all or a portion of the structural base 502 from the one or more LEDs 226 before and/or after the dicing. In some embodiments, the structural base 502 is removed from the one or more LEDs 226 using a conventional laser liftoff process, a chemical mechanical polishing (CMP) process, a wet-etch process, or a combination thereof.

**[0044]** After formation of the LEDs 226, the LEDs 226 are positioned in a predetermined array or configuration adjacent a micro-lens, such as micro-lens 224r, 224b, 224g. In one example, LEDs 226 may be arranged on and coupled to a display panel 310 (shown in Figure 3A) in a pixel arrangement 202 (shown in Figure 2A).

**[0045]** Figures 6A and 6B are schematic illustrations of pixel arrangements 602A, 602B, according to other embodiments. The pixel arrangements 602A, 602B may be used in place of pixel arrangement 202 in Figure 2A.

**[0046]** The pixel arrangement 602A includes a plurality of pixels 620A (only one is shown for clarity). Each pixel 620A includes a plurality of red LEDs 226r<sub>(1, 2, 3)</sub>, a plurality of green LEDs 226g<sub>(1, 2, 3)</sub>, and a plurality of blue LEDs 226b<sub>(1, 2, 3)</sub>, which generate light that is subsequently directed by a micro-lens array 624. The micro-lens array 624 is a flat lens, such as a meta lens, that includes a plurality of light-directing features 650 thereon (nine are shown, with one light-directing feature 650 corresponding to a respective LED). The light directing-features 650 are positioned and configured to direct light from the red LEDs 226r<sub>(1, 2, 3)</sub>, the green LEDs 226g<sub>(1, 2, 3)</sub>, and the blue LEDs 226b<sub>(1, 2, 3)</sub> in predetermined directions, with corresponding LEDs having light directed in a same angular direction. For example, LEDs 226r<sub>1</sub>, 226g<sub>1</sub>, and 226b<sub>1</sub> are directed by the micro-lens array 624 in a same direction to generate a first angular resolution (“View X”). Similarly, corresponding LEDs 226r<sub>2</sub>, 226g<sub>2</sub>, and 226b<sub>2</sub>, as well as corresponding LEDs 226r<sub>3</sub>, 226g<sub>3</sub>, and 226b<sub>3</sub> likewise are directed by the micro-lens array 624 to generate additional angular resolutions (“View Y” And View Z”). It is to be noted that additional LEDs 226r<sub>i</sub>, 226b<sub>i</sub>, 226g<sub>i</sub> may be included in each pixel 620A, and additional light-directing features 650 may be included on the micro-lens array 624, to generate increased angular resolution (e.g., more “views”). The light directing features 650 may include one or more of angled lenses, flat lenses, prisms, concave lenses, convex lenses, nano-fins such as titanium dioxide nano-fins, or other surface features configured to redirect light.

**[0047]** While only one pixel 620A is shown, the pixel arrangement 602A generally includes a plurality of pixels 620Ai, arranged in array. To facilitate ease of manufacturing, LEDs 226ri, 226bi, 226gi of same color are manufactured on a single substrate in a dense array and then diced into linear strips 651 (or other configurations) on structural bases 502. The linear strips 651 are then positioned in a desired configuration, for example, parallel and adjacent to one another, to form pixels for image generation. Similarly, light-directing features 650 are formed on the micro-lens array 624 in a fully-dense array, corresponding to a desired pixel arrangement and angular resolution. In such a configuration, the number, placement, and orientation of the light-directing features 650 may be tailored to determine light ray direction, the number of pixels (e.g., spatial resolution), and the number of angular views (e.g., angular resolution). For ease of manufacturing, the micro-lens array 624 includes an optically-transparent substrate panel 670, such as a glass sheet, upon which the light-directing features 650 are formed. Formation of the light-directing features 650 on the substrate panel 670 reduces manufacturing time of a light-field display, because the light-directing features 650 need not be individually aligned with a respective LED. Rather, proper positioning of the substrate panel 670 results in alignment of light-directing features 650 and all corresponding LEDs.

**[0048]** The example of Figure 6A utilizes a single (unitary) micro-lens array 624 (covering all pixels 620Ai), the micro-lens array 624 having a plurality of light-directing features 650 thereon. Alternatively, a plurality of discrete micro-lens arrays, for example, indicated by box 655 (one is shown), may be used. In such an example, each discrete micro-lens array would include a plurality of light-directing features 650.

**[0049]** While Figure 6A illustrates micro-lens array 624 as a flat lens, it is also contemplated that the micro-lens array 624 may include a plurality of convex or concave lenses positioned over each pixel 620A, as similarly shown with respect to Figure 2B. In such an example, the plurality of convex or concave lenses may be formed on the substrate panel 670, or may be discrete units.

**[0050]** Figure 6B illustrates a pixel arrangement 602B. The pixel arrangement 602B is similar to the pixel arrangement 602A, but rather than linear strips 651, the pixel arrangement 602b utilizes pixels 620B in clusters. In a specific example, the clusters have a triangular arrangement, as similarly shown and described with respect to Figure 2C. Other cluster arrangements are contemplated. In addition to a densifying the arrangement of pixels per unit area, it is contemplated that the triangular arrangement may improve perceived resolution which may otherwise be reduced by the relatively large pixels, caused by the increased number of LEDs per pixel.

