US010490599B2

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

(10) **Patent No.: US 10,490,599 B2**
(45) **Date of Patent: Nov. 26, 2019**

(54) **COLLIMATED, DIRECTIONAL MICRO-LED LIGHT FIELD DISPLAY**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 45 days.

(21) Appl. No.: **15/904,100**

(22) Filed: **Feb. 23, 2018**

(65) **Prior Publication Data**

US 2019/0019840 A1 Jan. 17, 2019

Related U.S. Application Data

(60) Provisional application No. 62/532,158, filed on Jul. 13, 2017.

(51) **Int. Cl.**
H01L 27/15 (2006.01)
G02B 27/22 (2018.01)
(Continued)

(52) **U.S. Cl.**
CPC ***H01L 27/156*** (2013.01); ***G02B 27/0983*** (2013.01); ***G02B 27/22*** (2013.01); ***H05B 33/0803*** (2013.01)

(58) **Field of Classification Search**
CPC ... H01L 27/156; H01L 33/58; H01L 25/0753; H01L 33/32; H01L 33/20; H01L 33/24;
(Continued)

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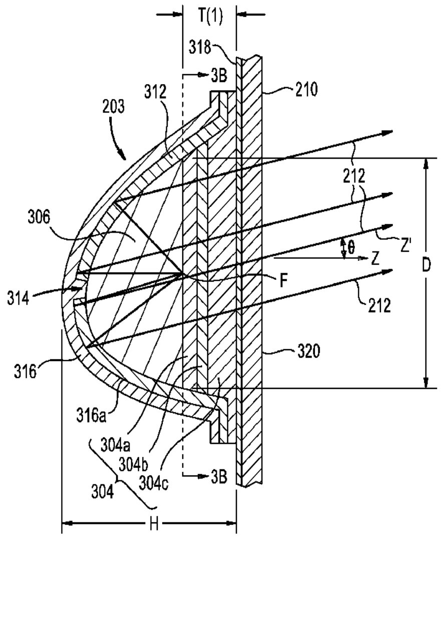
Primary Examiner — Koosha Sharifi-Tafreshi

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

(57) **ABSTRACT**

Embodiments described herein provide for light field displays and methods of forming light field displays where micro-LED arrays are each configured to provide at least a macro-pixel of effective native hardware resolution, where each macro-pixel provides single pixel of spatial resolution and plurality of pixels of angular resolution, and where each pixel of angular resolution includes a plurality of sub-pixels each provided by a directional collimating micro-LED device described herein.

11 Claims, 10 Drawing Sheets



(51) **Int. Cl.**
H05B 33/08 (2006.01)
G02B 27/09 (2006.01)

(58) **Field of Classification Search**
CPC G02B 27/2214; G02B 3/0056; G02B 27/0172; G02B 3/0006
See application file for complete search history.

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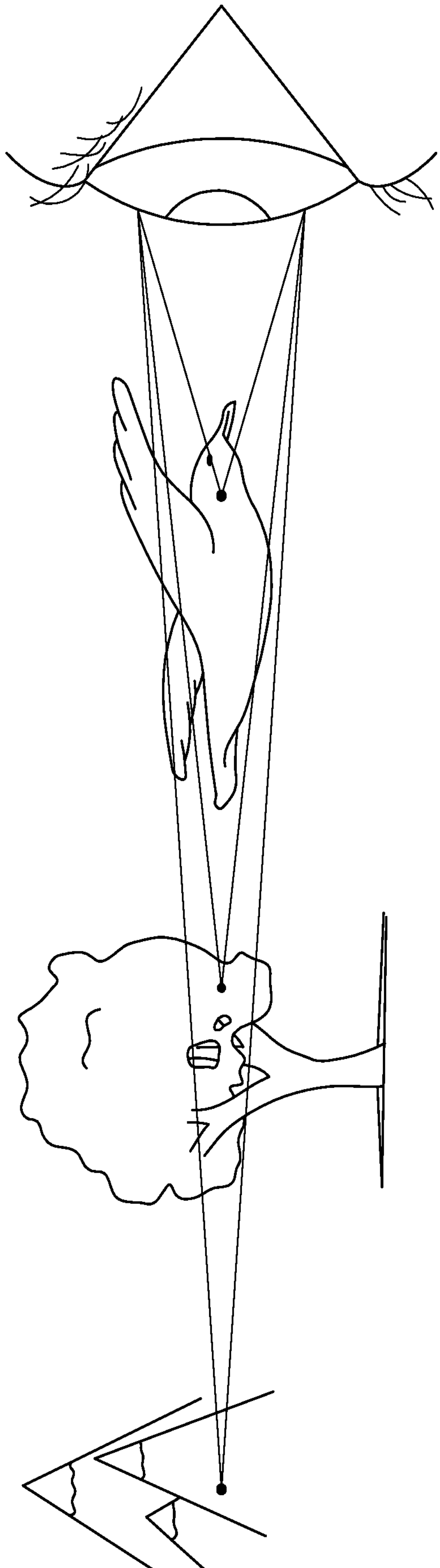


FIG. 1

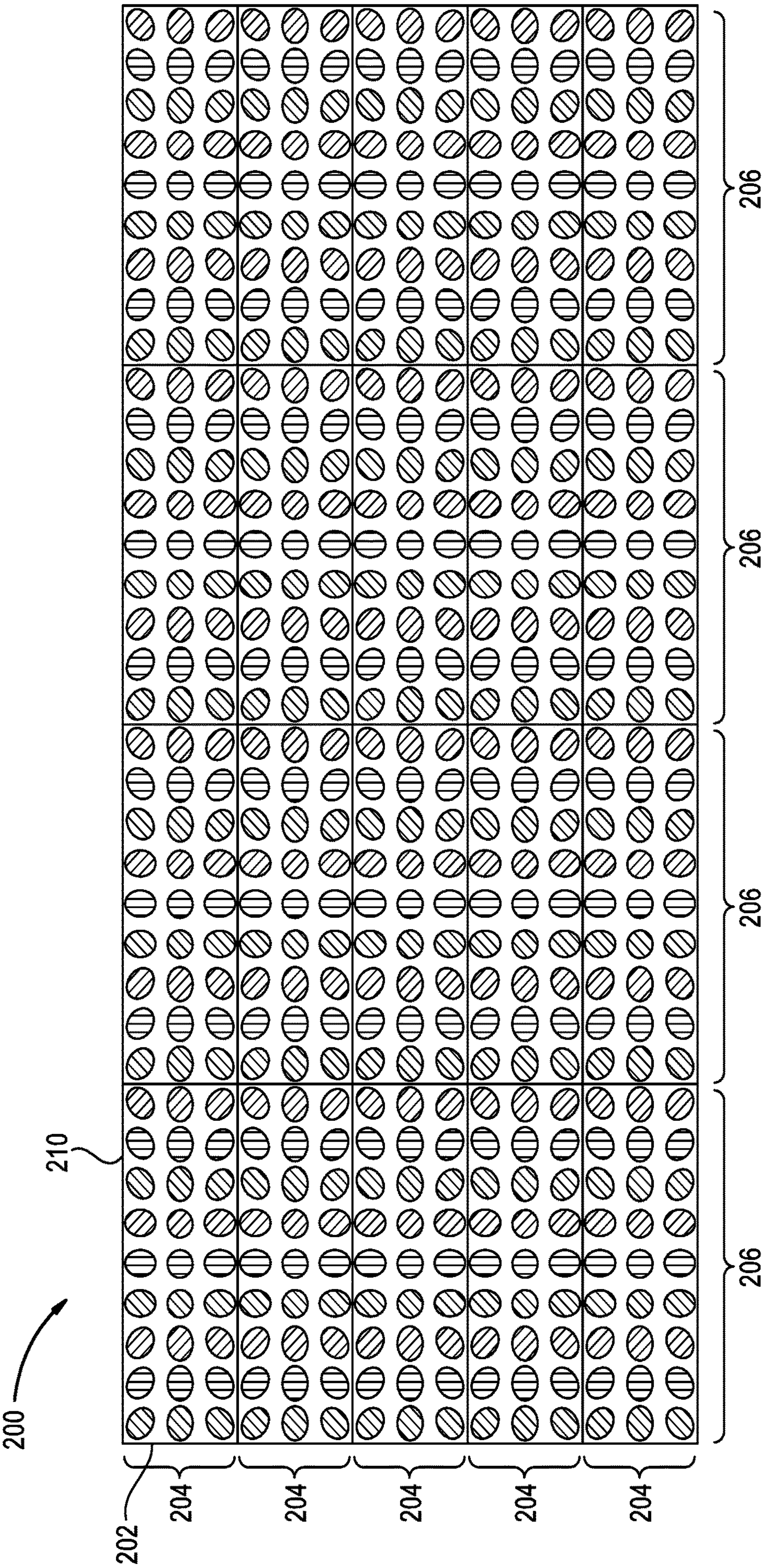
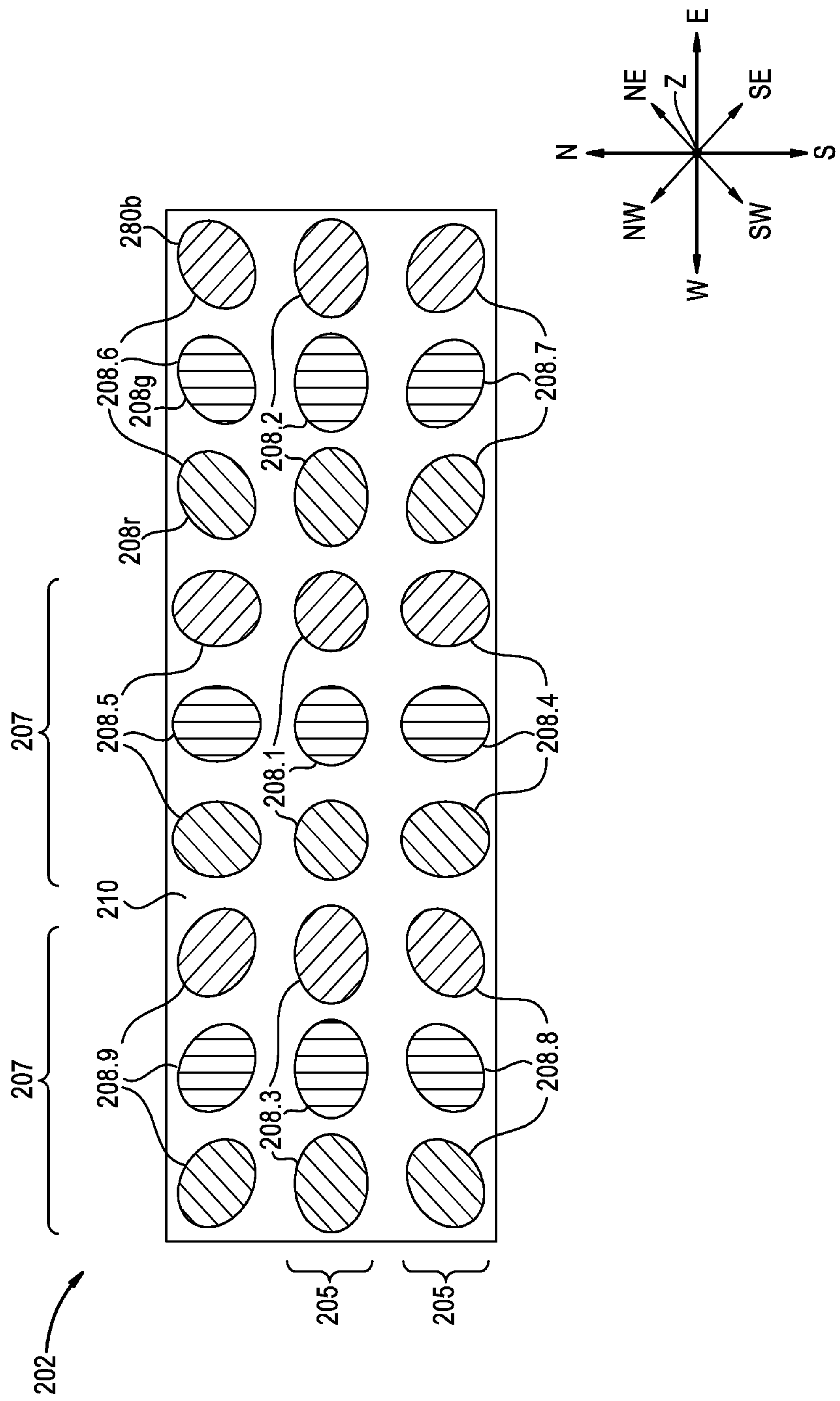


