US010559730B2

(12) **United States Patent**
Thothadri et al.

(10) **Patent No.: US 10,559,730 B2**

(45) **Date of Patent: Feb. 11, 2020**

(54) **COLLIMATED LED LIGHT FIELD DISPLAY**

(71) Applicant: **Applied Materials, Inc.**, Santa Clara, CA (US)

(72) Inventors: **Manivannan Thothadri**, Mountain View, CA (US); **Christopher Dennis Bencher**, Cupertino, CA (US); **Robert Jan Visser**, Menlo Park, CA (US); **John M. White**, Hayward, CA (US)

(73) Assignee: **APPLIED MATERIALS, INC.**, Santa Clara, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **16/369,574**

(22) Filed: **Mar. 29, 2019**

(65) **Prior Publication Data**

US 2019/0229246 A1 Jul. 25, 2019

Related U.S. Application Data

(63) Continuation of application No. 15/837,654, filed on Dec. 11, 2017, now Pat. No. 10,256,382.

(Continued)

(51) **Int. Cl.**

H01L 33/58 (2010.01)
H01L 27/15 (2006.01)

(Continued)

(52) **U.S. Cl.**

CPC ***H01L 33/58*** (2013.01); ***G02B 17/002*** (2013.01); ***G02B 27/2214*** (2013.01); ***H01L 25/0655*** (2013.01); ***H01L 27/156*** (2013.01); ***H04N 13/307*** (2018.05); *G02B 3/0056* (2013.01); *G02B 5/045* (2013.01);

(Continued)

(58) **Field of Classification Search**

CPC ... H01L 33/58; H01L 27/156; H01L 25/0655; H04N 13/307; G02B 17/002; G02B 19/0028; G02B 19/0061; G02B 5/045; G02B 3/0056; G02B 27/2214

USPC 438/141, 311, 597, 780; 257/88, 89, 98, 257/99, 80, 81, E21.006, E21.007, 257/E21.053, E21.077, E21.127, E33.058, 257/E33.059, E33.062, E33.072; 345/82, 345/419; 362/231, 240, 574

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,736,512 B2	5/2004	Balogh
7,045,375 B1	5/2006	Wu et al.

(Continued)

FOREIGN PATENT DOCUMENTS

WO	2012081569 A1	6/2012
WO	2017087033 A1	5/2017

OTHER PUBLICATIONS

Maaskant, Pleun P. et al., "High-Speed Substrate-Emitting Micro-Light-Emitting Diodes for Applications Requiring High Radiance", Applied Physics Express 6 (2013).

(Continued)

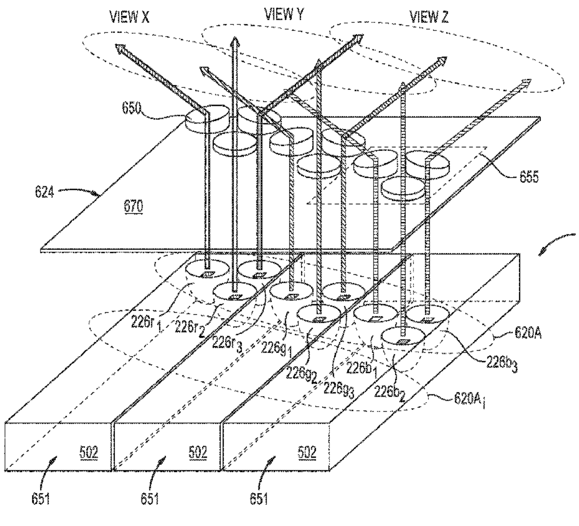
Primary Examiner — Dao H Nguyen

(74) *Attorney, Agent, or Firm* — Patterson + Sheridan LLP

(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.

20 Claims, 9 Drawing Sheets



Related U.S. Application Data

(60) Provisional application No. 62/432,156, filed on Dec. 9, 2016.

(51) **Int. Cl.**

H01L 25/065	(2006.01)
G02B 27/22	(2018.01)
H04N 13/307	(2018.01)
G02B 17/00	(2006.01)
G02B 3/00	(2006.01)
G02B 5/04	(2006.01)
G02B 19/00	(2006.01)

(52) **U.S. Cl.**

CPC *G02B 19/0028* (2013.01); *G02B 19/0061* (2013.01); *H01L 2933/0058* (2013.01)

(56) **References Cited**

U.S. PATENT DOCUMENTS

7,518,149 B2 4/2009 Maaskant et al.
7,638,808 B2 12/2009 Owen et al.
8,362,695 B2 1/2013 Aanegola et al.
9,450,148 B2 9/2016 Shepherd
9,502,595 B2 11/2016 Percival
9,559,250 B2 * 1/2017 Bonar H01L 33/405
10,256,382 B2 4/2019 White et al.
2004/0070337 A1 4/2004 Goh et al.
2006/0238545 A1 10/2006 Bakin et al.
2007/0217473 A1 9/2007 Abe et al.
2010/0203448 A1 8/2010 Teshima et al.
2010/0285167 A1 * 11/2010 Sandhu B82Y 10/00 425/385
2011/0037201 A1 * 2/2011 Koole B82Y 10/00 264/447
2011/0200795 A1 * 8/2011 Lammers B82Y 10/00 428/195.1
2013/0207964 A1 8/2013 Fleck et al.
2013/0228808 A1 * 9/2013 Lester H01L 33/44 257/98
2014/0300709 A1 10/2014 Futterer et al.
2015/0008392 A1 1/2015 Bonar et al.
2015/0070476 A1 3/2015 Wei
2015/0070657 A1 3/2015 Said
2015/0288935 A1 * 10/2015 Shinozaki H04N 5/2176 348/322
2016/0076731 A1 3/2016 Monch et al.
2016/0313180 A1 10/2016 Percival et al.
2017/0025469 A1 1/2017 Percival
2017/0038028 A1 2/2017 Cho et al.
2017/0054060 A1 * 2/2017 Hashiya H01L 33/505
2017/0213502 A1 7/2017 Henry et al.
2017/0271557 A1 9/2017 Brennan et al.
2017/0316736 A1 11/2017 Hughes et al.
2019/0019840 A1 * 1/2019 Thothadri H01L 27/156

OTHER PUBLICATIONS

Bill Henry, "A Multi-pixel LED Print-Head for Novel Imaging Applications", InfiniLED (2012).

