US 20200135703A1

(19) United States
(12) Patent Application Publication
(10) Pub. No.: US 2020/0135703 A1
AHMED et al.
(43) Pub. Date: Apr. 30, 2020

(54) LIGHT FIELD DISPLAY FOR HEAD MOUNTED APPARATUS USING METAPIXELS

(71) Applicant: **Intel Corporation**, Santa Clara, CA (US)

(72) Inventors: **Khaled AHMED**, Anaheim, CA (US); **Richmond HICKS**, Aloha, OR (US); **Seth HUNTER**, Santa Clara, CA (US); **Alexey SUPIKOV**, San Jose, CA (US); **Jun JIANG**, Portland, OR (US)

(21) Appl. No.: **16/176,605**

(22) Filed: **Oct. 31, 2018**

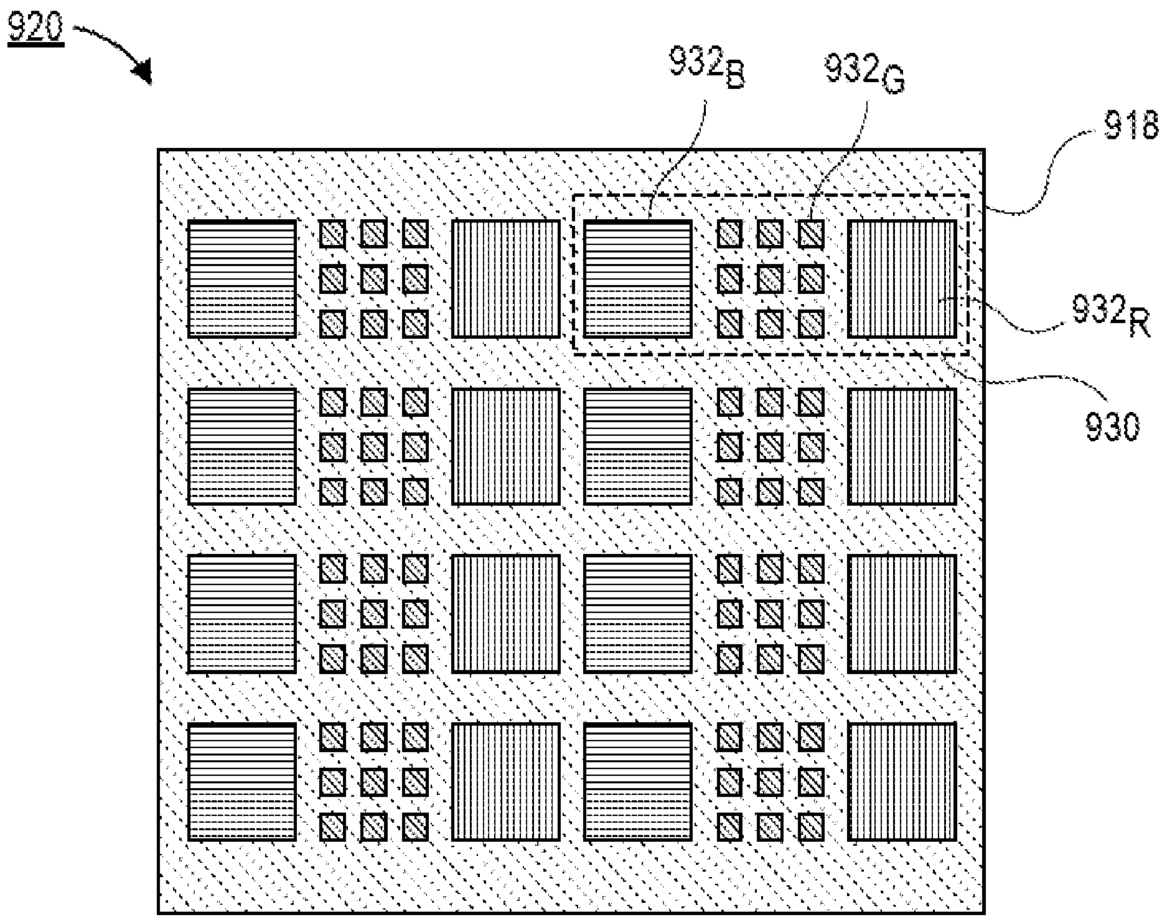
Publication Classification

(51) **Int. Cl.**
H01L 25/075 (2006.01)
G02B 27/22 (2006.01)
H01L 33/58 (2006.01)

(52) **U.S. Cl.**
CPC ***H01L 25/0753*** (2013.01); ***H01L 33/58*** (2013.01); ***G02B 27/22*** (2013.01)

(57) **ABSTRACT**

Embodiments disclosed herein include 3D displays with meta-surfaces and methods of forming such displays. In an embodiment, a display may comprise a display backplane substrate, and a light emission source on the display backplane substrate. In an embodiment, a meta-surface may be formed over the light emission source. In an embodiment, the meta-surface comprises a plurality of nano-features for modifying a path of light emitted by the light emission source.