FIG. 2A

FIG. 2B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S
NW
SW
W
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208.6
208g
208.2
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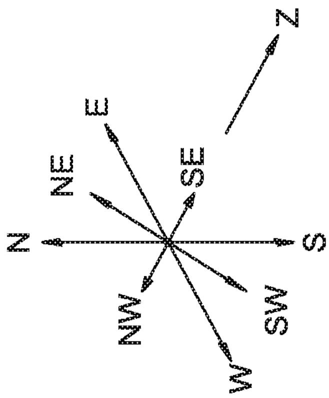
207
208.9
208.3
208.8
205
205
202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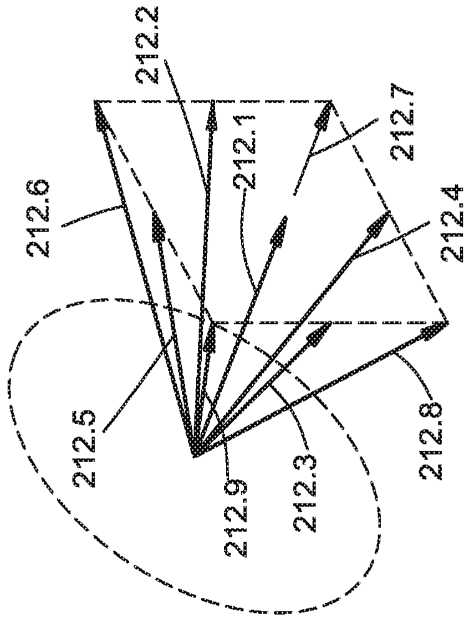
NW
Z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212.5
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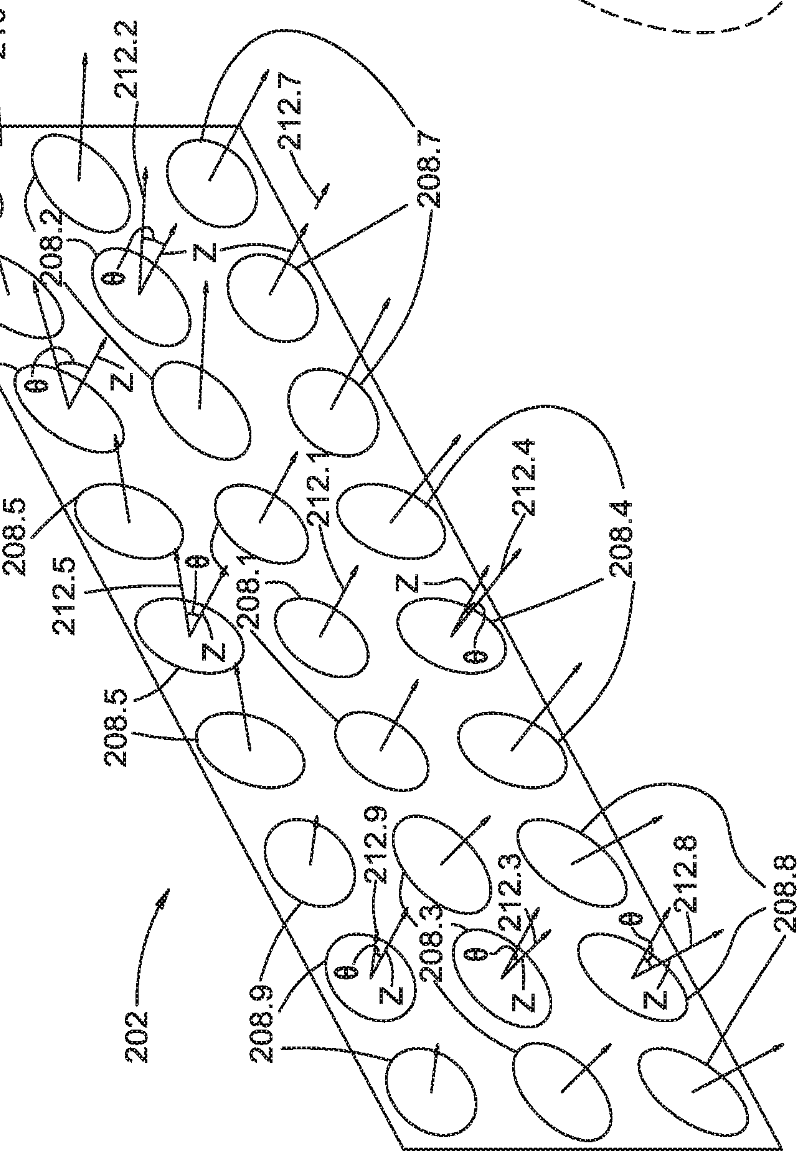
212.3
212.8

FIG. 2D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210
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212.6
208.2
212.2
212.7
208.7
Z
θ
208.5
212.5
208.1
212.1
212.4
208.4
208.9
212.9
208.3
212.3
212.8
208.8

FIG. 2C

FIG. 3A

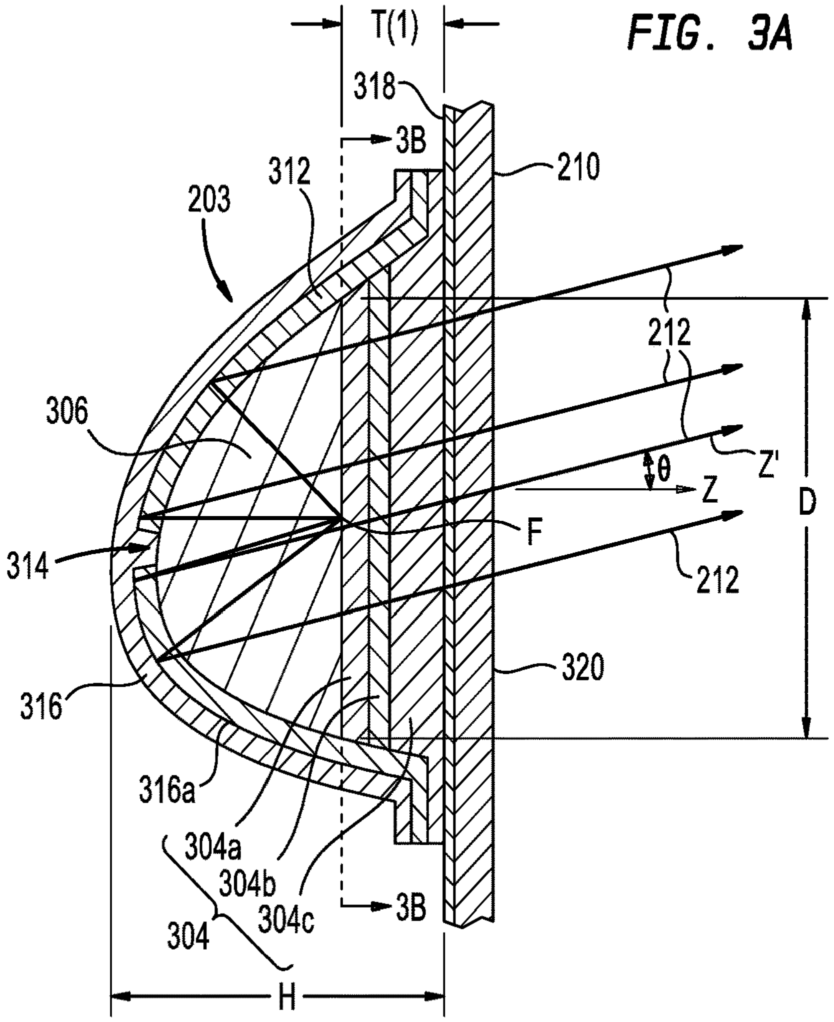

T(1)
318
3B
312
210
203
212
306
θ
Z'
Z
D
F
314
212
316
320
316a
304a
304b
304c
3B
304
H