* cited by examiner

FIG. 1

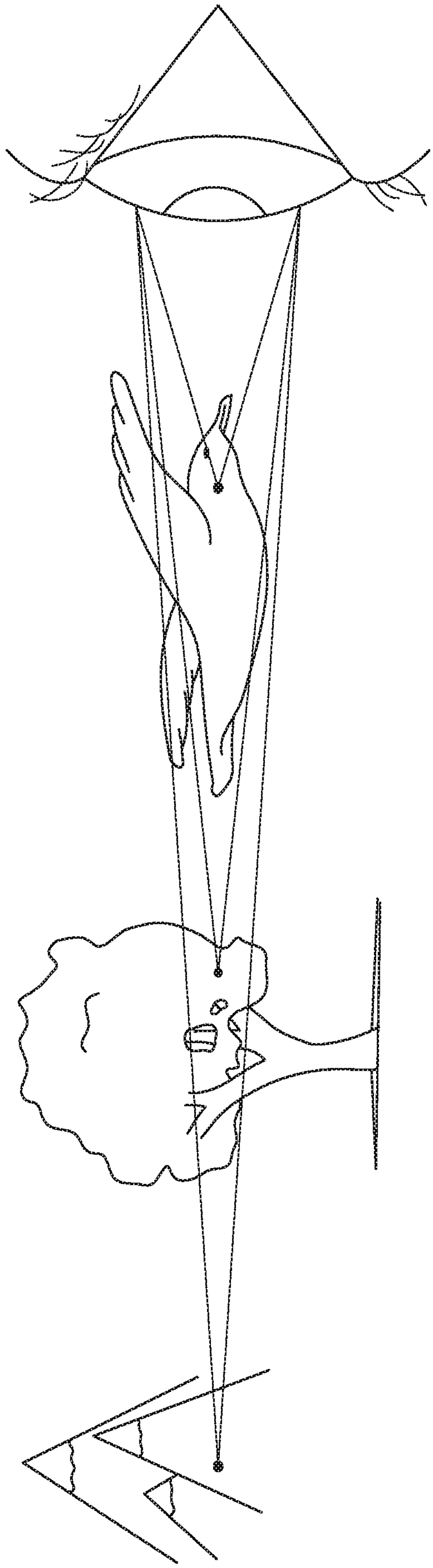


FIG. 2A

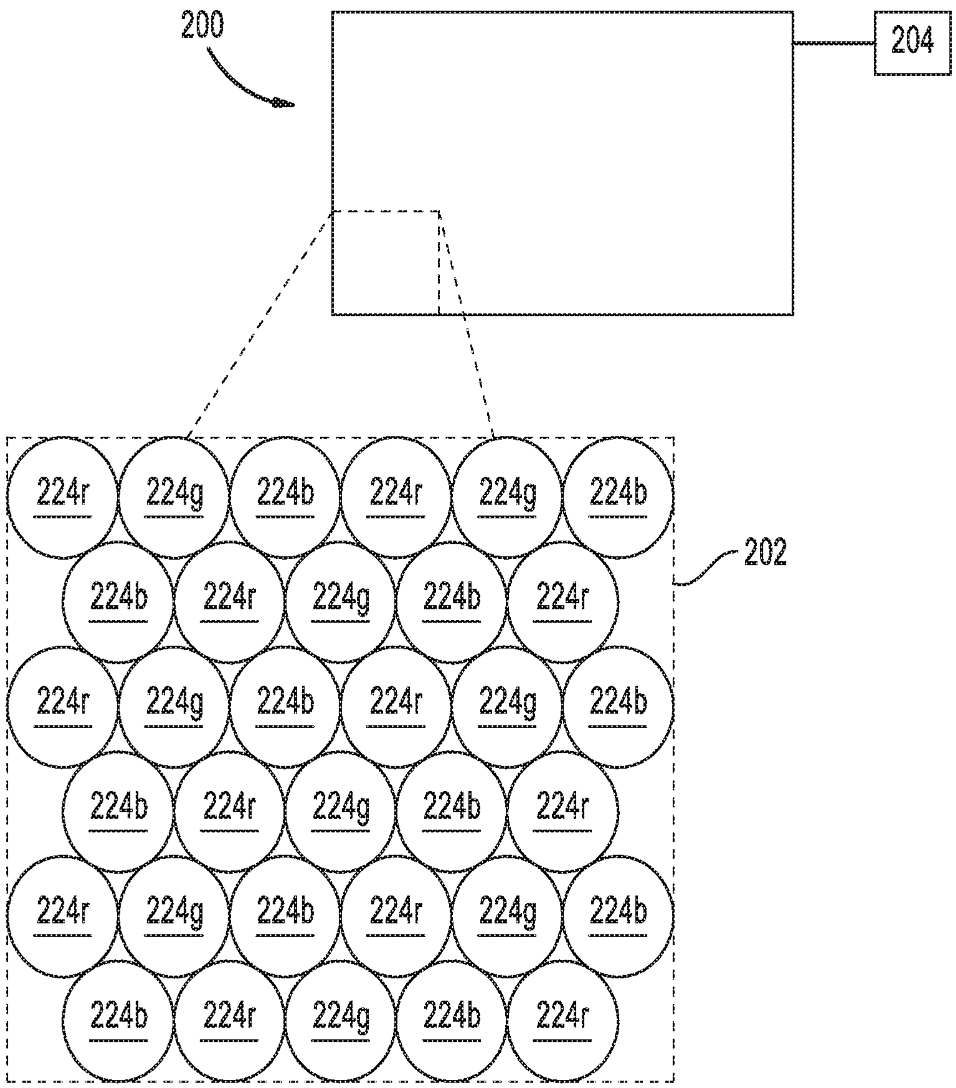


FIG. 2B

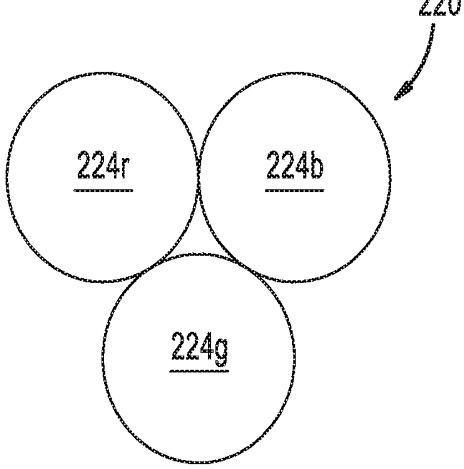
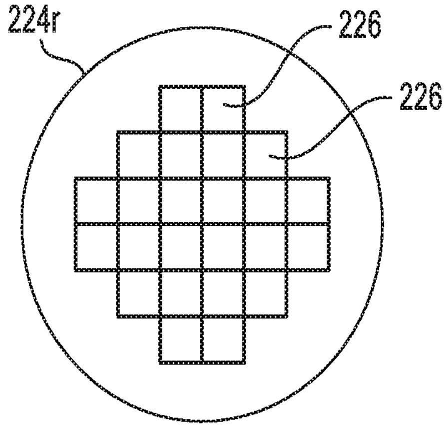