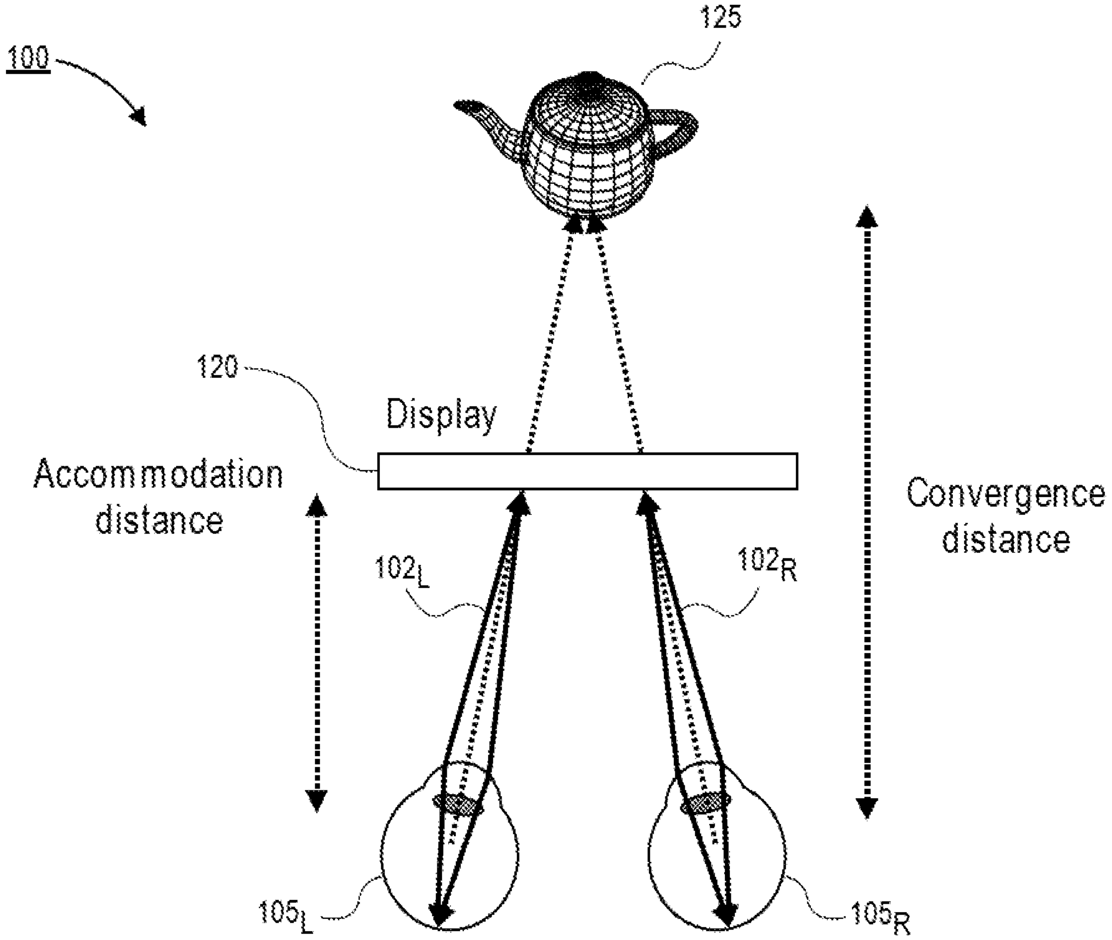

100
125
120
Display
Accommodation distance
Convergence distance
102_L
102_R
105_L
105_R