FIG. 3B

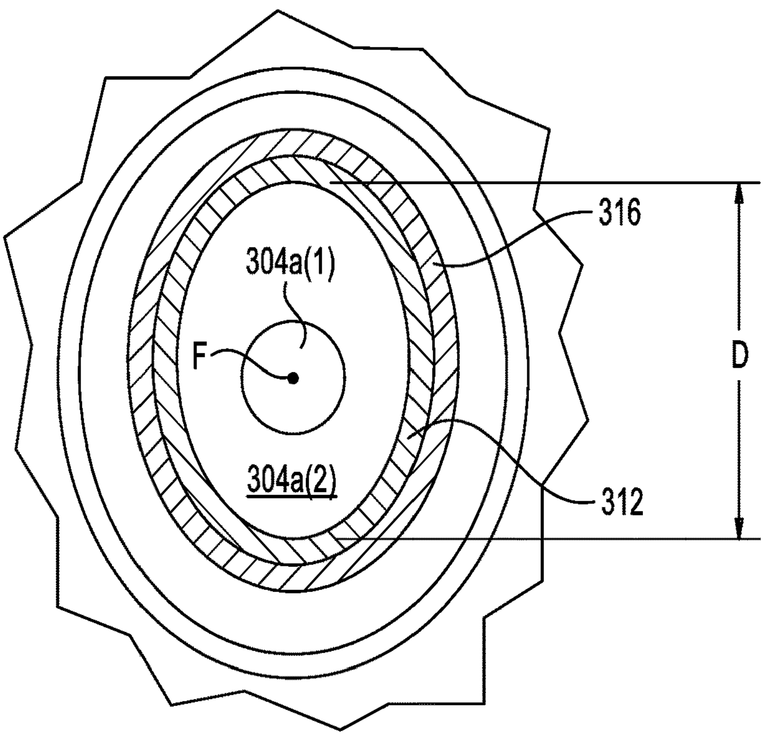
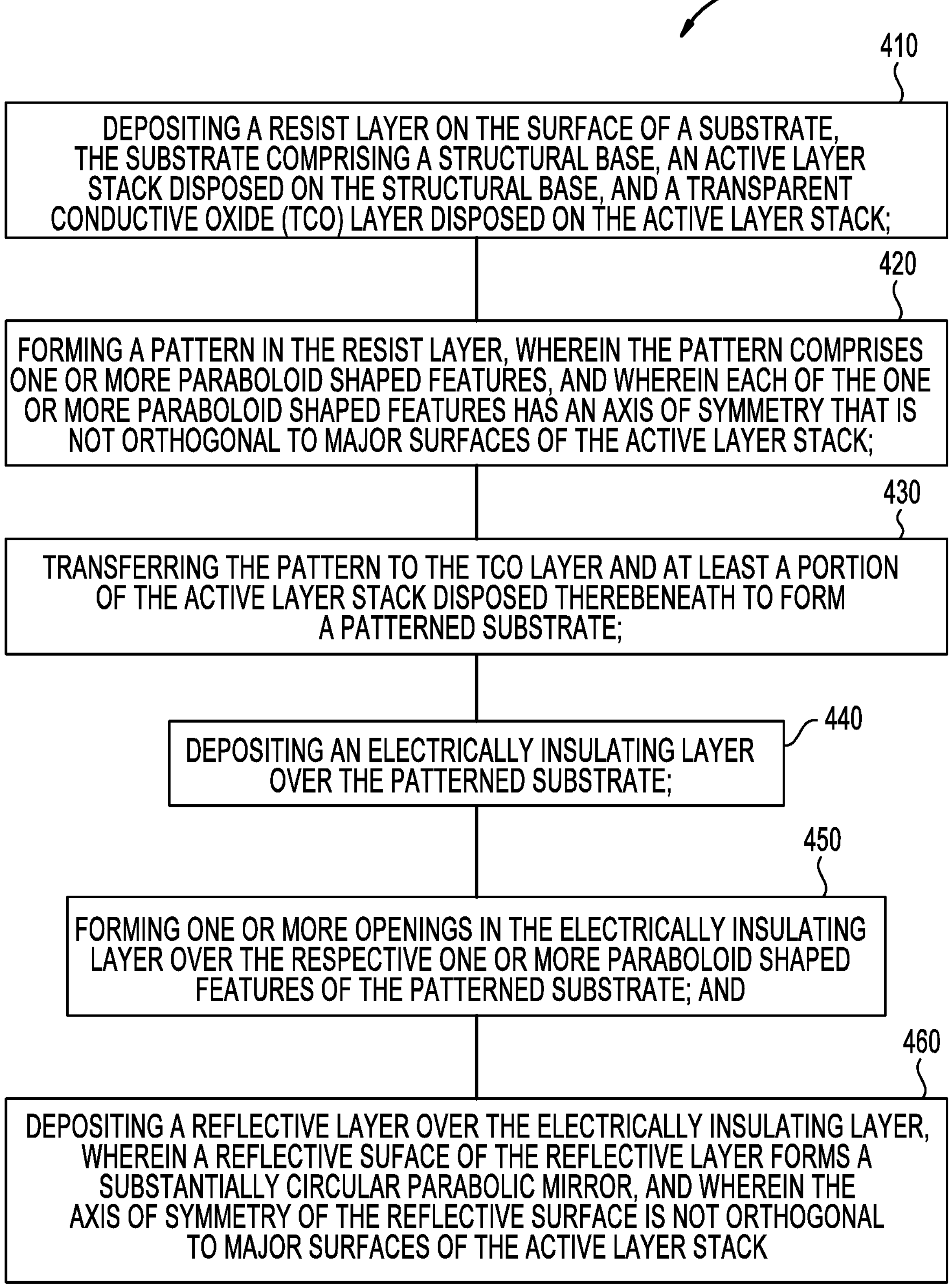

316
304a(1)
F
D
304a(2)
312

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, WHEREIN THE PATTERN COMPRISES ONE OR MORE PARABOLOID SHAPED FEATURES, AND WHEREIN EACH OF THE ONE OR MORE PARABOLOID SHAPED FEATURES HAS AN AXIS OF SYMMETRY THAT IS NOT ORTHOGONAL TO MAJOR SURFACES OF THE ACTIVE LAYER STACK;
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, AND WHEREIN THE AXIS OF SYMMETRY OF THE REFLECTIVE SURFACE IS NOT ORTHOGONAL TO MAJOR SURFACES OF THE ACTIVE LAYER STACK