FIG. 2C



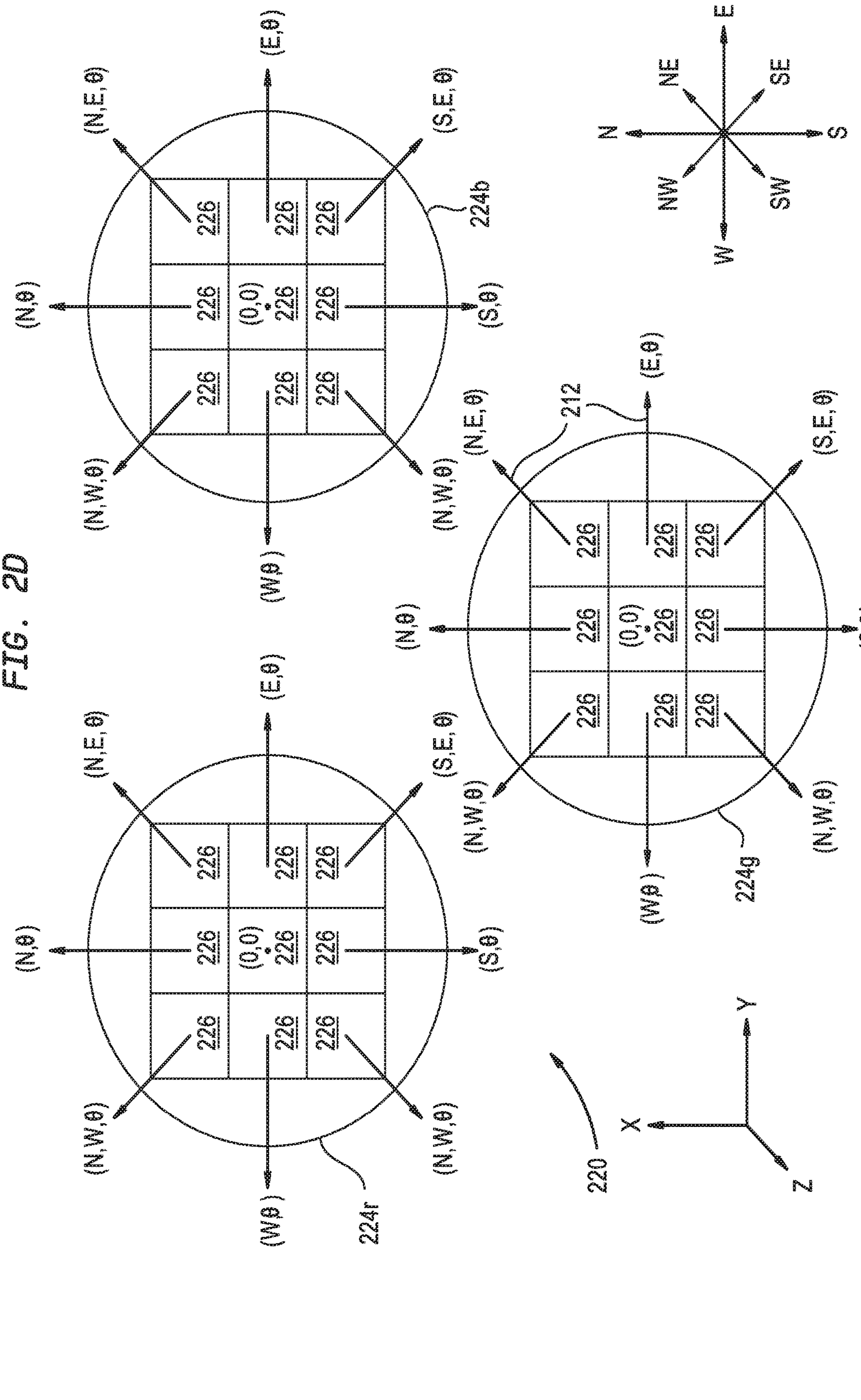

(N,θ)
(N,E,θ)
(E,θ)
(S,E,θ)
(S,θ)
(N,W,θ)
(Wθ)
226
(0,0)
224b
224r
224g
212
220
N
NE
E
SE
S
SW
W
NW
X
Y
Z