FIG. 1

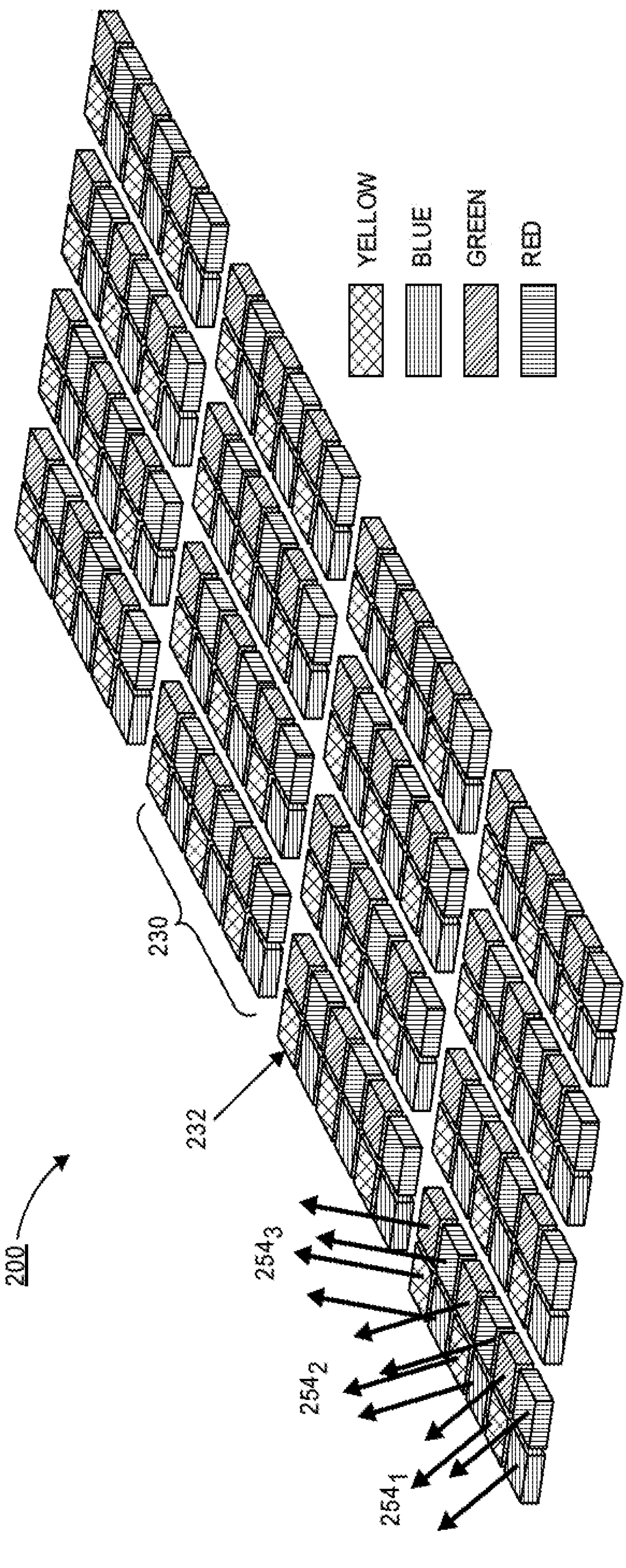


FIG. 2

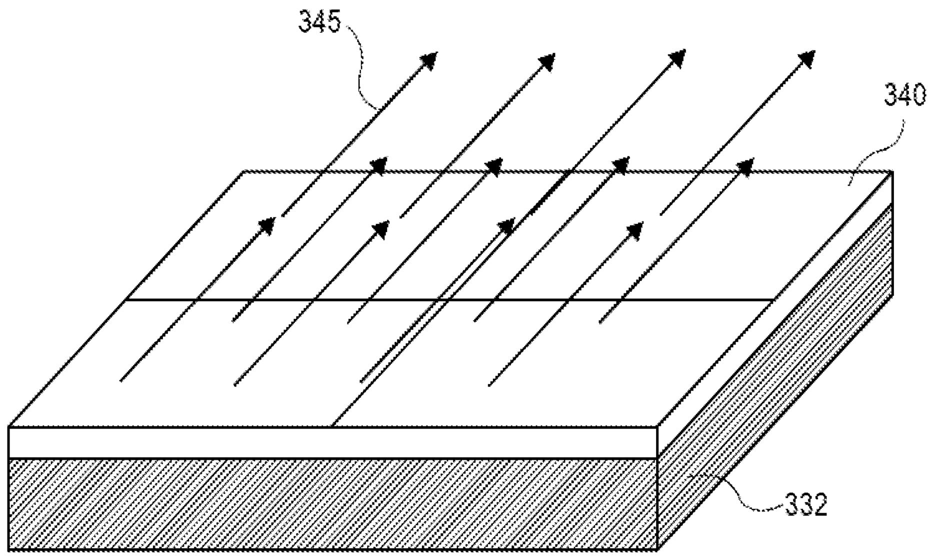


FIG. 3A

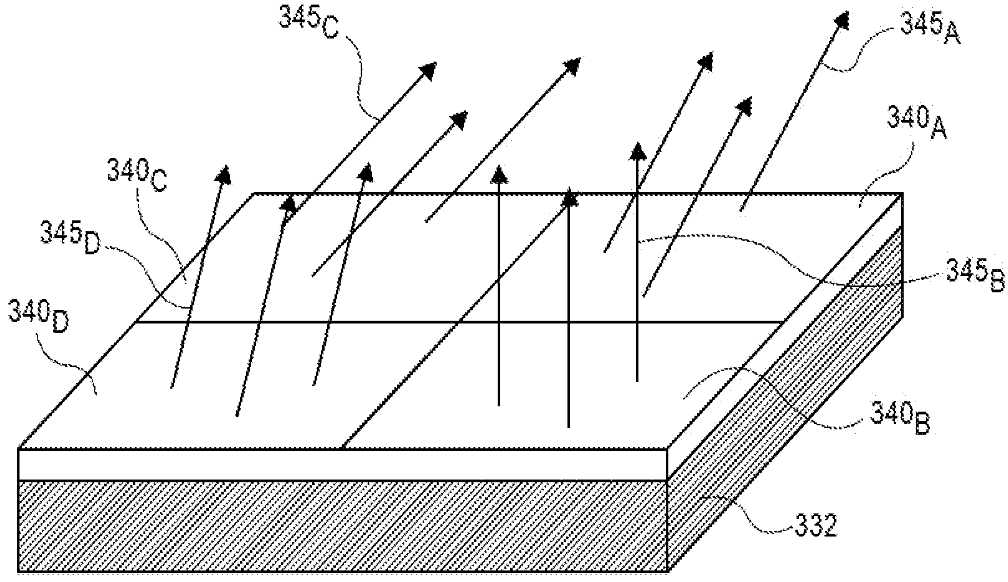