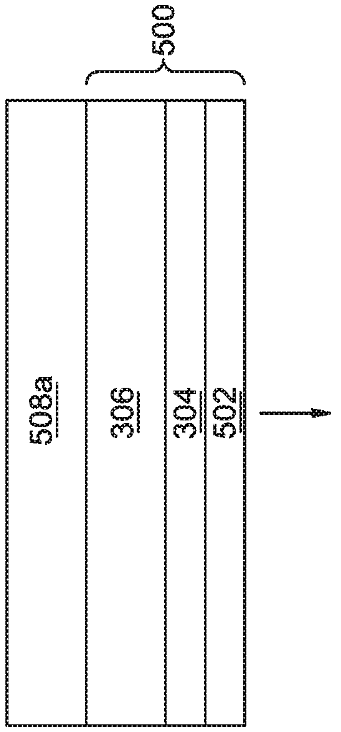


FIG. 5A

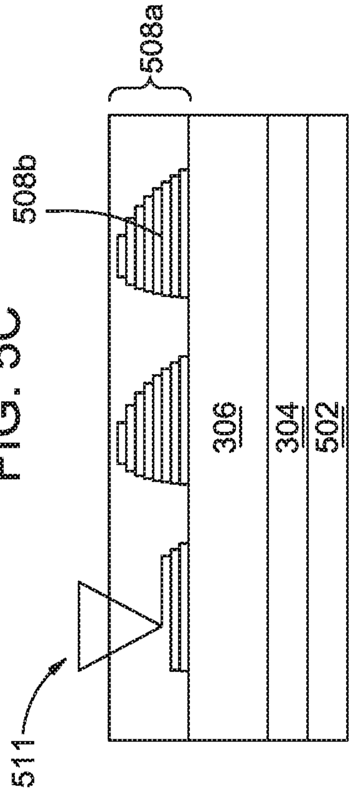


FIG. 5C

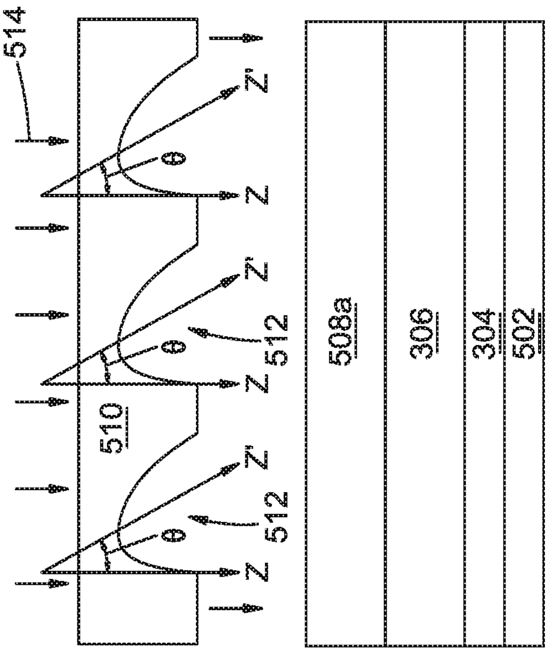


FIG. 5B

FIG. 5D

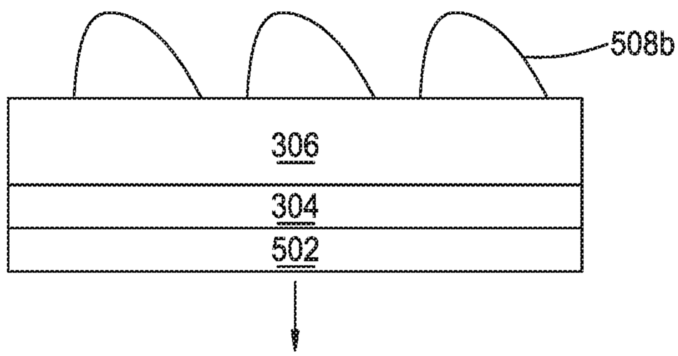


FIG. 5E

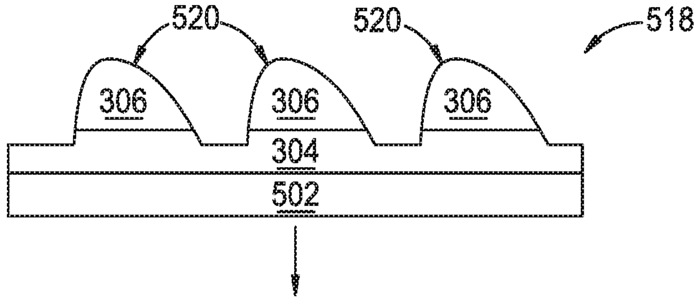


FIG. 5F

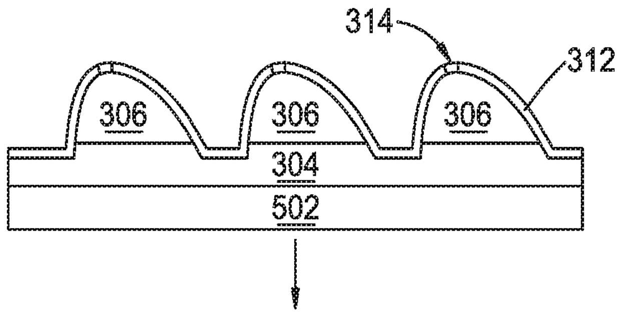


FIG. 5G

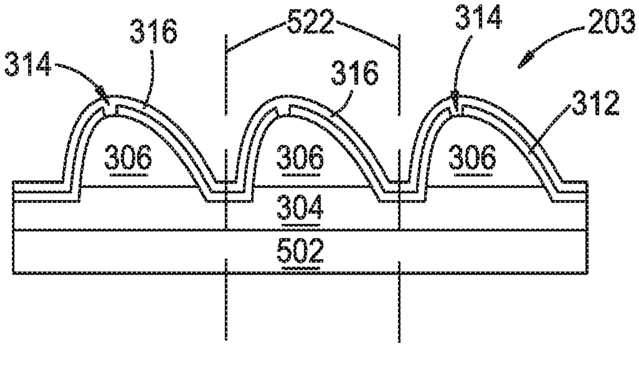


FIG. 6

600

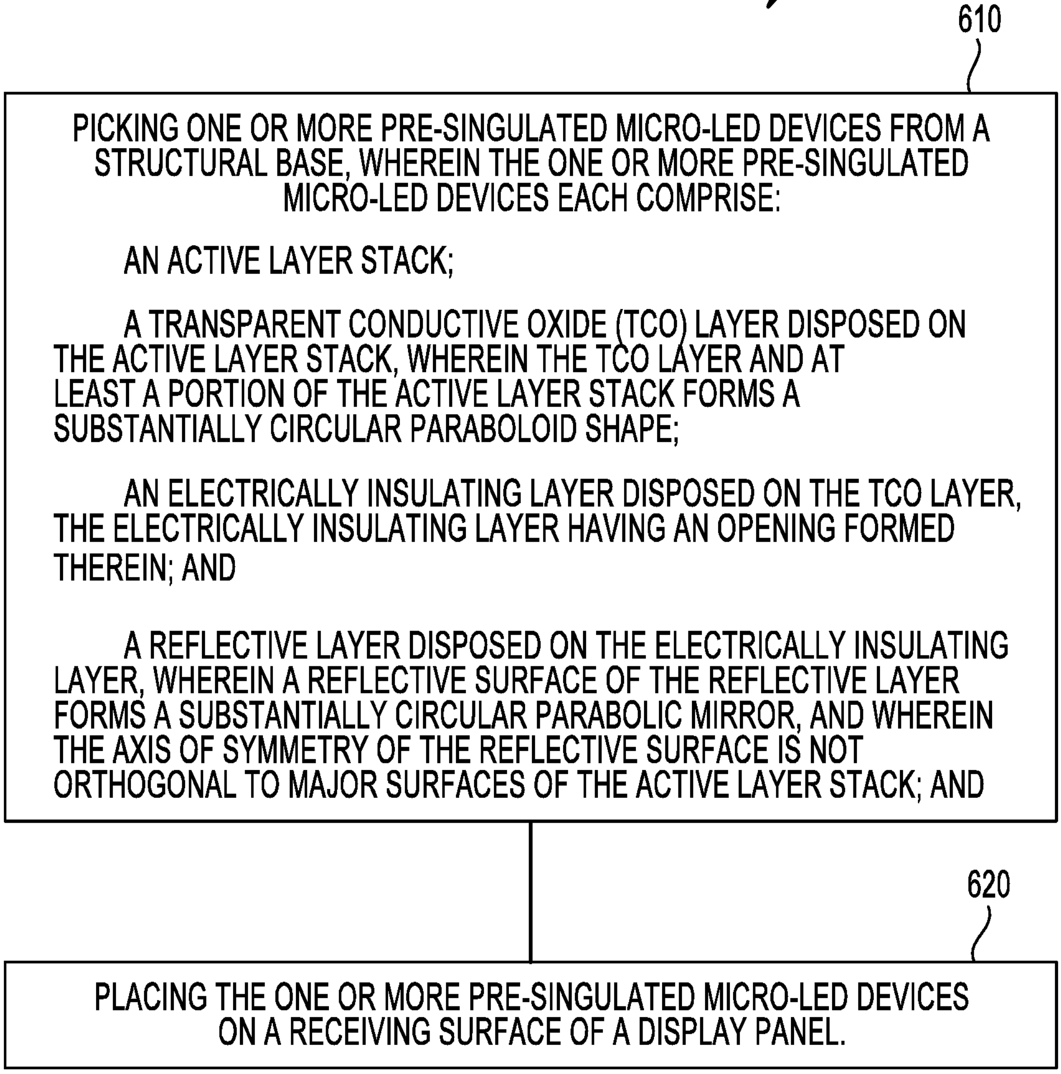

610
PICKING ONE OR MORE PRE-SINGULATED MICRO-LED DEVICES FROM A STRUCTURAL BASE, WHEREIN THE ONE OR MORE PRE-SINGULATED MICRO-LED DEVICES EACH COMPRISE:
AN ACTIVE LAYER STACK;
A TRANSPARENT CONDUCTIVE OXIDE (TCO) LAYER DISPOSED ON THE ACTIVE LAYER STACK, WHEREIN THE TCO LAYER AND AT LEAST A PORTION OF THE ACTIVE LAYER STACK FORMS A SUBSTANTIALLY CIRCULAR PARABOLOID SHAPE;
AN ELECTRICALLY INSULATING LAYER DISPOSED ON THE TCO LAYER, THE ELECTRICALLY INSULATING LAYER HAVING AN OPENING FORMED THEREIN; AND
A REFLECTIVE LAYER DISPOSED ON THE ELECTRICALLY INSULATING LAYER, WHEREIN A REFLECTIVE SURFACE OF THE REFLECTIVE LAYER FORMS A SUBSTANTIALLY CIRCULAR PARABOLIC MIRROR, AND WHEREIN THE AXIS OF SYMMETRY OF THE REFLECTIVE SURFACE IS NOT ORTHOGONAL TO MAJOR SURFACES OF THE ACTIVE LAYER STACK; AND
620
PLACING THE ONE OR MORE PRE-SINGULATED MICRO-LED DEVICES ON A RECEIVING SURFACE OF A DISPLAY PANEL.