**[0051]** While embodiments of the disclosure are discussed with respect to LEDs, it is contemplated that organic LEDS (OLEDs) may be used in place thereof. Additionally, it is to be understood that the angular resolution of a pixel by be adjusted by varying the number of LEDs per micro-lens of each pixel. For example, each micro-lens of a pixel may include three or more corresponding LEDs, such as five or more, nine or more, 16 or more, 25 or more, 36 or more, and the like.

**[0052]** Benefits of the disclosed subject matter include increased resolution compared to conventional displays.

**[0053]** While the foregoing is directed to embodiments of the present disclosure, other and further embodiments of the disclosure may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.

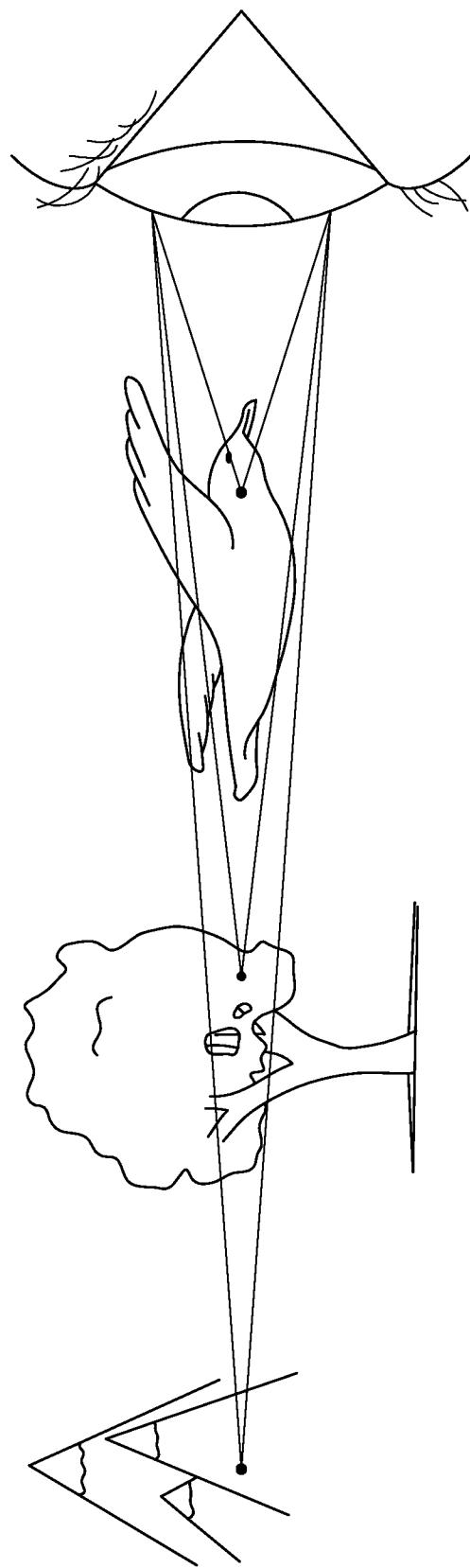
What is claimed is:

1. A pixel, comprising:
  - a plurality of micro-lenses; and
  - a plurality of collimated light emitting diodes (LEDs) positioned beneath each micro-lens, wherein LEDs under a respective micro-lens of the plurality of micro-lenses are configured to generate light of the same color.
2. The pixel of claim 1, wherein the plurality of micro-lenses includes three concave lenses arranged in a triangular configuration, and wherein the plurality of collimated LEDs includes at least three LEDs per micro-lens of the plurality of micro-lenses.
3. The pixel of claim 1, wherein the plurality of micro-lenses includes light directing features formed on a flat substrate panel, the light-directing features include nano fins.
4. The pixel of claim 1, wherein the plurality of collimated LEDs corresponding to each micro-lens of the plurality of micro-lenses are arranged in a hexagonal array.
5. A light-field display, comprising:
  - a plurality of pixels, each pixel of the plurality of pixels comprising:
    - a plurality of micro-lenses; and
    - a plurality of collimated light emitting diodes (LEDs) positioned beneath each micro-lens, wherein LEDs under a respective micro-lens of the plurality of micro-lenses are configured to generate light of the same color.
6. The light-field display of claim 5, wherein the plurality of pixels are arranged in a hexagonal array.
7. The light-field display of claim 5, wherein the plurality of micro-lenses of each pixel included concave lenses.

8. The light-field display of claim 7, wherein the plurality of micro-lenses of each pixel is three concave lenses arranged in a triangular configuration.
9. The light-field display of claim 5, wherein the plurality of collimated LEDs of each pixel includes at least three LEDs per micro-lens of the plurality of micro-lenses.
10. The light-field display of claim 5, wherein the plurality of micro-lenses of each pixel includes light directing features formed on a flat substrate panel.
11. The light-field display of claim 10, wherein the light-directing features include nano fins.
12. The light-field display of claim 10, wherein the flat substrate panel spans multiple pixels of the plurality of pixels.
13. The light-field display of claim 5, wherein the plurality of collimated LEDs corresponding to each micro-lens of the plurality of micro-lenses are arranged in a hexagonal array.
14. A light-field display, comprising:
  - a plurality of pixels, each pixel of the plurality of pixels comprising:
    - a plurality of light-directing features formed on a substrate panel; and
    - a plurality of collimated light emitting diodes (LEDs) positioned beneath respective light-directing features, the plurality of collimated LEDs arranged strips according to a color of light generated thereby.
15. The light-field display of claim 14, wherein the plurality of collimated LEDs are arranged in linear strips or clusters, wherein the substrate panel spans the plurality of pixels.