FIG. 3B

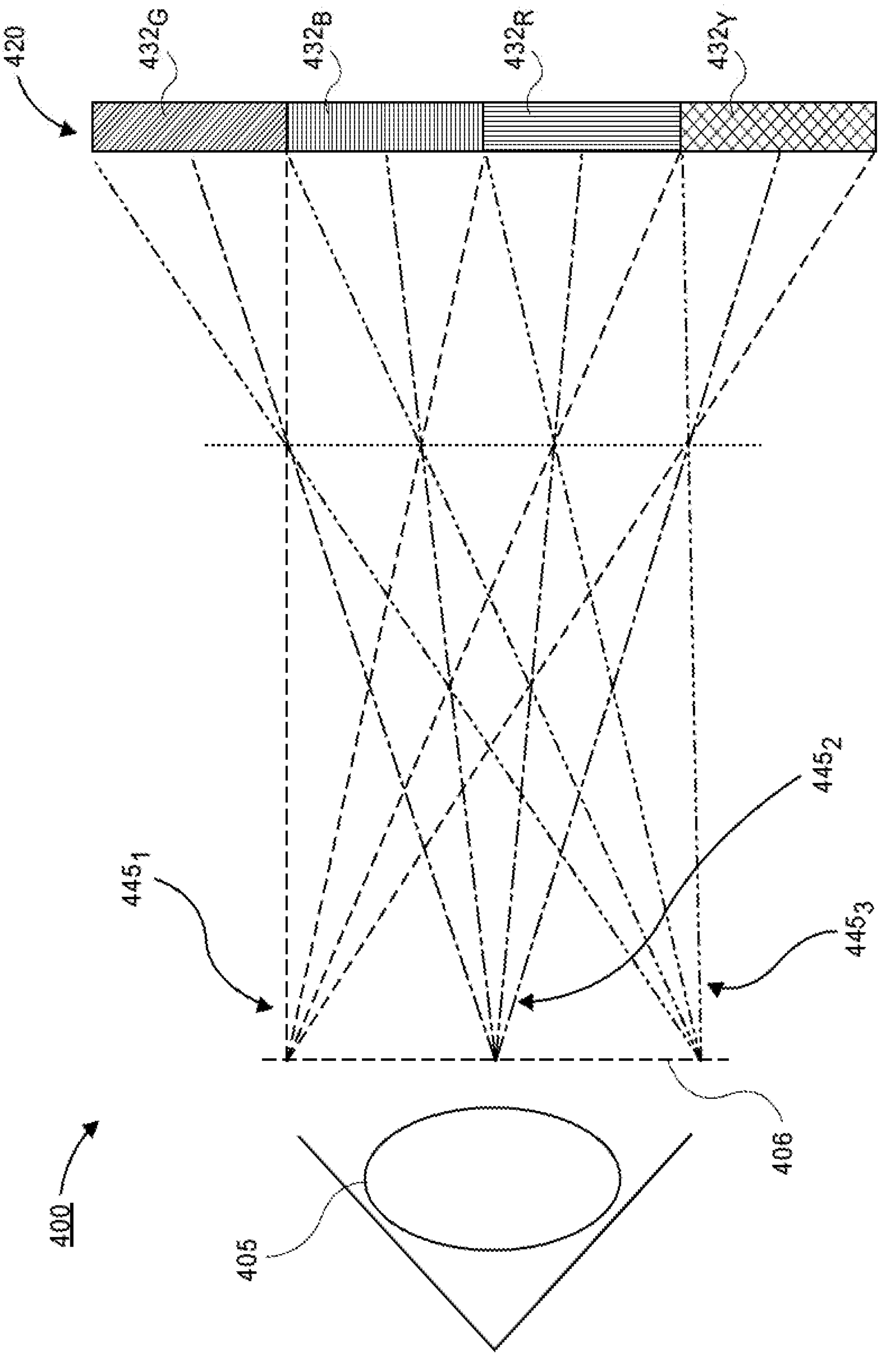


FIG. 4

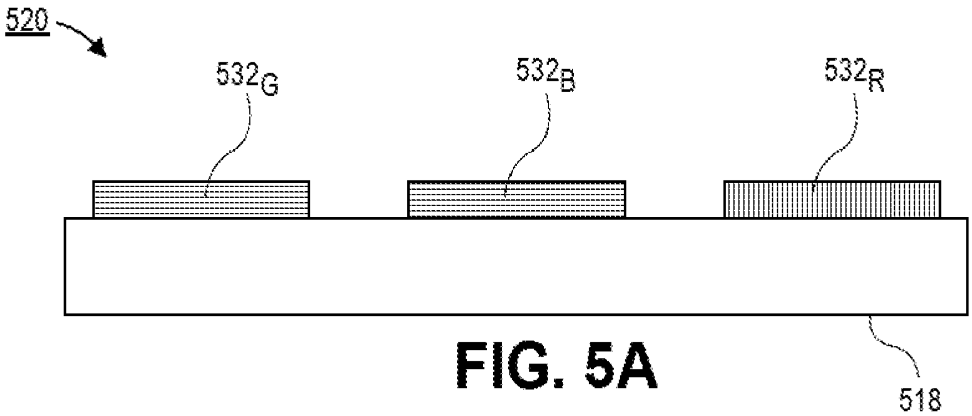


FIG. 5A

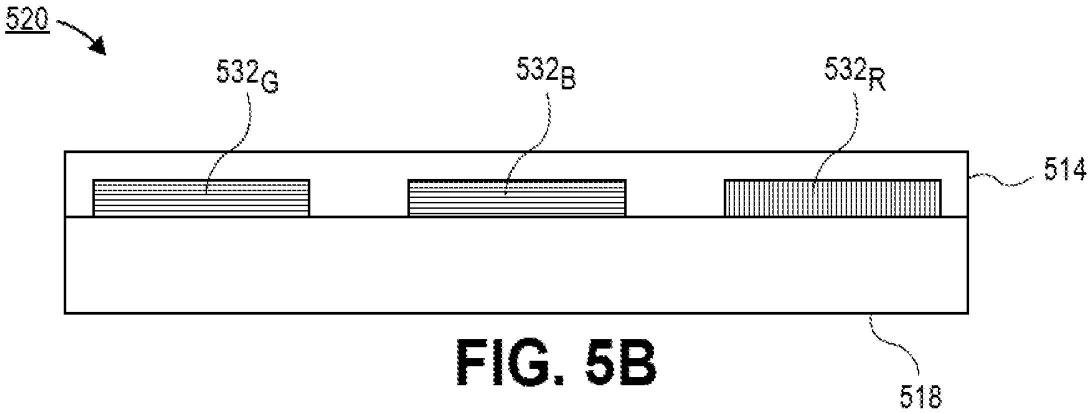