FIG. 7A

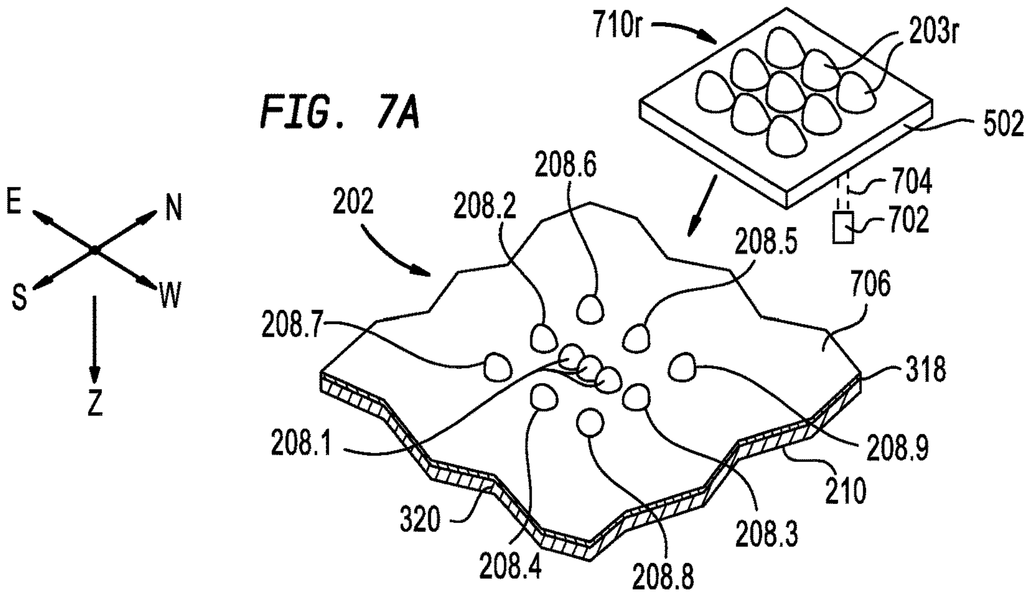


FIG. 7B

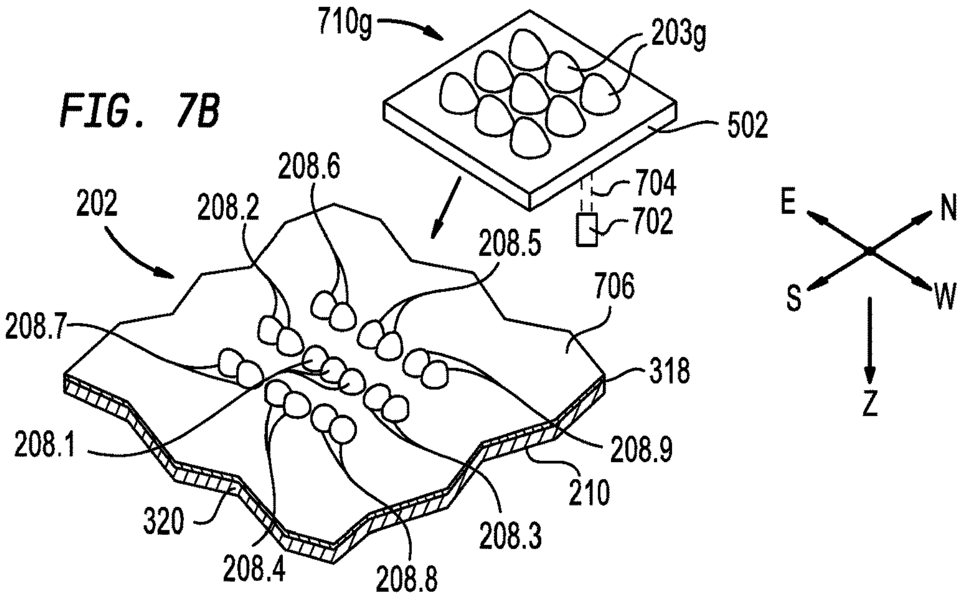
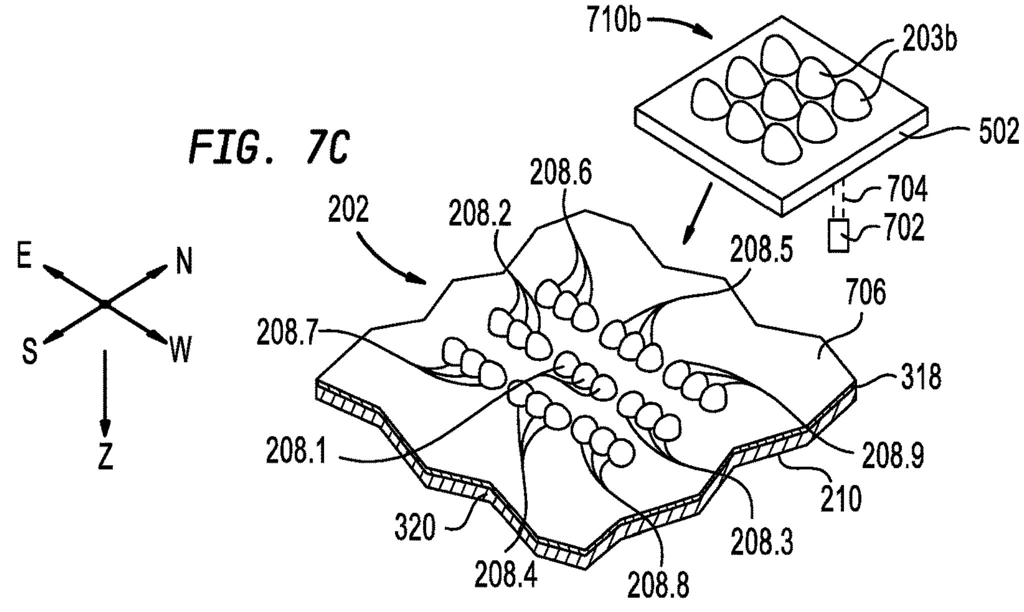


FIG. 7C



COLLIMATED, DIRECTIONAL MICRO-LED LIGHT FIELD DISPLAY

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority to United States Provision Application Ser. No. 62/532,158, filed on Jul. 13, 2017, which is herein incorporated by reference in its entirety.

BACKGROUND

Field

Embodiments of the present disclosure generally relate to light field displays and methods of forming light field displays, in particular, light field displays formed of directional collimating micro-LED devices, directional collimating micro-LED devices, and methods of forming the directional collimating micro-LED devices.

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 they 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 and methods of forming high angular resolution light field displays.

SUMMARY

Embodiments of the present disclosure generally relate to light field displays and methods of forming a light field display, in particular, light field displays formed of directional collimating micro-LED devices, methods of forming the light field displays, and methods of forming the directional collimating micro-LED devices.

In one embodiment, a light field display is provided. The light field display includes a plurality of micro-LED arrays, where each micro-LED array provides a pixel of spatial resolution comprising a plurality of pixels of angular resolution, where each micro-LED array comprises a plurality of micro-LED devices providing the plurality of pixels of angular resolution, and where each of the plurality micro-LED devices comprises a reflective surface forming a substantially circular parabolic mirror. In some embodiments, each micro-LED array of the light field display includes a plurality of micro-LED groups, where each of the plurality of micro-LED groups comprises at least three micro-LED devices, and where each of the at least three micro-LED devices provide different colors of light from each other to each provide a sub-pixel of angular resolution. In some embodiments, the at least three micro-LED devices of the light field display further comprise at least a blue light emitting micro-LED device, a green light emitting micro-LED device, and a red light emitting micro-LED device. In some embodiments, one or more of the plurality of micro-LED devices comprises an active layer stack and a transparent conductive oxide (TCO) layer disposed on the active layer stack, where the TCO layer and at least a portion of the active layer stack forms a substantially circular paraboloid shape, an electrically insulating layer disposed on the TCO layer, where the electrically insulating layer has an opening formed therein, and a reflective layer disposed on the electrically insulating layer, where the reflective layer comprises the reflective surface, and where the axis of symmetry of the reflective surface is not orthogonal to major surfaces of the active layer stack. In some embodiments, the active layer stack of the one or more of the plurality of micro-LED devices comprises an n-type layer, a p-type layer, and one or more quantum well layers interposed between the n-type layer and the p-type layer, where a focal point of the reflective surface is proximate to a surface the p-type layer. In some embodiments, the active layer stack provides a red light, a green light, or a blue light. In some other embodiments, the light field display comprises a plurality of mono-chromatic micro-LED devices.

In another embodiment, a micro-LED device is provided. The micro-LED device comprises an active layer stack, a transparent conductive oxide (TCO) layer disposed on the active layer stack, where the 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 TCO layer, where the electrically insulating layer has an opening formed therein, and a reflective layer disposed on the electrically insulating layer, where a reflective surface of the reflective layer forms a substantially circular parabolic mirror, and where the axis of symmetry of the reflective surface is not orthogonal to major surfaces of the active layer stack. In some embodiments, the active layer stack comprises an n-type layer, a p-type layer, and one or more quantum well layers interposed between the n-type layer and the p-type layer, and a focal point of the reflective surface is proximate to a surface the p-type layer. In some embodiments, the active layer stack provides a red light, a green light, or a blue light. In some other embodiments, the plurality of micro-LED devices are mono-chromatic.

In another embodiment, a method of forming one or more micro-LED devices is provided. The method includes 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. The method further includes forming a pattern in the resist layer, where the pattern comprises one or more paraboloid shaped features, and where each of the one or more paraboloid shaped features has an axis of symmetry that is not orthogonal to major surfaces of the active layer stack. The method further includes transferring the pattern to the TCO layer and at least a portion of the active layer stack disposed there beneath to form a patterned substrate. The method further includes depositing an electrically insulating layer over the patterned substrate, forming one or more openings in the electrically insulating layer over the respective one or more paraboloid shaped features of the patterned substrate, and depositing a reflective layer over the electrically insulating layer, where a reflective surface of the reflective layer forms a substantially circular parabolic mirror, and where the axis of symmetry of the reflective surface is not orthogonal to major surfaces of the active layer stack. In some embodiments, the structural base comprises a lattice-matching material and one or more layers of the active layer stack epitaxially formed thereon. In some embodiments, the active layer stack comprises an n-type layer, a p-type layer, and one or more quantum well layers interposed between the n-type layer and the p-type layer. In some embodiments, a focal point of the reflective surface is proximate to a surface the p-type layer. In some embodiments, the method further includes selectively treating a surface of the p-type layer to form a light emissive region about the focal point and a non or low light emissive region circumscribing the light emissive region. In some embodiments, the active layer stack provides a red light, a green light, or a blue light. In some embodiments, forming a pattern in the resist layer comprises an imprint lithography process, a grey-scale lithography process, a tilted directional etch process, or a combination thereof. In some embodiments, the method further includes removing the one or more micro-LED devices from the structural base. In some embodiments, the micro-LED device comprises the active layer stack, the transparent conductive oxide (TCO) layer disposed on the active layer stack, the electrically insulating layer, and the reflective layer.

In another embodiment, a method of forming a light field display is provided. The method includes picking one or more pre-singulated micro-LED devices from a structural base, where the one or more pre-singulated micro-LED devices each comprise an active layer stack, a transparent conductive oxide (TCO) layer disposed on the active layer stack, wherein the TCO layer and at least a portion of the active layer stack forms a substantially circular paraboloid shape, an electrically insulating layer disposed on the TCO layer, the electrically insulating layer having an opening formed therein, and a reflective layer disposed on the electrically insulating layer, where a reflective surface of the reflective layer forms a substantially circular parabolic mirror, and where the axis of symmetry of the reflective surface is not orthogonal to major surfaces of the active layer stack. The method further includes placing the one or more pre-singulated micro-LED devices on a receiving surface of a display panel.

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 its scope, for the disclosure may admit to other equally effective embodiments.

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

FIG. **2**A is a schematic view of a light field display, according to one embodiment.

FIG. **2**B is a close up view of one of the micro-LED arrays of the light field display described in FIG. **2**A.

FIG. **2**C is an isometric view of the micro-LED array described in FIG. **2**B.

FIG. **2**D is a close up view of directed collimated light provided by the micro-LED array described in FIG. **2**C.

FIG. **3**A is a schematic cross-sectional view of a micro-LED device, such as a micro-LED device used in the micro-LED arrays described in FIGS. **2**A-**2**C, according to one embodiment.

FIG. **3**B is a sectional view of a portion of the micro-LED device 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 a micro-LED device, such as the micro-LED device described in FIGS. **3**A-**3**B, according to one embodiment.

FIGS. **5**A-**5**G illustrate the method described in FIG. **4**.

FIG. **6** is a flow diagram illustrating a method of forming a light field display, according to one embodiment.

FIGS. **7**A-**7**C illustrate the method described in FIG. **6**.

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

Embodiments of the present disclosure generally relate to light field displays and methods of forming light field displays, in particular, light field displays formed of directional collimating micro-LED devices, directional collimating micro-LED devices, and methods of forming the directional collimating micro-LED devices.