FIG. 2D

FIG. 3A

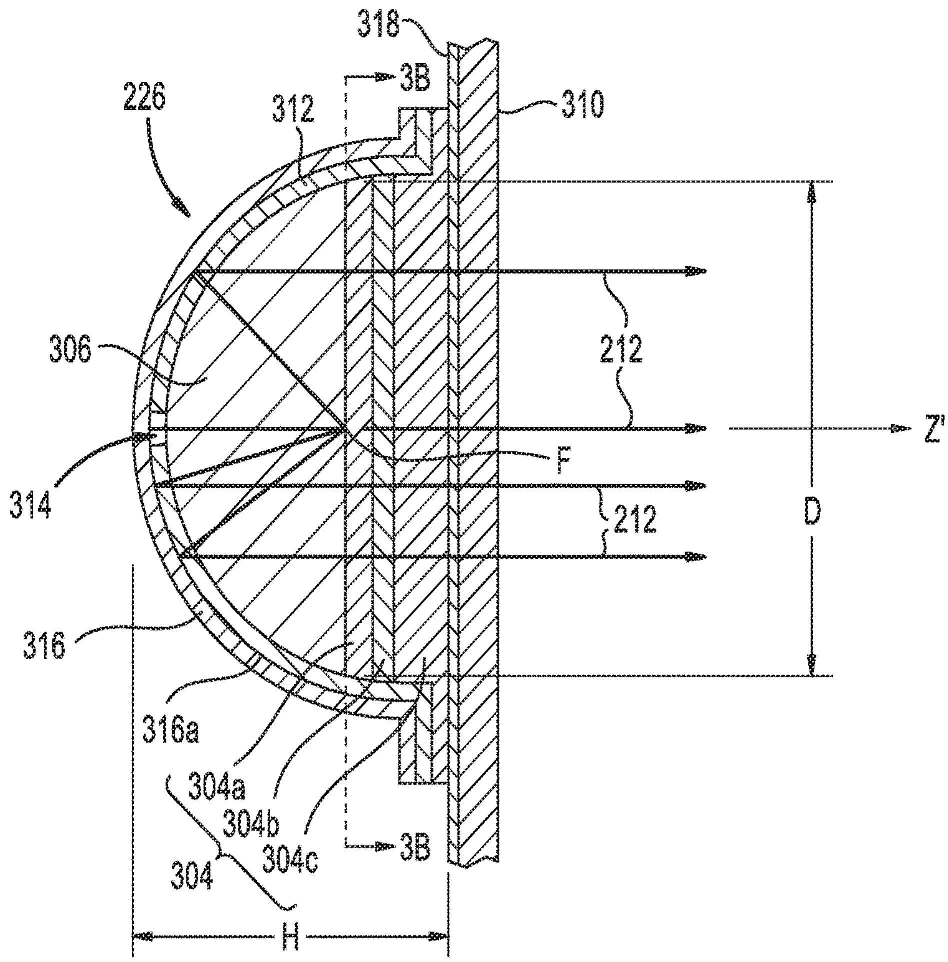

318
3B
226
312
310
306
212
Z'
F
314
212
D
316
316a
304a
304b
304c
3B
304
H

FIG. 3B

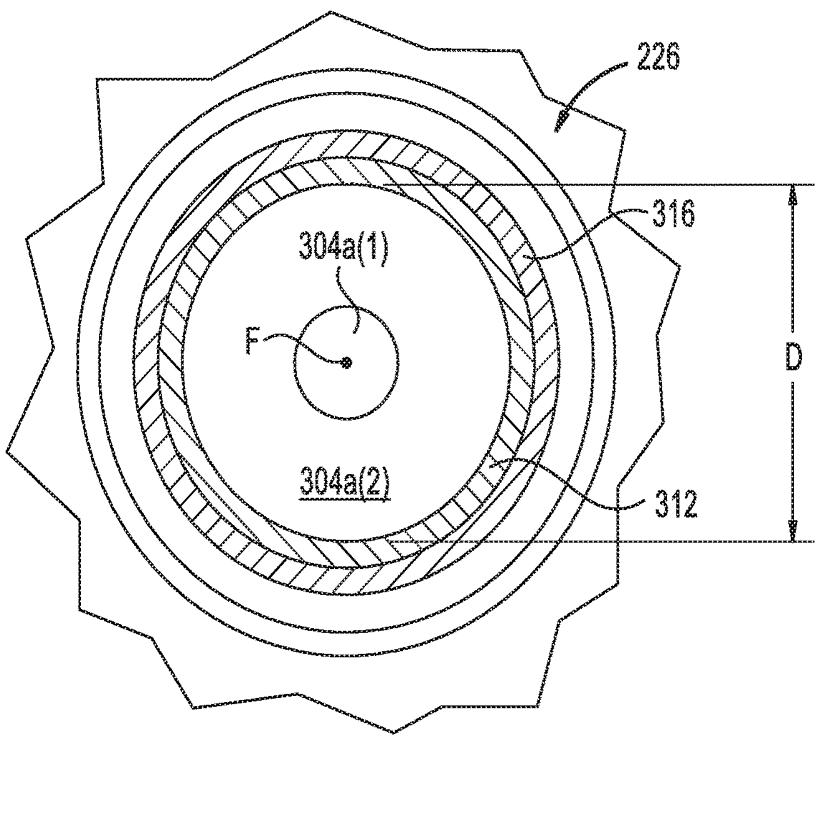

226
316
304a(1)
F
D
304a(2)
312

FIG. 4

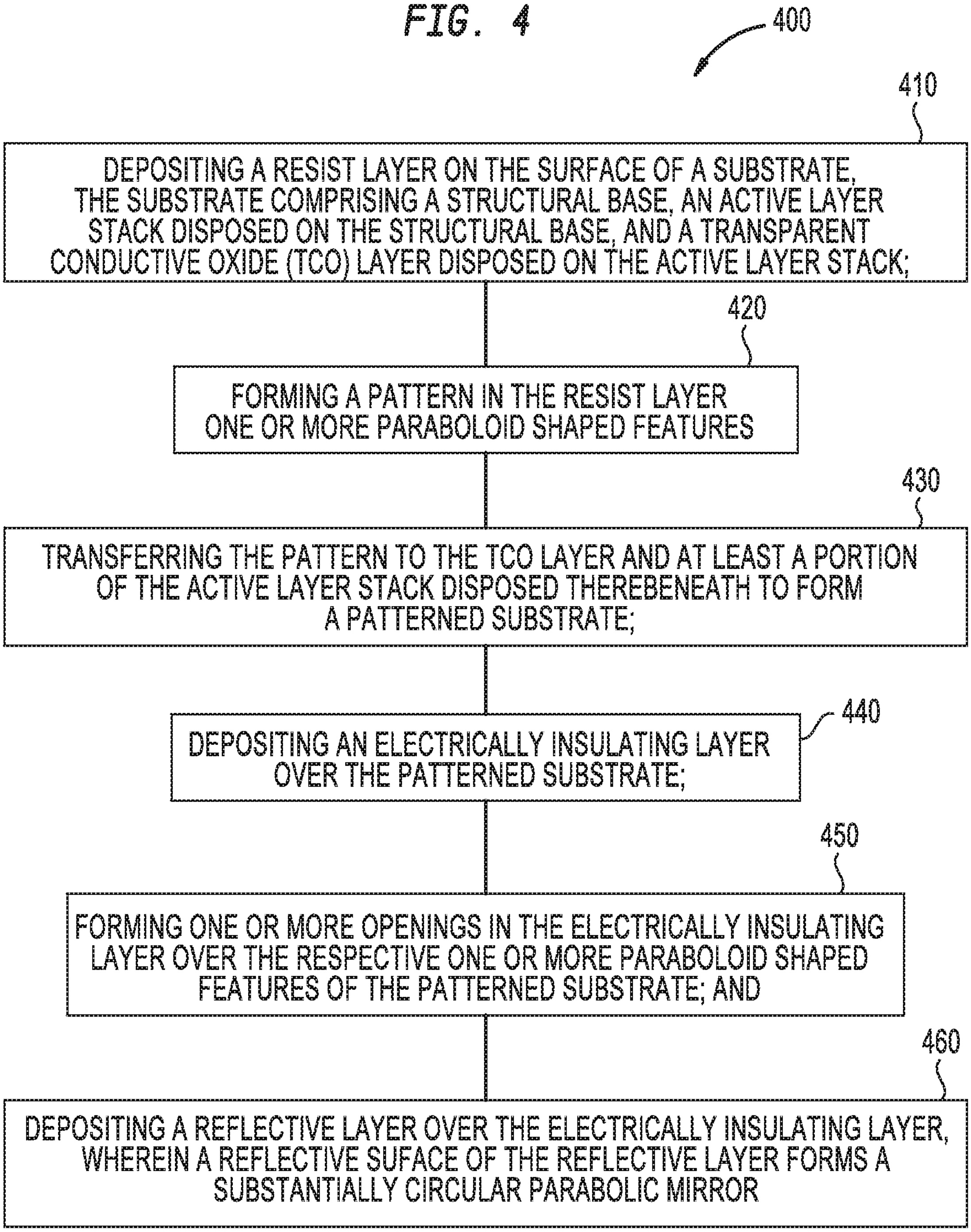

400
410
DEPOSITING A RESIST LAYER ON THE SURFACE OF A SUBSTRATE, THE SUBSTRATE COMPRISING A STRUCTURAL BASE, AN ACTIVE LAYER STACK DISPOSED ON THE STRUCTURAL BASE, AND A TRANSPARENT CONDUCTIVE OXIDE (TCO) LAYER DISPOSED ON THE ACTIVE LAYER STACK;
420
FORMING A PATTERN IN THE RESIST LAYER ONE OR MORE PARABOLOID SHAPED FEATURES
430
TRANSFERRING THE PATTERN TO THE TCO LAYER AND AT LEAST A PORTION OF THE ACTIVE LAYER STACK DISPOSED THEREBENEATH TO FORM A PATTERNED SUBSTRATE;
440
DEPOSITING AN ELECTRICALLY INSULATING LAYER OVER THE PATTERNED SUBSTRATE;
450
FORMING ONE OR MORE OPENINGS IN THE ELECTRICALLY INSULATING LAYER OVER THE RESPECTIVE ONE OR MORE PARABOLOID SHAPED FEATURES OF THE PATTERNED SUBSTRATE; AND
460
DEPOSITING A REFLECTIVE LAYER OVER THE ELECTRICALLY INSULATING LAYER, WHEREIN A REFLECTIVE SUFACE OF THE REFLECTIVE LAYER FORMS A SUBSTANTIALLY CIRCULAR PARABOLIC MIRROR