FIG. 5B

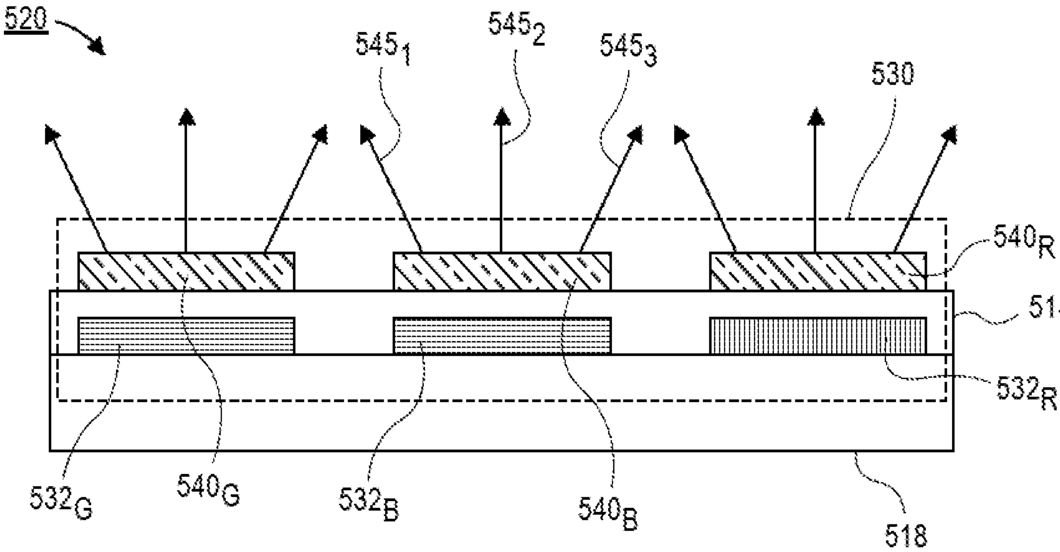


FIG. 5C

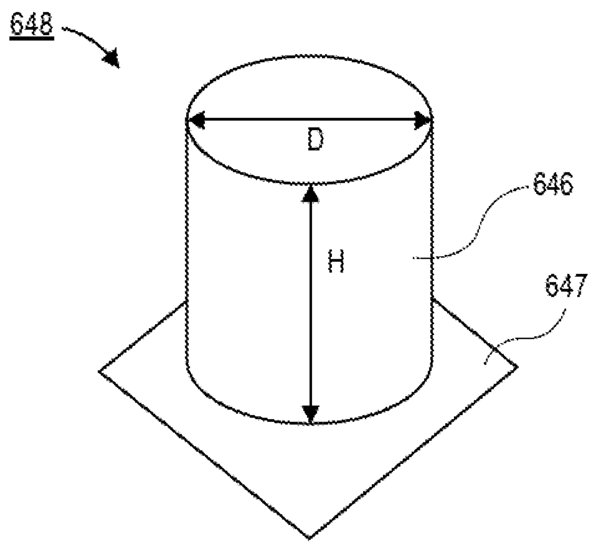


FIG. 6A

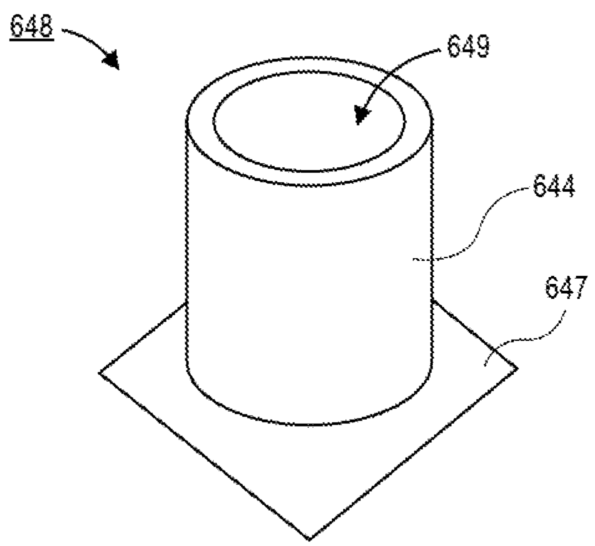