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FIG. 1



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FIG. 2A

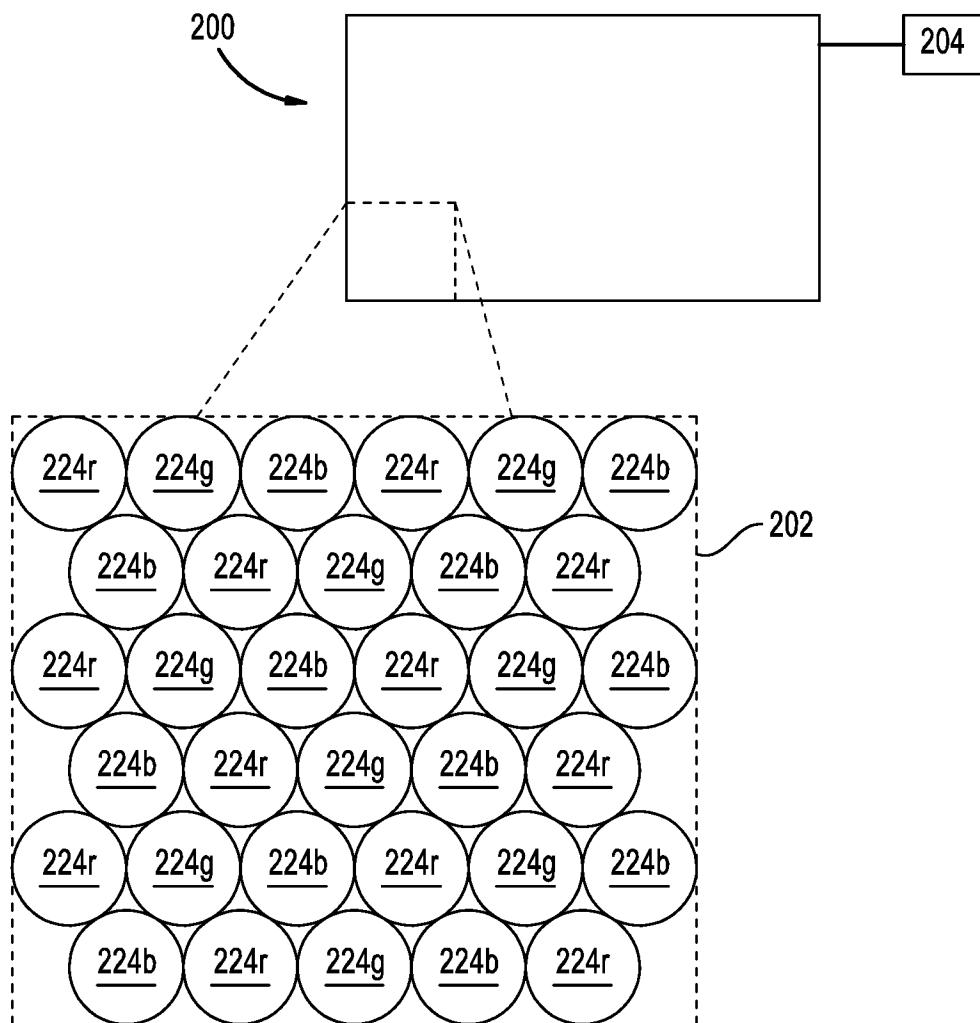


FIG. 2B

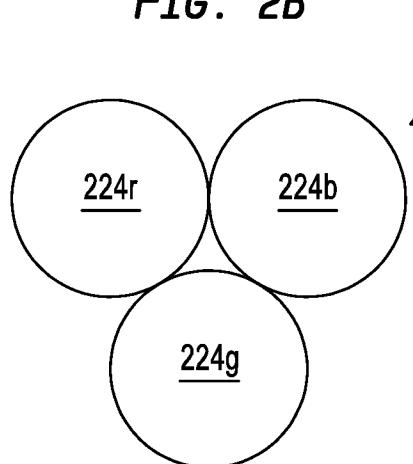
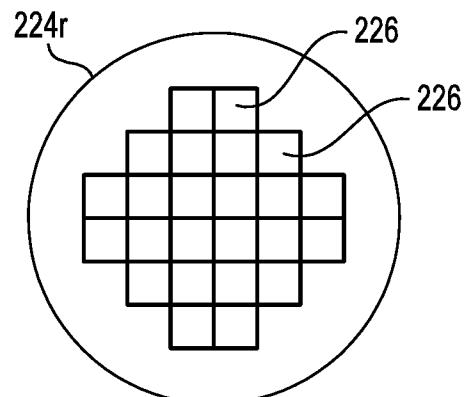
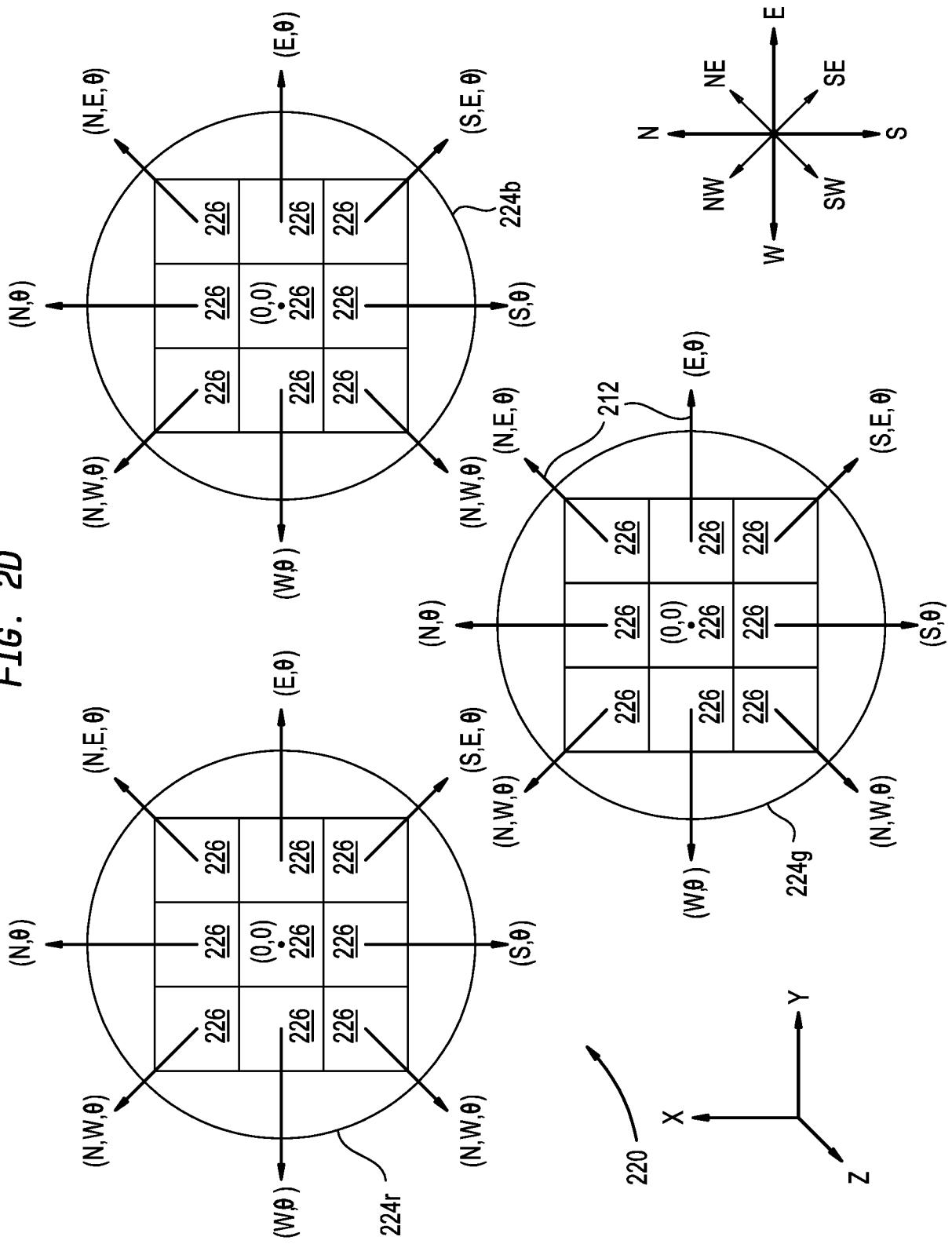