FIG. 5A

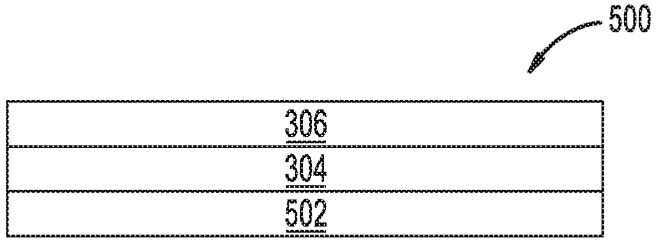


FIG. 5B

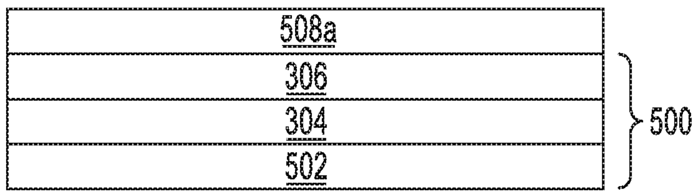


FIG. 5C

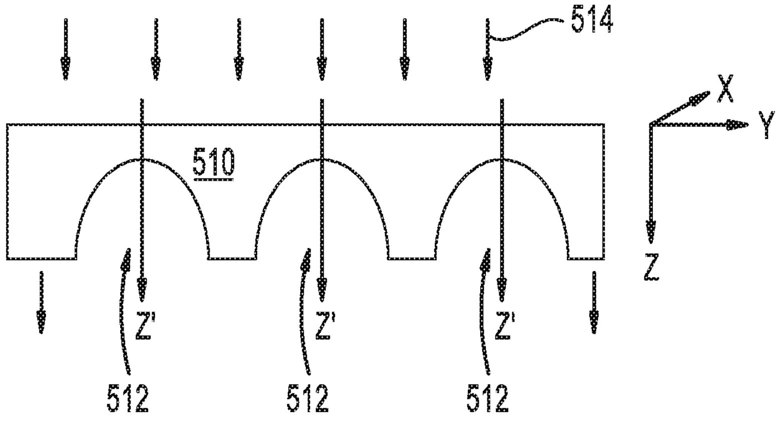


FIG. 5D

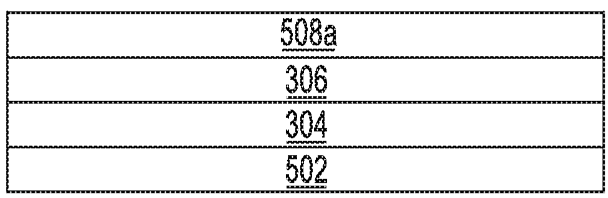


FIG. 5E

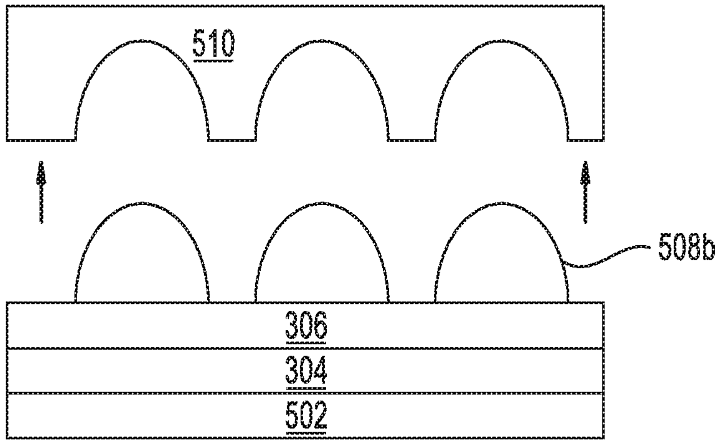


FIG. 5F

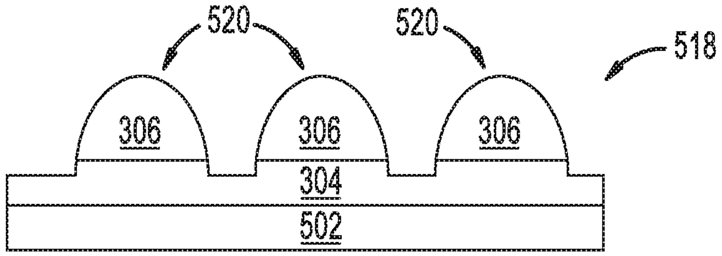


FIG. 5G

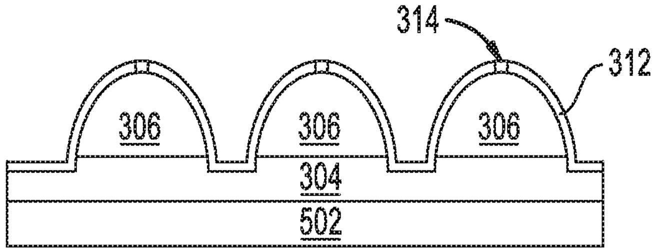


FIG. 5H

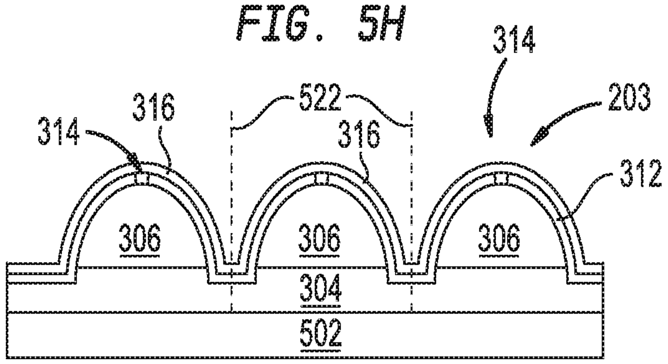
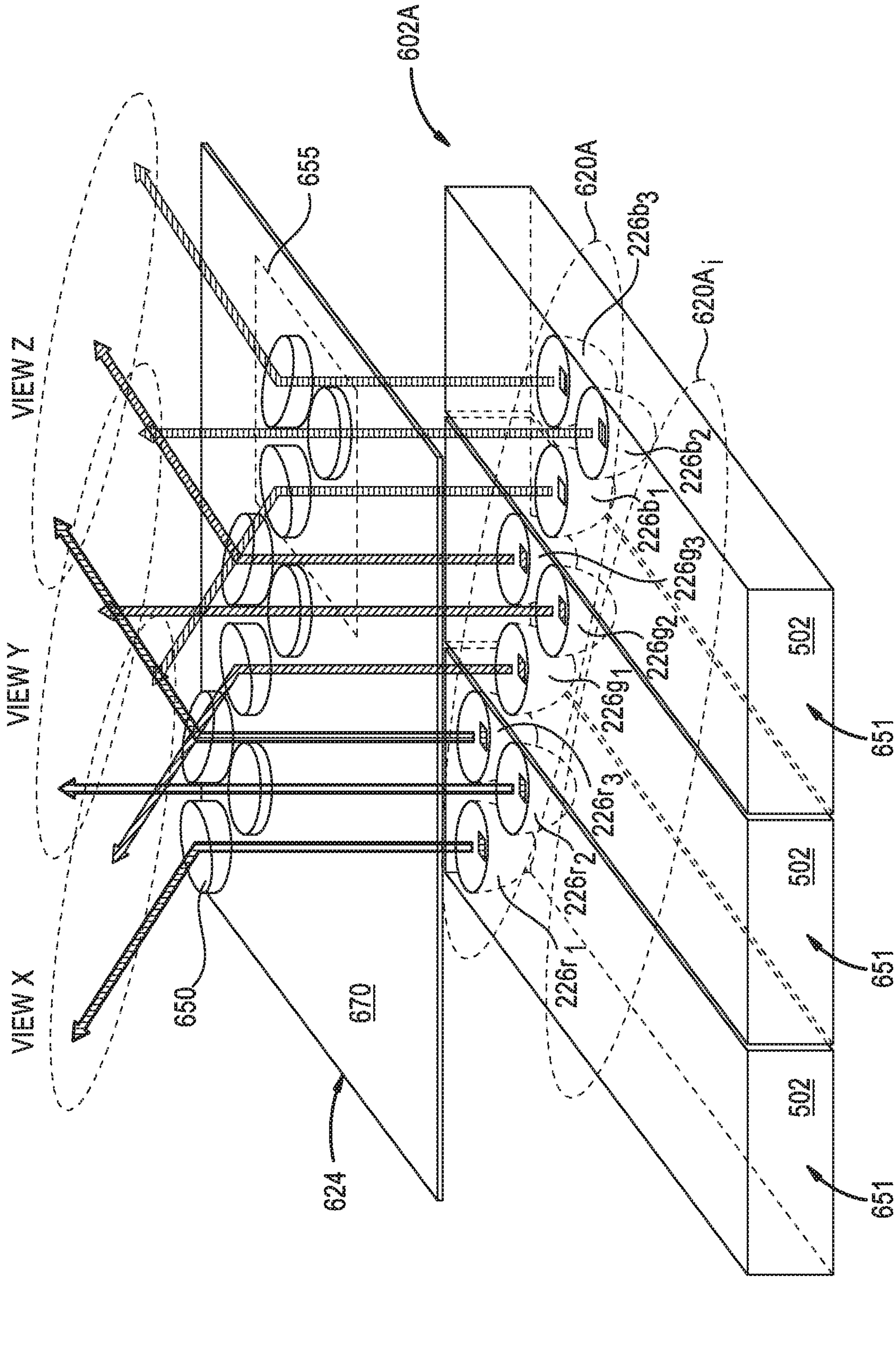
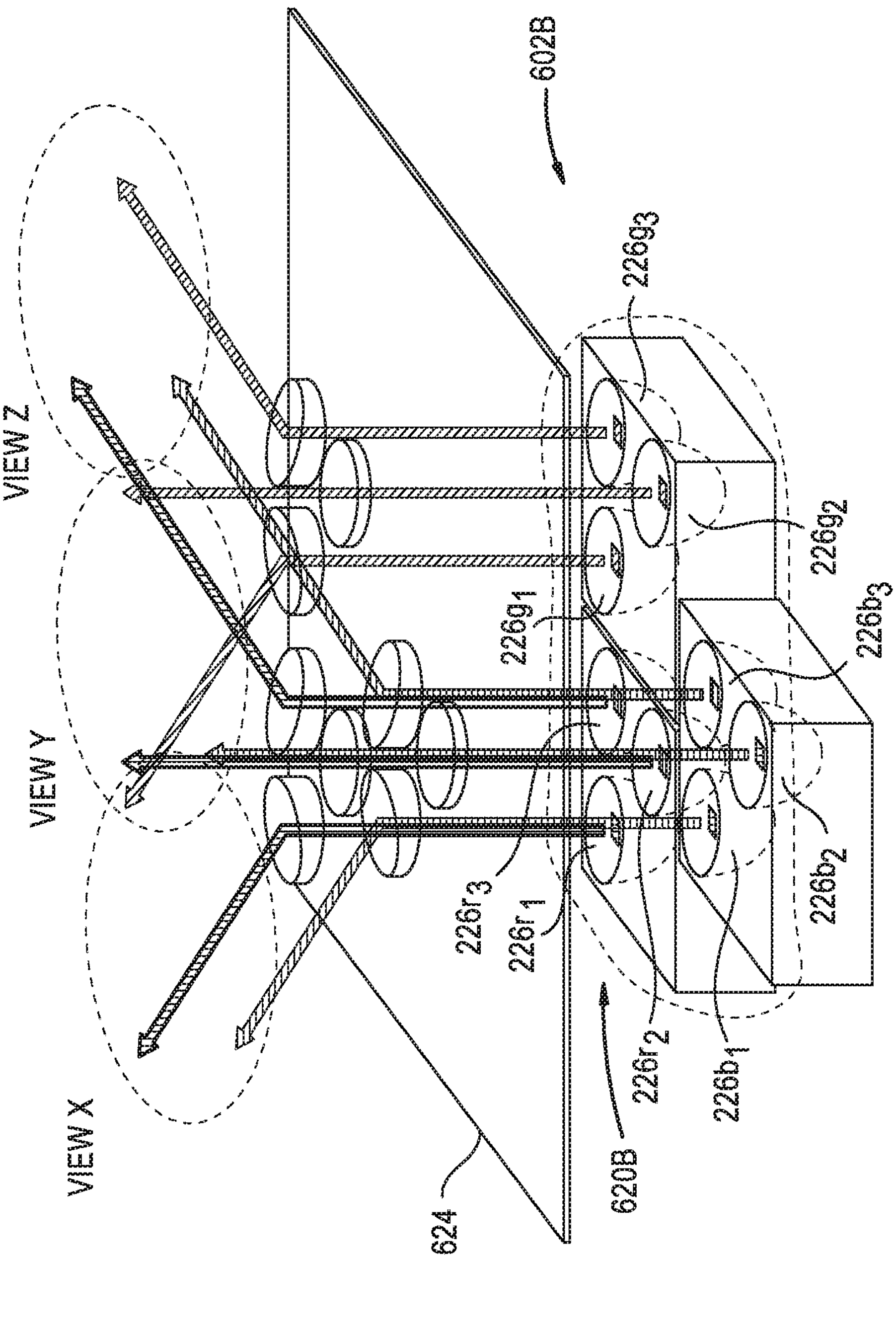


FIG. 6A



602A
VIEW X
VIEW Y
VIEW Z
655
620A
226b3
620A1
226b2
226b1
226g3
226g2
226g1
226r3
226r2
226r1
650
670
624
502
502
502
651
651
651

FIG. 6B



602B
VIEW Z
VIEW Y
VIEW X
226g3
226g2
226g1
226b3
226b2
226b1
226r3
226r1
226r2
620B
624

COLLIMATED LED LIGHT FIELD DISPLAY

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 15/837,654, filed on Dec. 11, 2017, now U.S. patent Ser. No. 10,256,382, issued on Apr. 9, 2019, which claims benefit of U.S. Provisional Patent Application Ser. No. 62/432,156, filed Dec. 9, 2016, both of which are herein incorporated by reference.

BACKGROUND

Field

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

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 FIG. **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.

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

SUMMARY

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.

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.

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

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.

FIG. **1** illustrates angular light information from the perspective of a viewer.

FIGS. **2**A-**2**C schematically illustrate a pixel arrangement of a display according to one aspect of the disclosure.

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

FIG. **3**A is a schematic cross-sectional view of an LED, according to one embodiment.

FIG. **3**B is a sectional view of a portion of the LED described in FIG. **3**A taken along line **3**B-**3**B of FIG. **3**A.

FIG. **4** is a flow diagram illustrating a method of forming an LED, according to one embodiment.

FIGS. **5**A-**5**H schematically illustrate formation of an LED according to the method described in FIG. **4**.

FIGS. **6**A and **6**B are schematic illustrations of pixel arrangements, according to other embodiments.

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

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.

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

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 **224***r*, **224***b*, **224***g*, under which a plurality of plurality of collimated (LEDs), such as collimated micro-LEDs, **226** are positioned. In the example shown, the micro-lenses **224***r*, **224***b*, **224***g* 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.