FIG. 6B

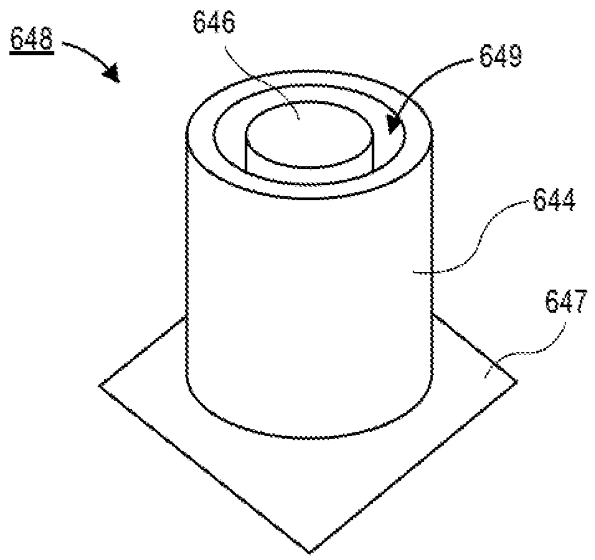


FIG. 6C

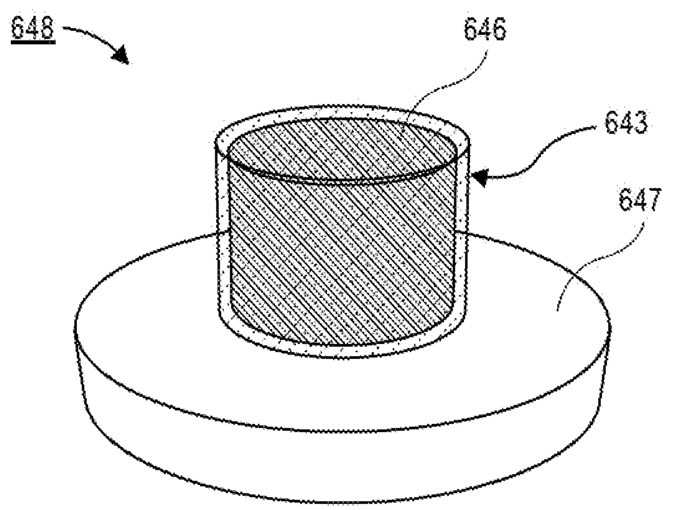


FIG. 6D