FIG. 2C



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FIG. 2D



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FIG. 3A

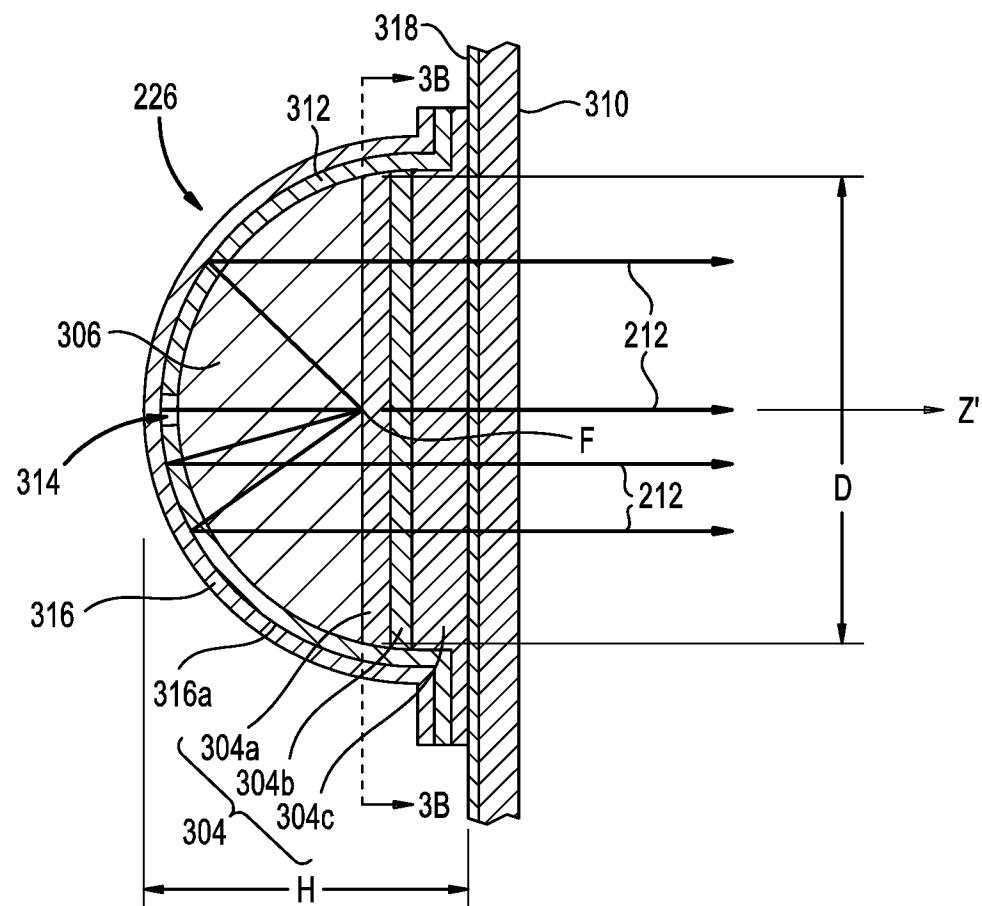
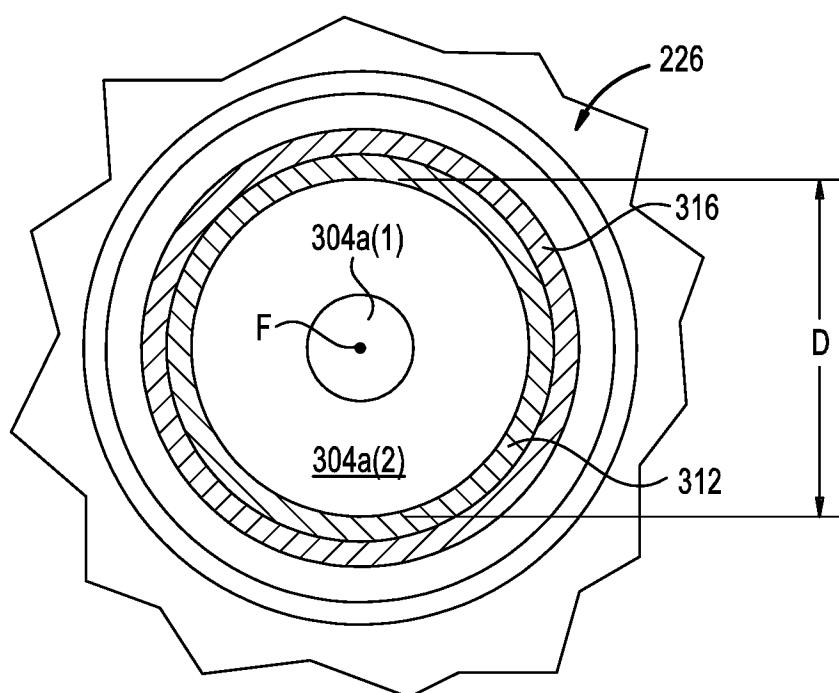
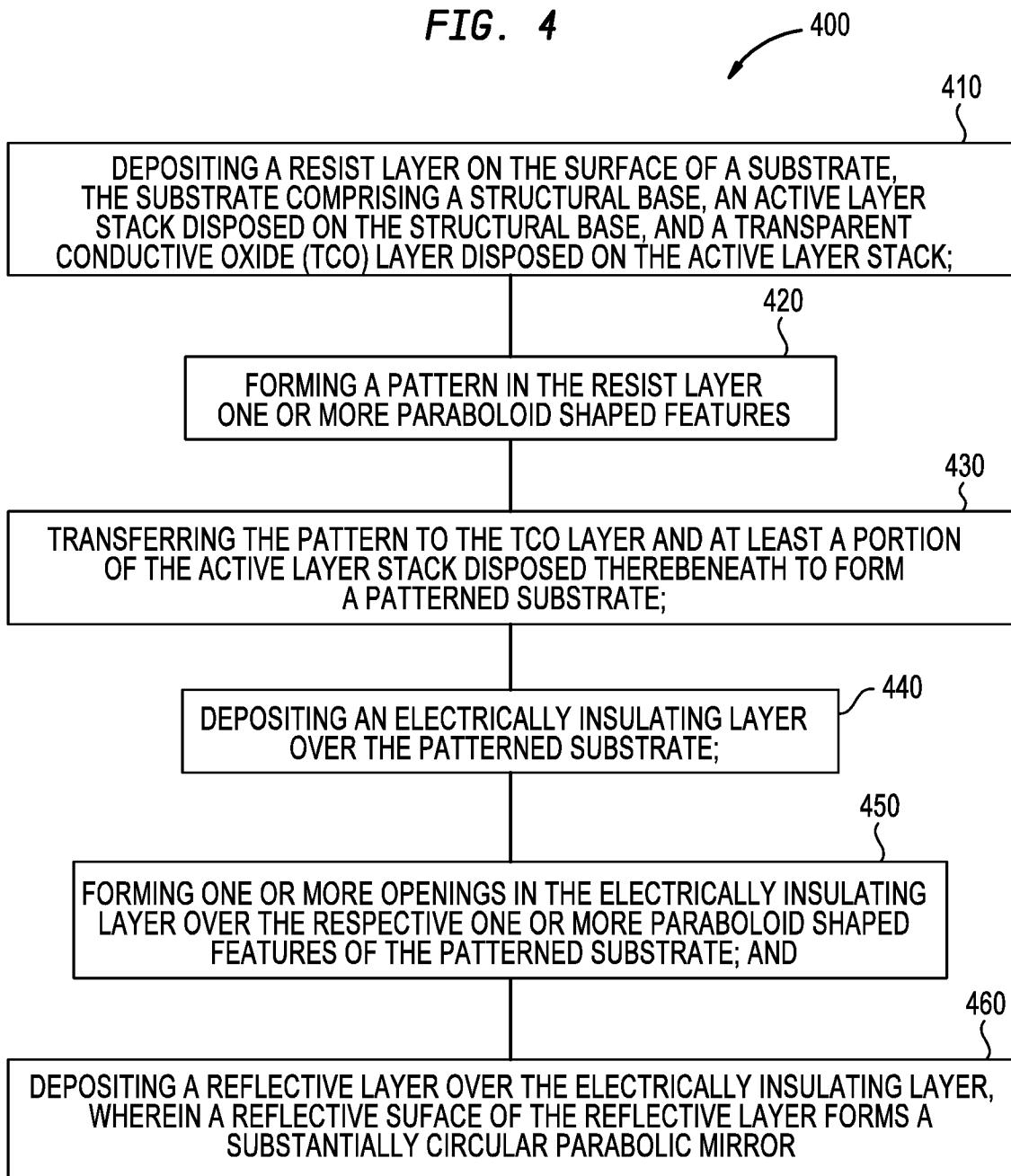