FIG. **2**A is a schematic view of a light field display, according to one embodiment. The light field display **200** in FIG. **2**A is a direct view LED light field display which includes a plurality of micro-LED arrays **202** herein arranged in 5 rows and 4 columns, where each micro-LED array **202** provides a macro-pixel of resolution of the light-field display, which is 20 macro-pixels for the 4×5 array shown in FIG. **2**A, i.e., a macro-pixel is present at each column-row intersection. A macro-pixel provides a single pixel of spatial resolution and a plurality of pixels of angular (i.e., directional) resolution, where the number of macro-pixels and the number of pixels of angular resolution per macro-pixel determine the effective native hardware pixel resolution of the light field display **200**. For example, a light field display comprising 1920×1080 pixels of spatial resolution, where each pixel of spatial resolution comprises 25 pixels of angular resolution has an effective light field resolution of 48000×27000. As shown in FIG. **2**A, the plurality of micro-LED arrays **202** are arranged in a grid pattern comprising a plurality of parallel rows **204** and a plurality of parallel columns **206** that are orthogonal to the plurality of parallel rows **204**. In other embodiments, the plurality of micro-LED arrays **202** are arranged in any other suitable pattern, such as hexagonal pattern.

FIG. **2**B is a close up view of one of the micro-LED arrays **202** of the light field display **200** shown in FIG. **2**A. FIG. **2**C is an isometric view of the micro-LED array **202** described in FIG. **2**B. FIG. **2**D further illustrates the directed collimated light rays **212.1**-**212.9** provided by respective micro-LED groups **208.1**-**208.9** of the micro-LED array **202** described in FIGS. **2**B-**2**C. Herein, each micro-LED array **202** comprises a plurality micro-LED groups **208.1**-**208.9**, where each of the plurality of micro-LED groups **208.1**-**208.9** includes three micro-LED devices, a red micro-LED device **203***r*, a green micro-LED device **203***g*, and a blue micro-LED device **203***b*. Typically, red micro-LED devices **203***r* provide light having a wavelength in the range between about 620 nm and about 780 nm, green micro-LED devices **203***g* provide light having a wavelength in the range between about 495 nm and about 580 nm, and blue micro-LED devices **203***b* provide light having wavelengths in the range between about 450 nm and about 495 nm.

In the micro-LED arrays **202**, and as shown in FIGS. **2**C and **2**D, each micro-Led has a preferential primary direction of light emission with respect to the display surface **210**. Thus, each of the micro-LEDs are configured and arranged in the micro-LED array **202** to direct light in a direction measured with respect to the deviation of the primary emission direction from the Z-direction normal to the surface of the micro-LED array **202**, here angle θ, 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**, and where N is here set to be a direction extending directly upwardly when from the perspective of a viewer viewing the micro-LED array of FIGS. **2**B and **2**C. Thus, the primary light emission direction of each micro-Led can be notated as (direction, angle θ), where the direction is based on the NSEW, i.e., compass, direction coordinates, except where the primary emission direction is the Z direction substantially normal to the display surface **210**, and the angle θ is the angle is the angle between the primary emission direction of the micro-LED and the Z-axis. Thus, for example, the primary emission direction of the micro-LEDs **208.1** is the Z-direction, and they therefore have the notation (none, 0), wherein the emission direction does not have a NSEW direction because it is orthogonal to the array surface, and the angle is 0 because it does not deviate from the Z direction. Slight angular deviation is not considered in this notation.

Herein, the directional components N, S, E, and W respectively correspond to the upward, downward, rightward, and leftward directions of a display surface **210** of the light field display **200**, and/or the micro-LED arrays **202** thereof, from the perspective of a viewer facing the micro LED array **202**. Collimated light emanating from the light field display **200** in rays, such as collimated light rays **212.1**, that are orthogonal to the display surface **210** are emanating in the Z direction where the angle θ of the light rays with respect to the Z direction perpendicular to the display surface **210** is about 0, and collimated light rays emanating from the display surface **210** in a direction that is not orthogonal to the display surface **210**, such as collimated light rays **212.2**-**212.9**, deviate from the Z direction at the display surface **210** by an angle θ and in a N, S, E, or W direction, or a direction therebetween, for example a NE direction which is halfway between N and E or 45° clockwise from N, a SE direction which is halfway between E and S or 135° clockwise from N, a SW direction which is halfway between S and W or 180° clockwise from N, or a NW direction which is halfway between N and W or 225° clockwise from N. Herein, micro-LED groups **208.2**-**208.9** are each configured to respectively direct collimated light rays **212.1**-**212.9** in E, W, S, N, NE, SE, SW, and NW directions at the angle θ (shown in FIG. **2**C) with respect to the Z axis, where the angle θ is between more than 0° and less than about 45°, such as between more than 0° and about 30°, such as between about 0.5° and about 30°. In one embodiment, the micro-LED groups **208.2**-**208.9** are each configured to respectively direct collimated light rays **212.2**-**212.9** in a respective E, W, S, N, NE, SE, SW, and NW direction where each of the respective collimated light rays **212.2**-**212.9** diverge from the Z direction at the surface of the display by the angle θ, where the angle θ is between about more than 0° and about 5°. In further embodiments, additional micro-LED groups **208** in the micro-LED array **202** are configured to provide collimated directed light in further directions, such as directions between E, W, S, N, NE, SE, and NW directions and/or at different angles from the Z-direction such as θ+x where x is between more than 0° and 10°, such as between more than 0° and about 5°.

Typically, each of the micro-LED devices **203***r,g,b* in a micro-LED group **208.1**-**208.9** is located adjacent and/or proximate to another micro-LED device **203***r,g*, or b of the same micro-LED group **208.1**-**208.9**. In other embodiments, micro-LED devices **203***r,g,b* of each respective micro-LED group **208.1**-**208.9** are positioned at locations within the micro-LED array **202** that are distal from and/or not adjacent to the other micro-LED devices **203***r,g*, or b of the same micro-LED group **208**. Herein, the micro-LED groups **208.1**-**208.9** include at least one of each of a red micro-LED device **203***r*, a green micro-LED device **203***g*, and a blue micro-LED device **203***b*, where each micro-LED device **203***r,g*, or b of an RGB micro-LED group **208.1**-**208.9** is configured to direct collimated light in substantially the same direction from the display surface **210** as the other micro-LED devices **203***r,g*, or b of the same group.

In other embodiments, the micro-LED arrays **202** of the light field display **200** include a plurality of monochromatic micro-LED's (not shown) where the plurality of monochromatic micro-LED's are configured to direct collimated light in a corresponding plurality of directions from the display surface **210**. Typically, the light provided by the plurality of monochromatic micro-LED's falls in the visible spectrum. In other embodiments, each of the micro-LED groups **208** includes at least a micro-LED device for emitting a first color light and at least a micro-LED device for emitting a second color light, where the first and second colors of light are different and where each micro-LED device **203** of the micro-LED group **208** is configured to direct collimated light in substantially the same direction as the other micro-LED devices **203** of the same micro-LED group **208**. In some other embodiments, each of the micro-LED groups **208** comprise 3 or more micro-LED's that each emit a different color of light, where each of the 3 or more micro-LED devices **203** in the micro-LED group is configured to direct collimated light rays **212** in substantially the same direction from the display surface **210**.

The micro-LED arrays **202** shown in FIGS. **2**A-**2**B comprise a 3×3 array of micro-LED groups **208.1**-**208.9** that form a macro-pixel of the display where the macro-pixel provides a single pixel of spatial resolution and 9 pixels of angular (i.e., directional) resolution, and where each pixel of angular resolution includes at least 3 sub-pixels provided by the micro-LED devices **203***r,g,b*. In further embodiments, the micro-LED array **202** is configured to provide more than 9 pixels of angular resolution, such as 16 pixels of angular resolution provided by a 4×4 array of 16 micro-LED groups **208** each configured to direct collimated light in a different direction from the display surface **210**, or 25 pixels of angular resolution provided by a 5×5 array of 25 micro-LED groups **208**, or any number of micro-LED groups **208** required to provide the desired angular resolution, for example in some embodiments the micro-LED array **202** comprises an array of 1920×1080 micro-LED groups or about 2.07M micro-LED groups configured to provide about 2.07M pixels of angular resolution. In some embodiments, the micro-LED array **202** will include the micro-LED group **208.1** configured to provide collimated light rays **212.1** substantially in the Z-direction i.e., substantially orthogonal to the display surface **210**, a first plurality of micro-LED groups, such as micro-LED groups **208.2-208.9**, configured to provide collimated light rays, such as collimated light rays **212.2-212.9**, in a plurality of compass directions deviating from the Z-direction by a first angle, such as the angle θ, and a second plurality of micro-LED groups (not shown) configured to provide collimated light rays in the plurality of compass directions deviating from the Z-direction by a second angle, such as θ+x.

Typically, each plurality of micro-LED groups includes more than 4 micro-LED groups, such as more than 6 micro-LED groups, for example at least 8 micro-LED groups. In some embodiments, each micro-LED array **202** will comprise more than 2 pluralities of micro-LED groups, where each of the pluralities of micro-LED groups is configured to direct collimated light rays at a different angle θ from the Z-direction. In other embodiments, the micro-LED array **202** includes more than one plurality of monochromatic micro-LED devices, where each of the pluralities of monochromatic micro-LED devices is configured to direct collimated light rays in a plurality of compass directions, and where each of the pluralities of monochromatic micro-LED devices is configured to direct light collimated light rays at a different angle θ from the Z-direction that the other pluralities of monochromatic micro-LED devices.

In FIG. **2**B the plurality of micro-LED groups **208.1-208.9** are arranged in a grid pattern comprising a plurality of parallel rows **205** and a plurality of parallel columns **207** orthogonal to the plurality of parallel rows **205**. In other embodiments, the plurality of micro-LED groups **208.1-208.9** and/or the micro-LED devices thereof, are arranged in other suitable patterns within the micro-LED array **202**, such as in a hexagonal pattern.