Beneath each micro-lenses **224***r*, **224***b*, **224***g* is a plurality of collimated LEDs **226** (two are labeled in FIG. **2**C) configured to emit light of a desired wavelength. While only micro-lens **224***r* is shown in FIG. **2**C, it is to be understood that micro-lenses **224***b* and **224***g* are similarly configured. In one example, the LEDs **226** beneath the micro-lens **224***r* are configured to emit red light, the LEDs **226** beneath micro-lens **224***b* are configured to emit green light, and the LEDs **226** beneath micro-lens **224***b* are configured to emit blue light. Stated otherwise, each group of LEDs **226** under a respective micro-lens **224***r*, **224***b*, **224***g*, 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 **203***b* generate light having wavelengths in the range between about 450 nm and about 495 nm.

For purposes of this disclosure, each group of three or more micro-lenses **224***r*, **224***b*, **224***g*, and the LEDs **226** associated therewith, constitute a pixel **220**, configured to emit RGB light. Each micro-lens **224***r*, **224***b*, **224***g* 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 **224***r*, **224***b*, **224***g*. 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 **224***r*, **224***b*, **224***g* 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**.

In one example, the light field display **200** includes 1920×1080 pixels **220**. Each pixel **220** includes micro-lenses **224***r*, **224***b*, **224***g*, each having 24 LEDs **226** corresponding thereto. Thus, each pixel **220** has an angular resolution of 24, generating an effective light field resolution of 46080×25920 for the light field display **200**. It is contemplated that more or less than 24 LEDs **226** may be positioned beneath each micro-lens **224***r*, **224***b*, **224***g*, or that more or less than 1902×1080 pixels **220** may be utilized in the light field display **200**.

The LEDs **226** are positioned in a "stepped diamond" configuration beneath each micro-lens **224***r*, **224***b*, **224***g*. 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.

The micro-lenses **224***r*, **224***b*, **224***g* 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 **224***r*, **224***b*, **224***g* 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 **224***r*, **224***b*, **224***g*, as described with respect to FIG. **2**D.

FIG. **2**D illustrates the directional components of light exiting micro-lenses **224***r*, **224***b*, **224***g* of a pixel **220**. To facilitate explanation, only nine LEDs **226** are shown adjacent each micro-lens **224***r*, **224***b*, **224***g* (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.

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 **224***r*, **224***b*, **224***g*, the light form 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 **224***r*, **224***b*, **224***g* are configured to direct light (indicated by **212**, two are marked) in a direction measured with respect to the deviation, here angle θ, 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 θ) 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**.

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 θ (in a respective directional component). It is contemplated, however, that in some instances, angle θ 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 θ_1, different than angle θ, in order to provide additional angular resolution. In such an example, the LEDs **226** having light directed at angle θ_1 may be positioned radially outward of the LEDs **226** having light directed at angle θ. In such an example, angle θ_1 is greater than angle θ. It is to be noted that additional LEDs **226** having light directed at angle θ_2, angle θ_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 θ (or angle θ_1, angle θ_2, etc.) is determined by the characteristics of a respective micro-lens **224***r*, **224***b*, **224***g*.

In a specific example of the above embodiment, a first LED **226** positioned centrally beneath a respective micro-lens **224***r*, **224***b*, **224***g* has light directed in the Z direction by a respective micro-lens **224**r, **224**b, **224**g. A plurality of LEDs **226**, spaced equidistant and radially outward from the first LED **226**, have light directed by a respective micro-lens **224**r, **224**b, **224**g at angle θ (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 **224**r, **224**b, **224**g at angle θ_1 (in a corresponding compass direction). Additional LEDs **226**, having lighted directed at additional angles θ_i, may be further included to provide additional angular resolution.

Returning to FIG. **2**D, to facilitate generation of an image, each LED **226** under the micro-lens **224**r is operable with and corresponds to an LED **226** at a corresponding location under micro-lens **224**b and micro-lens **224**g. For example, the LED **226** under micro-lens **224**r which directs a light ray **212** toward (NW, θ) corresponds to the LEDs **226** under micro-lens **224**b and micro-lens **224**g which also direct a light ray **212** toward (NW, θ), 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 **224**r, **224**b, **224**g, 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.

While FIG. **2**D 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.

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

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, AlGaInP, or combinations thereof, and includes a p-type layer **304**a, an n-type layer **304**c, and one or more quantum well (QW) layers **304**b interposed between the p-type layer **304**a and the n-type layer **304**c. 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.

The LED **226** is mounted to a display panel **310** of a light field display **200** (shown in FIG. **2**A), in a desired pixel arrangement **202** (shown in FIG. **2**A), 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 100 nm, 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**.

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 **316**a 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 **304**a. 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.

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).

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 μm, such as less than about 50 μm, less than about 20 μm, less than about 10 μm, for example less than about 5 μm, or between about 0.1 μm and about 10 μm, such as between about 0.5 μm and about 10 μm, for example between about 0.5 μm and about 5 μm. 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.

In some embodiments, portions of the surface of the p-type layer **304**a are selectively treated, for example plasma treated, to desirably form a non-or-low-light transmission region **304**a(**2**) circumscribing a light transmission region **304**a(**1**). Plasma treating the surface of the p-type layer in the non-or-low-light transmission region **304**a(**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 **304**a(**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 **316**a is in substantially the same direction as the Z-direction.

FIG. **4** is a flow diagram illustrating a method **400** of forming an LED **226**, according to one embodiment. FIGS.

5A-5H schematically illustrate formation of an LED according to the method described in FIG. 4.

The method 400 includes depositing a resist layer, such as the resist layer 508 shown in FIG. 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.

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 508*b* 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 508*b* 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 508*b* is formed using a grey-scale lithography process. In some other embodiments, the patterned resist layer 508*b* 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.

At activity 430, the method 400 further includes transferring the pattern formed in the patterned resist layer 508*b* 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 FIG. 5F. In FIG. 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.

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 FIG. 3.

In some embodiments, the method 400 includes dicing the one or more LEDs 226 along the dicing lines 522 shown in FIG. 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 FIG. 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.

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 224*r*, 224*b*, 224*g*. In one example, LEDs 226 may be arranged on and coupled to a display panel 310 (shown in FIG. 3A) in a pixel arrangement 202 (shown in FIG. 2A).

FIGS. 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 FIG. 2A.

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 $226r_{(1, 2, 3)}$, a plurality of green LEDs $226g_{(1, 2, 3)}$, and a plurality of blue LEDs $226b_{(1, 2, 3)}$, 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 $226r_{(1, 2, 3)}$, the green LEDs $226g_{(1, 2, 3)}$, and the blue LEDs $226b_{(1, 2, 3)}$ in predetermined directions, with corresponding LEDs having light directed in a same angular direction. For example, LEDs $226r_1$, $226g_1$, and $226b_1$ are directed by the micro-lens array 624 in a same direction to generate a first angular resolution ("View X"). Similarly, corresponding LEDS $226r_2$, $226g_2$, and $226b_2$, as well as corresponding LEDS $226r_3$, $226g_3$, and $226b_3$ 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 $226r_i$, $226b_i$, $226g_i$ 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 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.

While only one pixel 620A is shown, the pixel arrangement 602A generally includes a plurality of pixels $620A_i$, arranged in array. To facilitate ease of manufacturing, LEDs $226r_i$, $226b_i$, $226g_i$ 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.

The example of FIG. **6**A utilizes a single (unitary) micro-lens array **624** (covering all pixels **620**A_i), 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**.

While FIG. **6**A 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 **620**A, as similarly shown with respect to FIG. **2**B. In such an example, the plurality of convex or concave lenses may be formed on the substrate panel **670**, or may be discrete units.