FIG. 3B



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FIG. 4



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FIG. 5A

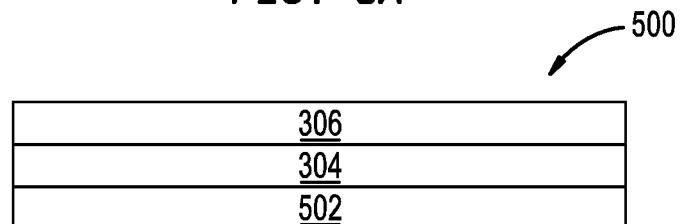


FIG. 5B

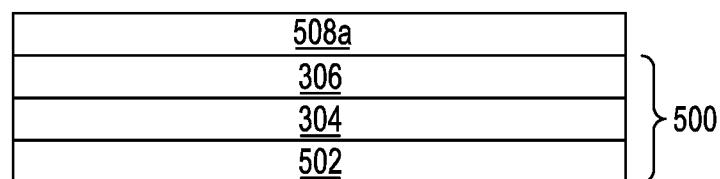


FIG. 5C

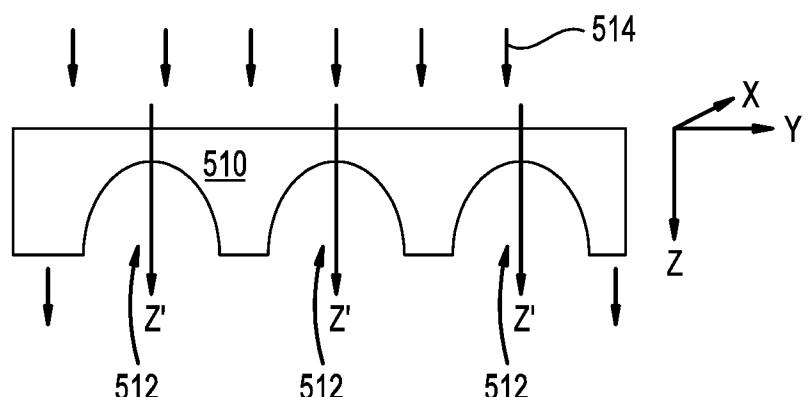
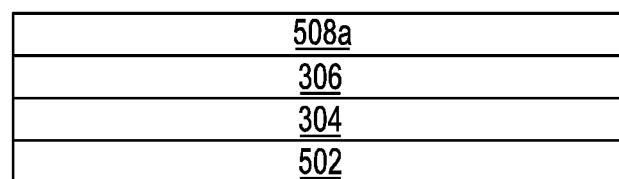