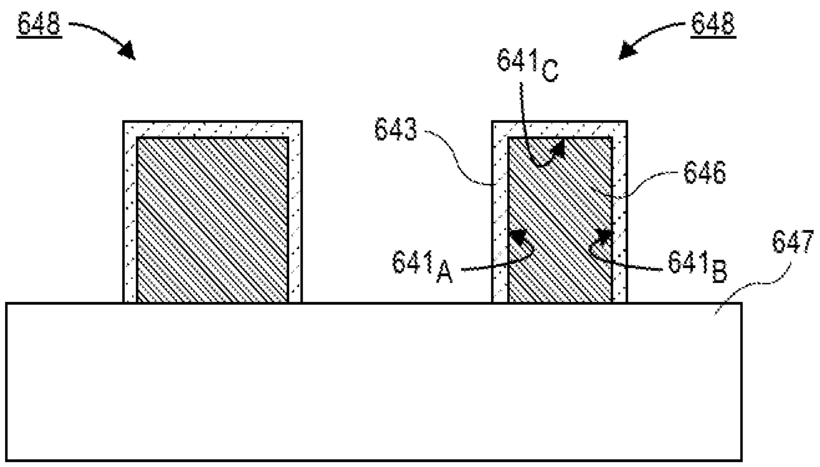


FIG. 6E

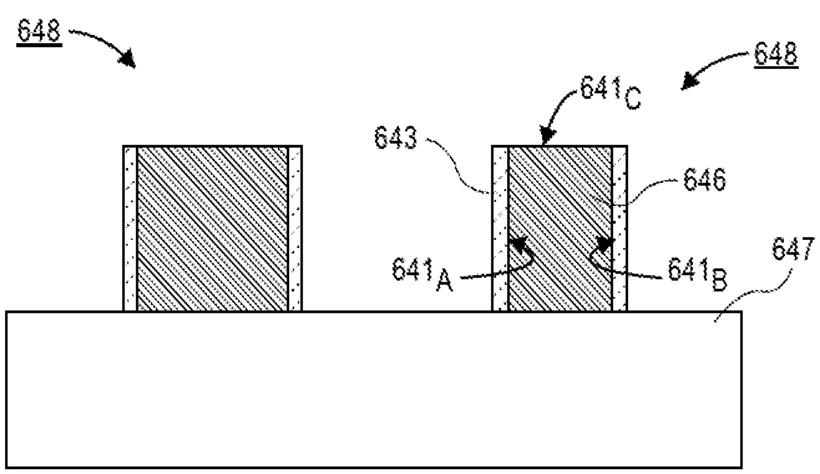


FIG. 6F

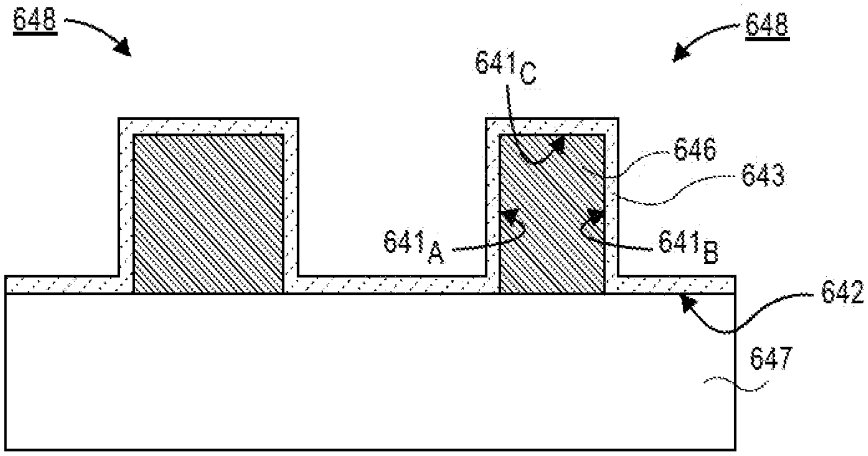


FIG. 6G