FIG. **3**A is a schematic cross-sectional view of a micro-LED device disposed on a portion of a display panel, such as a micro-LED device **203** used in the micro-LED array **202** described in FIGS. **2**A-**2**C, according to one embodiment. FIG. **3**B is a sectional view of a portion of the micro-LED device described in FIG. **3**A taken along line **3**B-**3**B of FIG. **3**A, according to some embodiments. Herein, the micro-LED device **203** 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 micro-LED devices **203** 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 micro-LED devices **203***b,g* 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 micro-LED, 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 micro-LED devices **203**. In some embodiments, the red micro-LED devices **203***r* 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. Herein, the micro-LED device **203** is mounted to the display panel **320** using a transparent conductive adhesive (TCA) layer **318** disposed therebetween, where major surface of the active layer stack **304** are substantially parallel to the display surface **210**. Typically, the active layer stack **304** has a thickness T(**1**) between about 10 nm and about 50 μm, such as between about 10 nm and about 5 μm, between about 10 nm and about 500 nm, between about 10 nm and about 100 nm, or between about 10 nm and about 50 nm, for example about 30 nm and forms an ohmic contact with the TCO layer **306** at the surfaces therebetween. Herein, 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 material composition of the TCO layer **306** is selected based on the material composition and material properties, e.g, work function, of the active layer stack **304** so that there is ohmic contact and, or, tunneling contact between at least a portion of the TCO layer **306** and the active layer stack **304**, and provide desirable optical transparency so that light emitted by the active layer stack **304** and reflected by the reflective layer **316** is able to travel therethrough. In one embodiment, the TCO layer **306** is formed of a p-type TCO material. Herein, the TCO layer **306** is formed on the active layer stack **304** using any suitable deposition method including chemical vapor deposition (CVD), physical vapor deposition (PVD), and plasma enhanced (PE) deposition methods, such as PECVD and PEPVD.

Herein, the TCO layer **306** and at least a portion of the active layer stack **304** form an elliptical paraboloid shape, such as a substantially circular paraboloid shape (i.e., the shape of a surface obtained by revolving a parabola about its axis of symmetry Z') at surfaces proximate to the dielectric layer **312**. The electrically insulating layer **312** is typically formed of a transparent dielectric material, such as silicon oxide, silicon nitride, or combinations thereof. Herein, the electrically insulating layer **312** is desirably 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 so that a reflective surface **316***a* of the reflective layer **316** disposed on the electrically insulating layer **312** forms an elliptical parabolic mirror, such as a circular 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**.

The material composition of the TCA layer **318** is selected based on the material composition and material properties, e.g, work function, of the active layer stack **304** to provide ohmic contact and, or, tunneling contact therebetween as well as to provide desirable optical transparency. In one embodiment, the TCA layer **318** is formed of an n-type TCA material. Herein, the TCA layer **318** is formed using any suitable deposition method including chemical vapor deposition (CVD), physical vapor deposition (PVD), and plasma enhanced (PE) deposition methods, such as PECVD and PEPVD. In other embodiments, the micro-LED device **203** is mounted to the display surface **210** using a transparent electrically non-conductive adhesive. In some embodiments, the micro-LED device **203** further includes a sapphire layer (not shown) disposed between the active layer stack **304** and the display panel **320** where the sapphire layer of the micro-LED device **203** is bonded to the display panel using a electrically non-conductive transparent adhesive layer (not shown). In other embodiments, the micro-LED device **203** 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 micro-LED device, 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 micro-LED device **203**.

For micro-LED devices **203** where the desired direction of collimated light rays **212** is substantially orthogonal to the display surface **210**, such as the collimated light rays **212.1** provided by the micro-LED group **208.1**, the axis of symmetry Z' of the reflective surface **316***a* is in substantially the same direction as the Z-direction. For micro-LED devices where a desired direction of collimated light rays **212** deviates from the Z-direction by the angle θ, such as for collimated light rays **212.2**-**212.9**, the axis of symmetry Z' of the reflective surface **316***a* deviates from the Z-direction by about the angle θ. Therefore, in some embodiments, the axis of symmetry Z' of the reflective surface **316***a* and the major surfaces of the active layer stack **304** form an angle that is less than or more than 90°, such as between about 60° and less than 90° or between more than 90° and less than about 120°, such as less than 89° or more than 91°, such as less than about 88° or more than 92°, for example less than 85° or more than 95°.

FIG. **4** is a flow diagram illustrating a method **400** of forming one or more micro-LED devices, such as the micro-LED device **203** described in FIG. **3**, according to one embodiment. FIGS. **5**A-**5**G illustrate the method **400** described in FIG. **4**.

At activity **410** the method **400** includes depositing a resist layer, such as the resist layer **508***a* shown in FIG. **5**A, on the surface of a substrate **500**. Herein, 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***a* herein comprises a UV curable resin material deposited and/or dispensed onto the surface of the substrate **500** using conventional means, such as but not limited to slot die coating, inkjet printing, gravure printing, spin-on coating, or a combination thereof. In some embodiments, the resist layer **508***a* is formed from a plurality of droplets of the UV curable resin material. In other embodiments, the resist layer **508***a* comprises an electron-sensitive resin material or a thermal curable resin material. Herein, the resist layer **508***a* is formed of a positive resist material. In other embodiments, a method of forming one or more micro-LED devices uses a negative resist material.

At activity **420** the method **400** includes forming a pattern in the resist layer **508***a*. In one embodiment, forming the pattern in the resist layer **508***a* includes physically imprinting a pattern into the resist layer **508***a* using an imprint lithography (IL) stamp, such as the IL stamp shown in FIG. **5**B. Herein, the IL stamp **510** includes one or more paraboloid shaped openings **512** formed therein. Physically pressing the IL stamp **510** into the resist layer **508***a* displaces the resin material about the pattern of the IL stamp. The resin material is cured using electromagnetic radiation, such as an ultra-violet (UV) radiation, provided through the IL stamp to form a patterned resist layer **508***b* comprising one or more paraboloid shaped features. Herein, an axis of symmetry Z' of the surface of the paraboloid shaped openings **512**, and thus the axis of symmetry of the resulting paraboloid shaped features formed in the patterned resist layer **508***b*, deviates from a Z-direction which is orthogonal to a horizontal plane defined by the surface of the IL stamp **510**. In some embodiments, the axis of symmetry Z' deviates from the Z-direction by an angle θ of more than 0°, such as more than about 1°, or more than about 2°, for example more than 5°, or between more than 0° and about 45°, such as between more than 0° and about 30°, such as between about 0.5° and about 30°. 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 where the IL stamp is heated to a desired temperature and the resin material of the resist layer **508***a* is thermally cured to form the patterned resist layer **508***b*. In other embodiments, the IL stamp **510** is formed using a maskless direct write lithography process, i.e., a digital lithography process, for example an electron beam (e-beam) or optical direct write lithography process.

For a macro-pixel, corresponding to a micro-LED array **202**, where each of the micro-LED devices **203** other than the one directing light in the Z-axis have the same angular deviation from the Z-direction, herein angle θ, a single IL stamp can be used in the formation of the plurality of parabolic shapes formed in the patterned resist layer **508***b*. In FIG. **5**B, the axes of symmetry Z' of the paraboloid shaped openings **512** each deviate from the Z-direction by substantially the same angle θ and in substantially the same direction (e.g. N, S, W, E, and directions therebetween) with respect to a surface of the IL stamp **510**. In other embodiments, for example for a macro-pixel, corresponding to a micro-LED array **202**, where at least some of the micro-LED devices **203** other than the ones directing light in the Z-direction have different angular deviation from the Z-direction, herein angle θ, the IL stamp **510** includes a plurality of paraboloid shaped openings **512** having a respective plurality of axes of symmetry Z' that deviate from the Z direction by a respective plurality of different angles θ and/or in a respective plurality of different directions, which is useful in reducing the number of pick and place operations needed to form a micro-LED array **202**, as described further in FIGS. **6** and **7**A-**7**C.

In another embodiment, forming a pattern in the resist layer at activity **420** comprises a maskless lithography process, such as e-beam direct write lithography process or an optical direct write lithography process, such as the optical direct write lithography process illustrated in FIG. **5**C. Herein, an e-beam or a beam of focused radiation, such as the focused UV light beam **511**, or a laser beam, is used to directly write (i.e., expose) an image into the resist layer **508***a*. Typically, the resist layer **508***a* is formed of an electron-sensitive resist material (for an e-beam process) or a light sensitive resist material (for an optical process), such as a UV light sensitive resist material. Herein, the resist layer **508***a* is formed of a positive resist material so that unexposed resist material is selectively removed to form the patterned resist layer **508***b* shown in FIG. **5**D. Typically, the image used to form the patterned resist layer **508***b* is a digital image, such as a bitmap image. In other embodiments, the patterned resist layer is formed using a grey-scale lithography process, or a combination of a direct write lithography process and a grey-scale lithography process.

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. **5**E comprising one or more paraboloid shaped features **520**. 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**, using conventional methods, such as lithographic patterning and etching, and depositing a reflective layer **316** over the electrically insulating layer **312** to form one or more micro-LED devices, such as the micro-LED device **203** described in FIG. **3**. In one embodiment, the reflective layer **316** is deposited using a conventional gap-fill method to ensure the material thereof fills the opening **314** which enables ohmic contact between the reflective layer **316** and the TCO layer **306**.

In some embodiments, the method **400** includes singulating the one or more micro-LED devices **203** along the singulation lines **522** shown in FIG. **5**G. Singulating the one or more micro-LED devices **203** is typically done using laser scribing, mechanical sawing, water/solvent knifing, ion beam milling, a multi-layer photolithography etch process, or a combination thereof.

In some embodiments, the method **400** further includes removing all or a portion of the structural base **502** from the one or more micro-LED devices **203** before and/or after the singulation thereof. In some embodiments, the structural base **502** is removed from the one or more micro-LED devices **203** using a conventional laser liftoff process, a chemical mechanical polishing (CMP) process, a wet-etch process, or a combination thereof.

FIG. **6** is a flow diagram illustrating a method of forming a light field display, according to one embodiment. FIGS. **7**A-**7**C Illustrate the method described in FIG. **6**. At activity **610** the method **600** includes picking one or more pre-singulated micro-LED devices of a first color, such as the red micro-LED devices **203***r* shown in FIG. **7**A, a second color, such as the green micro-LED devices **203***g* shown in FIG. **7**B, and a third color, such as the blue micro-LED devices **203***b* shown in FIG. **7**C from the structural bases **502** of a respective micro-LED device source **710***r*, **710***g*, and **710***b* and placing them in the desired position on the receiving surface **706** as further described at activity **620**. In some embodiments, the micro-LED device sources **710***r*, **710***g*, and/or **710***b* are formed according to embodiments described herein. In some embodiments, each of the plurality of micro-LED devices **203***r,g,b* of the respective micro-LED device sources **710***r,g,b* are formed on a respective structural base **502**, where each have a desired axis of symmetry Z' that deviates from the Z direction by substantially the same angle θ, each desirably emit substantially the same wavelength of light, and each are disposed in substantially the same direction (e.g., N, S, W, E and/or therebetween) with respect to a surface of the respective structural base **502**. In other embodiments, one or more of the micro-LED sources **710***r, g,b* include a plurality of respective micro-LED devices **203**,*r,g,b* comprising a plurality of desired axes of symmetry Z' deviating from the Z-direction in a respective plurality of angles θ. In some other embodiments, the axes of symmetry Z' or the plurality of micro-LED devices **203** are disposed in a respective plurality of different directions (N, S, W, E and/or therebetween) with respect to a surface of the respective structural base **502**.