FIG. 5D



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FIG. 5E

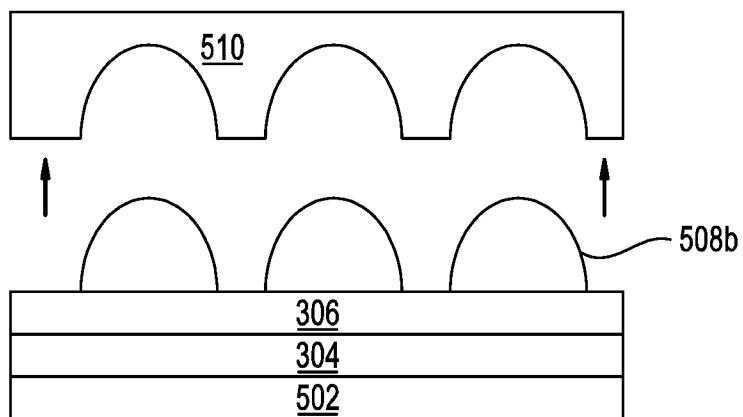


FIG. 5F

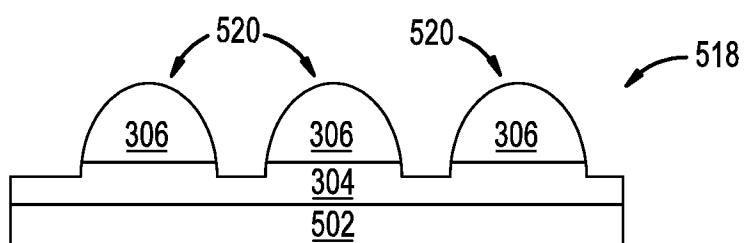


FIG. 5G

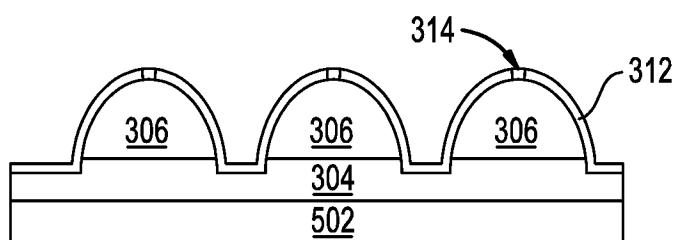
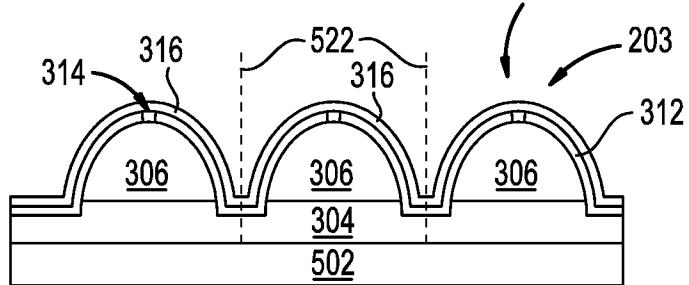
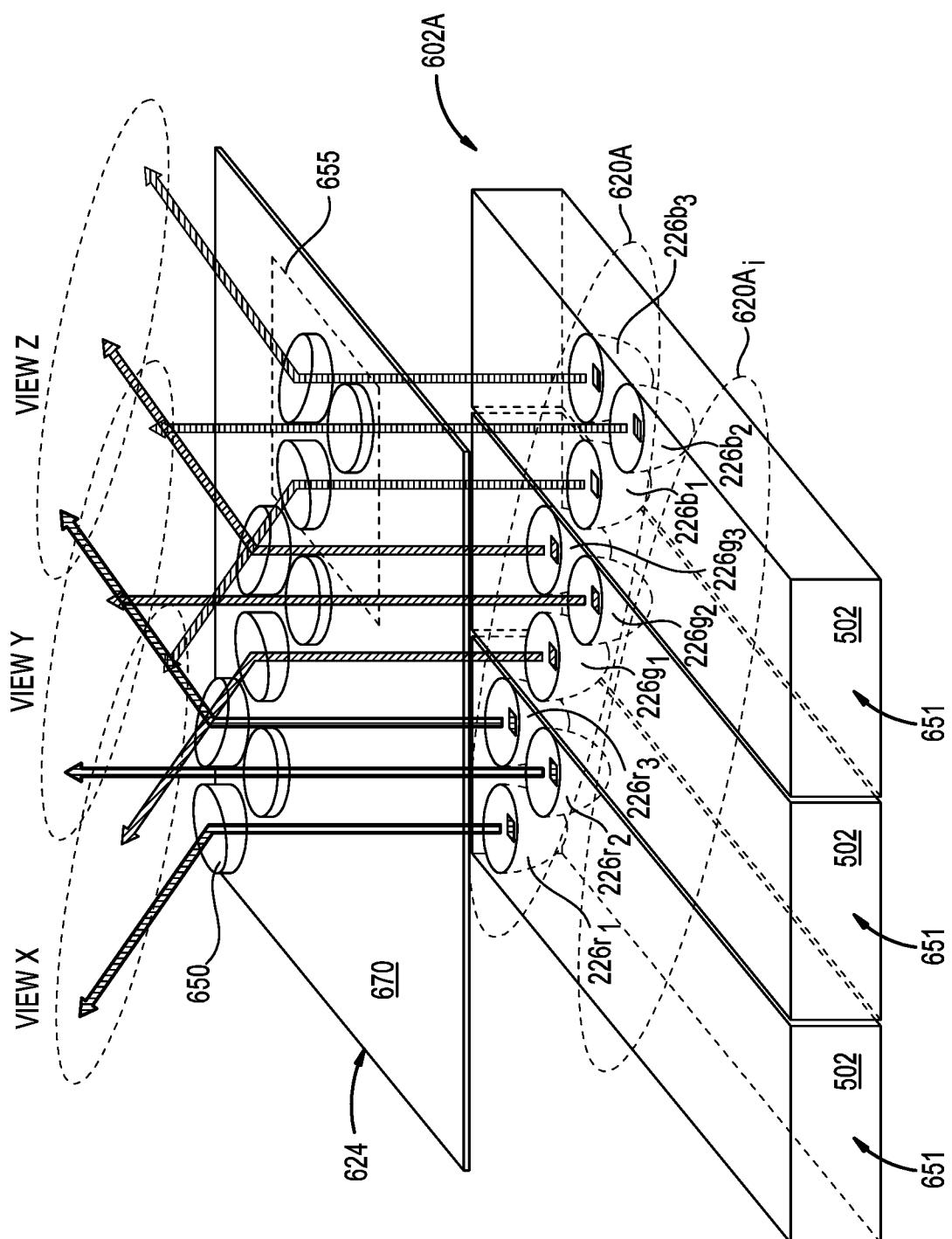