FIG. **6**B illustrates a pixel arrangement **602**B. The pixel arrangement **602**B is similar to the pixel arrangement **602**A, but rather than linear strips **651**, the pixel arrangement **602**B utilizes pixels **620**B in clusters. In a specific example, the clusters have a triangular arrangement, as similarly shown and described with respect to FIG. **2**C. 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.

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.

Benefits of the disclosed subject matter include increased resolution compared to conventional displays.

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 method of forming a light field display, comprising:
forming a plurality of light emitting diodes from a patterned substrate, comprising:
depositing a resist layer on a surface of a substrate, the substrate comprising:
a structural base;
an active layer stack disposed on the structural base; and
a transparent conductive oxide layer disposed on the active layer stack;
patterning the resist layer; and
transferring the pattern formed in the resist layer to the transparent conductive oxide layer and to at least a portion of the active layer stack disposed therebeneath to form the patterned substrate; and
arranging one or more of the plurality of light emitting diodes beneath a light-directing feature of a plurality of light-directing features formed on a substrate panel, wherein each of the light-directing features and at least one of the one or more light emitting diodes positioned there beneath forms a pixel of angular resolution of the light field display.

2. The method of claim **1**, wherein the active layer stack is formed of one or a combination of III-V materials.

3. The method of claim **1**, wherein a surface of the active layer stack which is proximate to the transparent conductive oxide layer has a diameter less than about 100 μm.

4. The method of claim **1**, wherein patterning the resist layer comprises one or a combination of an imprint lithography process or a grey-scale lithography process.

5. The method of claim **4**, wherein patterning the resist layer comprises pressing an imprint lithography stamp thereinto, the imprint lithography stamp comprising a plurality of paraboloid shaped openings formed in a surface thereof.

6. The method of claim **5**, wherein the imprint lithography stamp is transparent to electromagnetic radiation and patterning the resist layer comprises exposing the resist layer to electromagnetic radiation through the imprint lithography stamp.

7. The method of claim **6**, further comprising depositing an electrically insulating layer over the patterned substrate.

8. The method of claim **7**, further comprising:
forming a plurality of openings in through respective portions of the electrically insulating layer disposed over individual ones of the paraboloid shaped features; and
depositing a reflective layer over the electrically insulating layer.

9. The method of claim **8**, wherein the electrically insulating layer is formed of a transparent dielectric material.

10. The method of claim **8**, wherein a reflective surface of the reflective layer forms a substantially circular parabolic mirror.

11. The method of claim **1**, wherein the active layer stack comprises a p-type layer, an n-type layer, and one or more quantum well layers interposed between the p-type layer and the n-type layer.

12. The method of claim **1**, further comprising dicing the light emitting diodes formed on the patterned substrate into individual ones or groups before arranging one or more of the plurality of light emitting diodes beneath a light-directing feature of the plurality of light-directing features.

13. The method of claim **1**, wherein the light field display comprises a plurality of pixels of spatial resolution each comprising a plurality of the pixels of angular resolution.

14. The method of claim **13**, wherein a pixel of spatial resolution comprises light emitting diodes of different colors, and wherein groups of light emitting diodes that will emit the same color of light are arranged in linear strips or clusters.

15. A method of forming a light field display, comprising:
forming a plurality of light emitting diodes from a patterned substrate, comprising:
depositing a resist layer on a surface of a substrate, the substrate comprising:
a structural base;
an active layer stack disposed on the structural base; and
a transparent conductive oxide layer disposed on the active layer stack;
patterning the resist layer to form a plurality of paraboloid shaped features;
transferring the pattern formed in the resist layer to the transparent conductive oxide layer and to at least a

portion of the active layer stack disposed therebeneath to form the patterned substrate;

depositing an electrically insulating layer over the patterned substrate;

forming a plurality of openings in through respective portions of the electrically insulating layer disposed over individual ones of the paraboloid shaped features; and

depositing a reflective layer over the electrically insulating layer; and

arranging one or more of the light emitting diodes beneath a light-directing feature of a plurality of light directing features formed on a substrate panel, wherein each of the light-directing features and the one or more light emitting diodes positioned there beneath forms a pixel of angular resolution of the light field display.

16. The method of claim **15**, wherein

the active layer stack is formed of one or a combination of III-V materials,

the electrically insulating layer is formed of a transparent dielectric material, and

a surface of the active layer stack proximate to the transparent conductive oxide layer has a diameter less than about 100 μm.

17. The method of claim **15**, wherein patterning the resist layer comprises one or a combination of an imprint lithography process or a grey-scale lithography process.

18. The method of claim **15**, wherein patterning the resist layer comprises pressing an imprint lithography stamp there into, the imprint lithography stamp comprising a plurality of paraboloid shaped openings formed in a surface thereof.

19. The method of claim **18**, wherein the imprint lithography stamp is transparent to electromagnetic radiation and patterning the resist layer comprises exposing the resist layer to electromagnetic radiation through the imprint lithography stamp.

20. A method of forming a light field display, comprising:

arranging one or more of a plurality of light emitting diodes beneath a light-directing feature of a plurality of light directing features formed on a substrate panel, wherein each of the light-directing features and one or more of the light emitting diodes positioned there beneath forms a pixel of angular resolution of the light field display, and wherein one or more of the plurality of light emitting diodes comprises:

an active layer stack;

a transparent conductive oxide (TCO) layer disposed on the active layer stack, wherein the transparent conductive oxide (TCO) layer and at least a portion of the active layer stack form a substantially circular paraboloid shape;

an electrically insulating layer disposed on the transparent conductive oxide (TCO) layer, the electrically insulating layer having an opening formed therein; and

a reflective layer disposed on the electrically insulating layer, wherein the reflective layer comprises the reflective surface formed to collimate light emitted by the active layer stack and to direct the collimated light towards the light directing feature positioned there above.

* * * * *

专利名称(译)	准直的LED光场显示		
公开(公告)号	[US10559730](US10559730)	公开(公告)日	2020-02-11
申请号	US16/369574	申请日	2019-03-29
[标]申请(专利权)人(译)	应用材料股份有限公司		
申请(专利权)人(译)	APPLIED MATERIALS，INC.		
当前申请(专利权)人(译)	APPLIED MATERIALS，INC.		
[标]发明人	THOTHADRI MANIVANNAN BENCHER CHRISTOPHER DENNIS VISSER ROBERT JAN WHITE JOHN M		
发明人	THOTHADRI, MANIVANNAN BENCHER, CHRISTOPHER DENNIS VISSER, ROBERT JAN WHITE, JOHN M.		
IPC分类号	H01L33/58 G02B19/00 G02B5/04 G02B3/00 G02B17/00 H04N13/307 H01L27/15 H01L25/065		
CPC分类号	H01L27/156 H04N13/307 H01L33/58 H01L25/0655 G02B17/002 G02B30/27 H01L2933/0058 G02B3/0056 G02B19/0061 G02B19/0028 G02B5/045		
优先权	15/837654 2019-04-09 US 62/432156 2016-12-09 US		
其他公开文献	US20190229246A1		
外部链接	Espacenet		

摘要(译)

本公开总体上涉及光场显示器以及利用光场阵列显示图像的方法。 在一个示例中，本公开涉及用于光场显示器中的像素布置。 每个像素包括位于每个像素的各个微透镜附近的多个LED，例如微型LED。