Typically, the micro-LED devices **203***r,g,b* shown in FIGS. **7**A-**7**C comprises an active layer stack, a transparent conductive oxide (TCO) layer disposed on the active layer stack, wherein the TCO layer and at least a portion of the active layer stack forms a substantially circular paraboloid shape, an electrically insulating layer disposed on the TCO layer, the electrically insulating layer having an opening formed therein, and a reflective layer disposed on the electrically insulating layer, where a reflective surface of the reflective layer forms a substantially circular parabolic mirror, and where the axis of symmetry of the reflective surface is not orthogonal to major surfaces of the active layer stack. In some embodiments, picking the one or more pre-singulated micro-LED devices **203***r,g,b* from the structural base further includes de-bonding the micro-LED device **203***r,g,b* from the structural base using a laser **704** provided by a laser source **702**.

At activity **620** the method **600** further includes placing the one or more pre-singulated micro-LED devices **203***r,g,b* on a receiving surface **706** of a display panel **320**. The receiving surface **706** of the display panel **320** is distal from the display surface **210** and includes a transparent conductive adhesive (TCA) layer **318** disposed thereon. Herein, the TCA layer **318** provides a common n-type connection to the to be placed micro-LED devices **203***r,g,b*. In other embodiments, the TCA layer **318** forms a discontinuous surface comprising a plurality of TCA patches (not shown) each configured to provide an individual n-type connection a respective to be placed micro-LED device **203***r,g,b*. In some embodiments, the display panel **320** is formed of a rigid or flexible transparent material such as glass or a transparent polymer, for example a polyethylene terephthalate (PET) sheet or a polyethylene terephthalate (PEN) sheet. In some embodiments, the transparent polymer sheet is disposed on a rigid glass, metal, or plastic base to facilitate handling of the light field display during the manufacturing process. In some embodiments, the display panel **320** is coated with an anti-reflective coating using to reduce the refractive index thereof.

Herein, placing the one or more pre-singulated micro-LED devices **203***r,b,g*, comprises individually positioning each of the micro-LED devices **203***r,b,g* or concurrently positioning a collection of micro-LED devices **203***r,b,g* at desired locations on the receiving surface **706** and with desired directional components (N, S, E, W and/or therebetween) with respect to the display surface **210**. For example, if the micro-LED devices **203***r,b,g* of the respective micro-LED sources **710***r,g,b* of FIGS. **7A-7C** all comprise devices having substantially the same axis of symmetry Z' orientated in substantially the same direction, such as N, on their structural base **502**, the individual micro-LED device **203***r, b,g* are positioned on the receiving surface **706** so that the individual micro-LED devices comprising micro-LED group **208.5** are all oriented with their axis of symmetry Z' is in a N direction which provides a primary light emission direction **212.5** (shown in FIGS. **2C** and **2D**) which is (N, θ). Likewise the micro-LED devices comprising micro-LED group **208.6**, **208.2**, **208.7**, **208.4**, **208.8**, **208.3**, and **208.9** are positioned so that the respective primary light emission directions **212.6**, **212.2**, **212.7**, **212.4**, **212.8**, **212.3**, and **212.9** are respectively (NE, θ), (E, θ), (SE, θ), (S, θ), (SW, θ), (W, θ), and (NW, θ). In FIGS. **7A-7C** the individual micro-LED devices **203***r,g,b* of micro-LED groups **208.1**-**208.9** are arranged so that each micro-LED device **203***r,g,b* of a respective micro-LED group **208** is proximate to and/or adjacent to other members of the group. In other embodiments, the micro-LED devices **203***r,g,b* of a micro-LED group **208** are positioned and/or arranged at any location within the micro-LED array **202**. For example, in embodiments where a micro-LED device source **710***r,g,b* comprises a plurality of micro-LED devices having a plurality of axes of symmetry Z' deviating from the Z-direction by plurality of angles θ and/or in a respective plurality of different directions (e.g., N, S, E, W, and directions therebetween) a plurality of micro-LED devices **203***r,g*, or b can be collectively picked from the respective micro-LED device source **710***r,g*, or b and collectively placed on the receiving surface **706** of the display panel **320** which desirably reduces the number of pick and place operations in the assembly of a light field display **200**. In some other embodiments, collections of micro-LED devices **203***r,g*, and/or b are arranged on a transfer carrier substrate (not shown) before being collectively transferred to the receiving surface **706** of the display panel **320** and positioned thereon.

In other embodiments, a mass transfer pick and place system is used to transfer a plurality of pre-singulated micro-LED devices **203***r, g*, or *b* comprising the same r, g, or b color and the same theta orientation to the receiving surface of a single display panel, such as the display panel **320**. In these embodiments, the plurality of pre-singulated micro-LED devices **203** *r, g*, or *b* (having the same color, angle θ, and compass direction) are transferred in a single mass transfer pick and place operation or operational sequence which reduces production time and costs associated therewith. Typically the plurality of pre-singulated micro-LED devices transferred in single mass transfer pick and place operation or operational sequence comprises more than 20%, more than 30%, or at least about 50%, such as about 100% of the pre-singulated micro-LED devices **203** *r, g*, or *b* (having the same color, angle θ, and compass direction) used to form a single panel display, e.g., more than 1 million micro-LED devices (having the same color, angle θ, and compass direction). Herein, the term about with respect to the number of micro-LED devices **203** transferred includes allowances to correct for misplacement of improperly transferred micro-LED devices or replacement of non-functioning micro-LED devices.

In other embodiments, the light field display is formed by picking and placing a plurality of micro-LED devices onto a back panel of the light field display so that light from the micro-LED devices is emitted in a direction away from the major surfaces of the back panel. In some of those embodiments, the micro-LED devices further comprise a planarized dielectric layer disposed over the reflective layer, where conductive interconnects formed through the planarized dielectric layer enable n-type and p-type connections to the micro-LED device. In some other embodiments, the light field display is formed using a roll-based multi-device (e.g., micro-LED device) transfer system.

The method **600** described above contemplates a light field display where each pixel of angular resolution comprises micro-LED arrays having micro-LED devices that at least emit sub-pixels of red, green, and blue light. In other embodiments, the pick and place methods described in FIG. **6** are used to form a light field display comprising micro-LED devices that emit sub-pixels of different colors of light and/or fewer colors of light (e.g., mono-chromatic or di-chromatic light field 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 light field display, comprising:

a plurality of micro-LED arrays;

wherein each micro-LED array provides a pixel of spatial resolution comprising a plurality of pixels of angular resolution;

wherein each micro-LED array comprises a plurality of micro-LED devices providing the plurality of pixels of angular resolution;

wherein each of the plurality micro-LED devices comprises a reflective surface forming a substantially circular parabolic mirror; and

wherein one or more of the plurality of micro-LED devices 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, and wherein the axis of symmetry of the reflective surface is not orthogonal to major surfaces of the active layer stack.

2. The light field display of claim **1**, wherein each micro-LED array comprises a plurality of micro-LED groups, each of the plurality of micro-LED groups comprising at least three micro-LED devices, wherein each of the at least three micro-LED devices emit a different color of light from that of the others to each provide a sub-pixel of angular resolution.

3. The light field display of claim **2**, wherein the three different colors of light comprise red, green, and blue.

4. The light field display of claim **2**, wherein the at least three micro-LED devices comprise a blue light emitting micro-LED device, a green light emitting micro-LED device, and a red light emitting micro-LED device.

5. The light field display of claim 1, wherein

the active layer stack of the one or more of the plurality of micro-LED devices comprises an n-type layer, a p-type layer, and one or more quantum well layers interposed between the n-type layer and the p-type layer, and

a focal point of the reflective surface is proximate to a surface the p-type layer.

6. The light field display of claim 5, wherein the active layer stack provides red light, a green light, or a blue light.

7. The light field display of claim 5, wherein the plurality of micro-LED devices are mono-chromatic.

8. The light field display of claim 5, wherein a surface of the p-type layer comprises a light emissive region about the focal point and a non or low light emissive region circumscribing the light emissive region.

9. A micro-LED device, comprising:

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 forms a substantially circular paraboloid shape;

an electrically insulating layer disposed on the TCO layer, the electrically insulating layer having an opening formed therein; and

a reflective layer disposed on the electrically insulating layer, wherein a reflective surface of the reflective layer forms a substantially circular parabolic mirror, and wherein the axis of symmetry of the reflective surface is not orthogonal to major surfaces of the active layer stack.

10. The micro-LED device of claim 9, wherein

the active layer stack comprises an n-type layer, a p-type layer, and one or more quantum well layers interposed between the n-type layer and the p-type layer, and

a focal point of the reflective surface is proximate to a surface the p-type layer.

11. The micro-LED device of claim 10, wherein the active layer stack provides a red light, a green light, or a blue light.

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专利名称(译)	准直定向微型LED光场显示器		
公开(公告)号	US10490599	公开(公告)日	2019-11-26
申请号	US15/904100	申请日	2018-02-23
[标]申请(专利权)人(译)	应用材料股份有限公司		
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IPC分类号	H01L27/15 G02B27/22 H05B33/08 G02B27/09		
CPC分类号	H01L27/156 H05B33/0803 G02B27/0983 G02B27/22 G02B17/002 G02B19/0028 G02B19/0066 G02B27/0075 G02B30/50 H01L25/0753 H01L33/42 H01L33/60 G02B30/00 H05B45/00		
优先权	62/532158 2017-07-13 US		
其他公开文献	US20190019840A1		
外部链接	Espacenet		

摘要(译)

本文描述的实施例提供了光场显示器和形成光场显示器的方法，其中，每个微型LED阵列被配置为提供至少有效本机硬件分辨率的宏像素，其中每个宏像素提供空间分辨率的单个像素，并且多个其中，角分辨率的每个像素包括多个子像素，每个子像素由本文所述的定向准直微型LED器件提供。