FIG. 5H



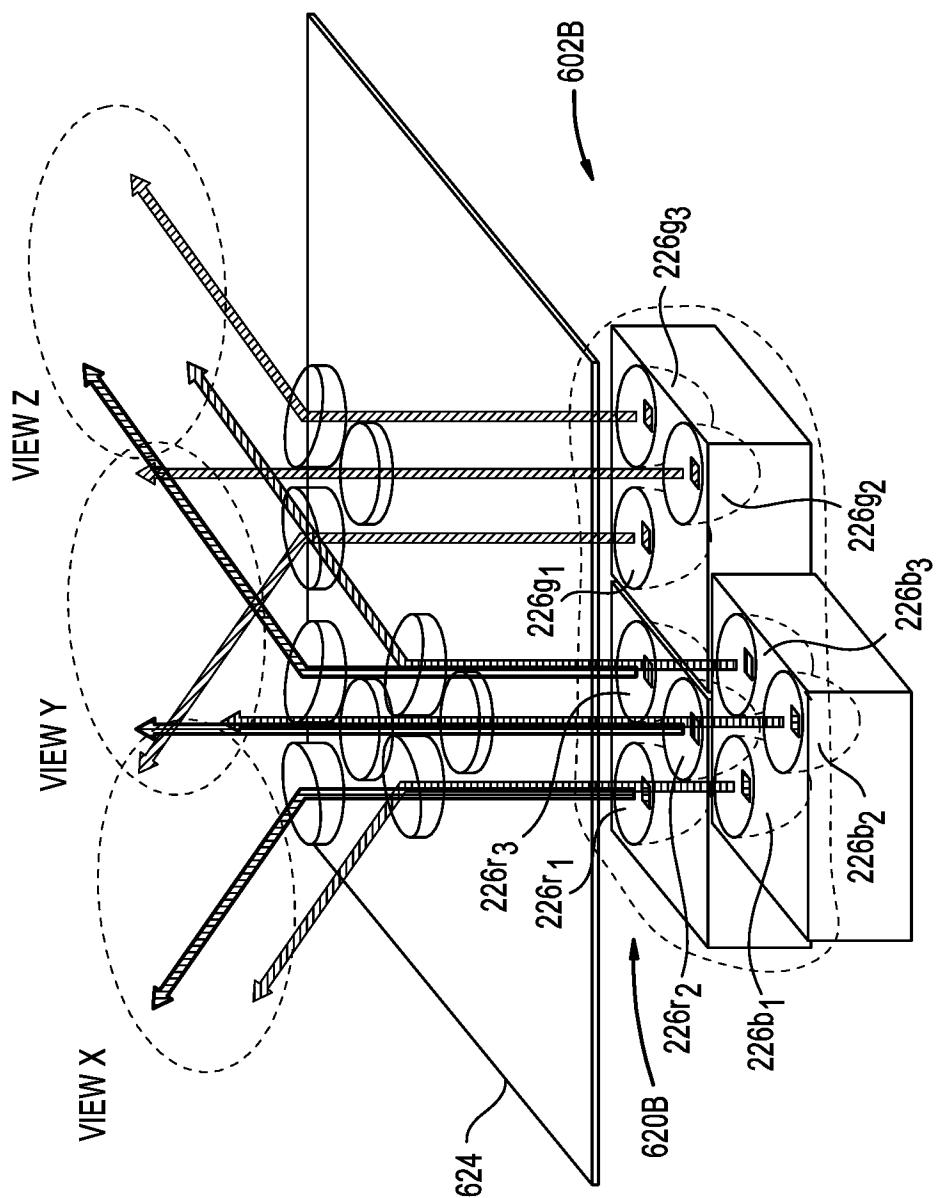
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FIG. 6A



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FIG. 6B



## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US2017/065563

## A. CLASSIFICATION OF SUBJECT MATTER

G02B 27/02(2006.01)i, G02B 27/01(2006.01)i, G02B 27/22(2006.01)i

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

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

G02B 27/02; F21V 5/00; F21V 17/06; F21V 9/00; H01S 5/00; H01J 9/00; H04N 13/04; G09G 5/00; G02B 27/01; G02B 27/22

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched  
Korean utility models and applications for utility models

Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)  
eKOMPASS(KIPO internal) & Keywords: micro-lens, collimate, LED, pixel, display

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2016-0076731 A1 (OSRAM OPTO SEMICONDUCTORS GMBH) 17 March 2016 See paragraphs [0018]–[0052], claims 18, 30, 34 and figures 1A–1C.	1–15
Y	US 2013-0207964 A1 (ROD G. FLECK et al.) 15 August 2013 See paragraphs [0028]–[0029] and figure 2.	1–15
A	US 2014-0300709 A1 (SEEREAL TECHNOLOGIES S.A.) 09 October 2014 See claim 1 and figures 2–8.	1–15
A	US 2007-0217473 A1 (KATSUNORI ABE et al.) 20 September 2007 See claim 1 and figures 17–2	1–15
A	US 2006-0238545 A1 (DMITRY BAKIN et al.) 26 October 2006 See claim 1 and figure 2.	1–15

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

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

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Date of the actual completion of the international search  
27 March 2018 (27.03.2018)Date of mailing of the international search report  
**28 March 2018 (28.03.2018)**Name and mailing address of the ISA/KR  
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**INTERNATIONAL SEARCH REPORT**

Information on patent family members

International application No.

**PCT/US2017/065563**

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2016-0076731 A1	17/03/2016	CN 105122450 A DE 102013104046 A1 DE 112014002084 A5 JP 2016-526276 A JP 2017-168855 A KR 10-2016-0003746 A WO 2014-173736 A1	02/12/2015 23/10/2014 31/12/2015 01/09/2016 21/09/2017 11/01/2016 30/10/2014
US 2013-0207964 A1	15/08/2013	TW 201403130 A TW I587008 B US 2016-0282625 A1 US 9368546 B2 US 9684174 B2 WO 2013-123237 A1	16/01/2014 11/06/2017 29/09/2016 14/06/2016 20/06/2017 22/08/2013
US 2014-0300709 A1	09/10/2014	DE 112012004398 A5 KR 10-2014-0079496 A TW 201317636 A WO 2013-056703 A2 WO 2013-056703 A3	07/08/2014 26/06/2014 01/05/2013 25/04/2013 13/06/2013
US 2007-0217473 A1	20/09/2007	JP 2007-173393 A	05/07/2007
US 2006-0238545 A1	26/10/2006	None	