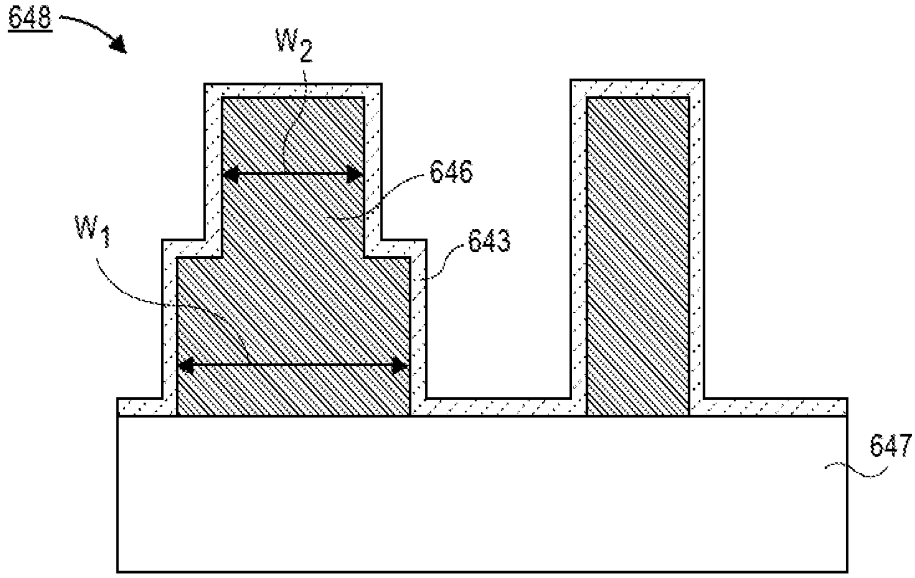


FIG. 6H

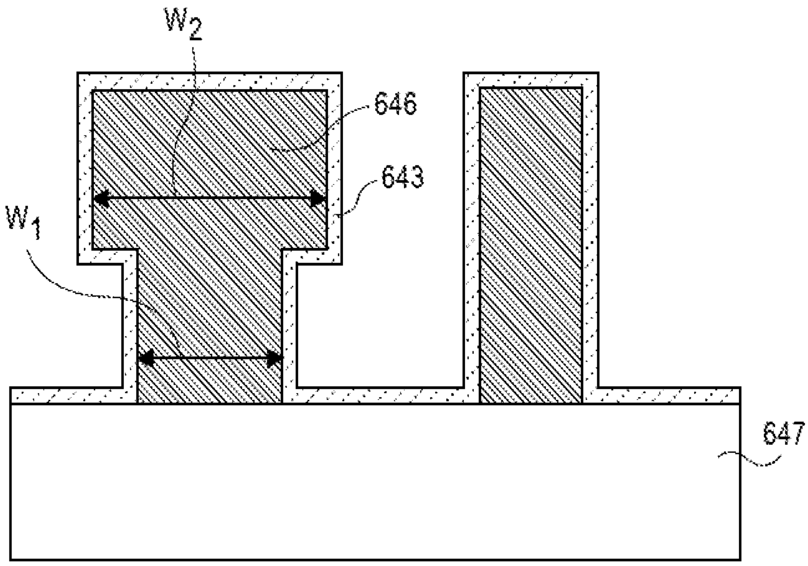


FIG. 6I

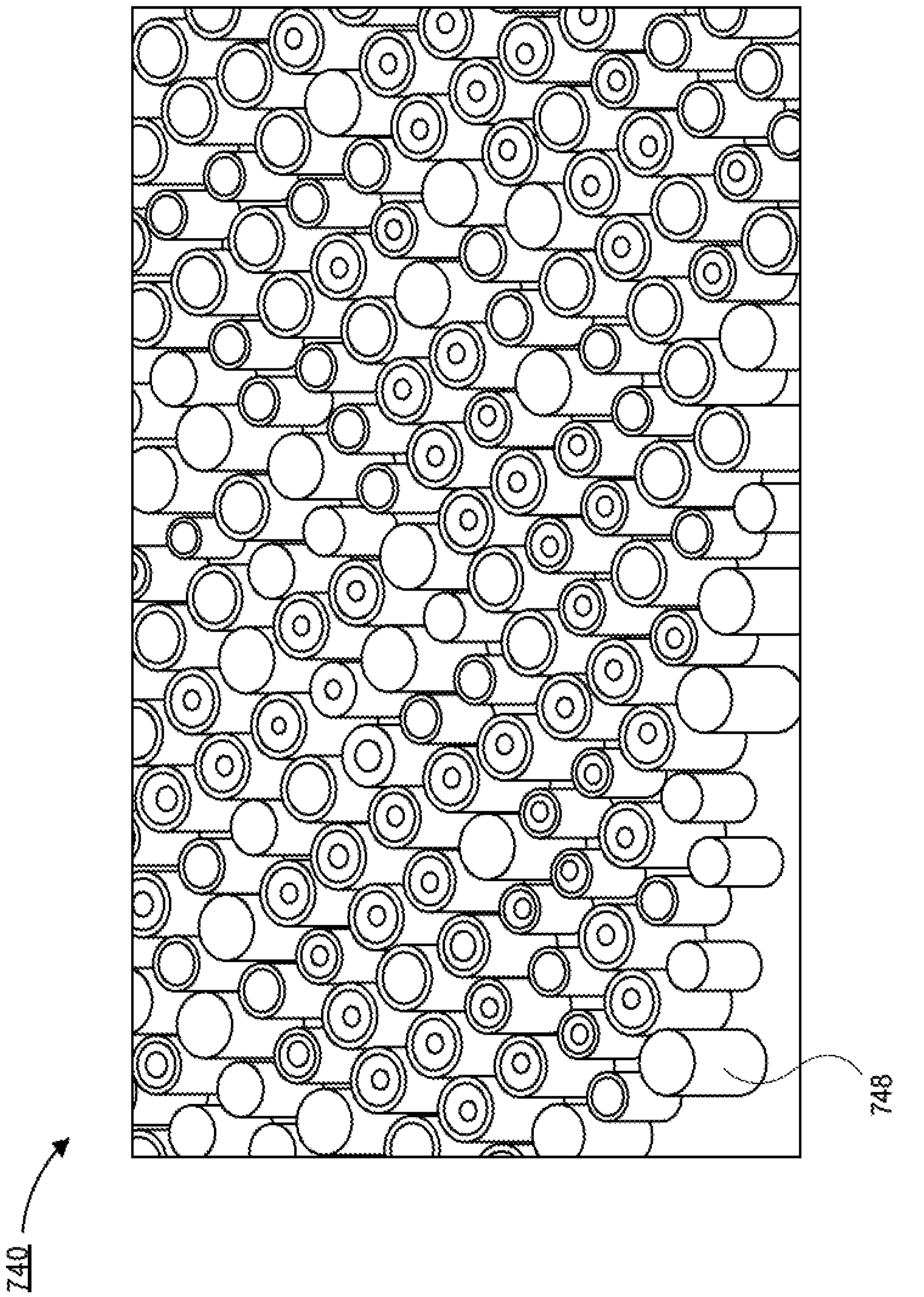


FIG. 7

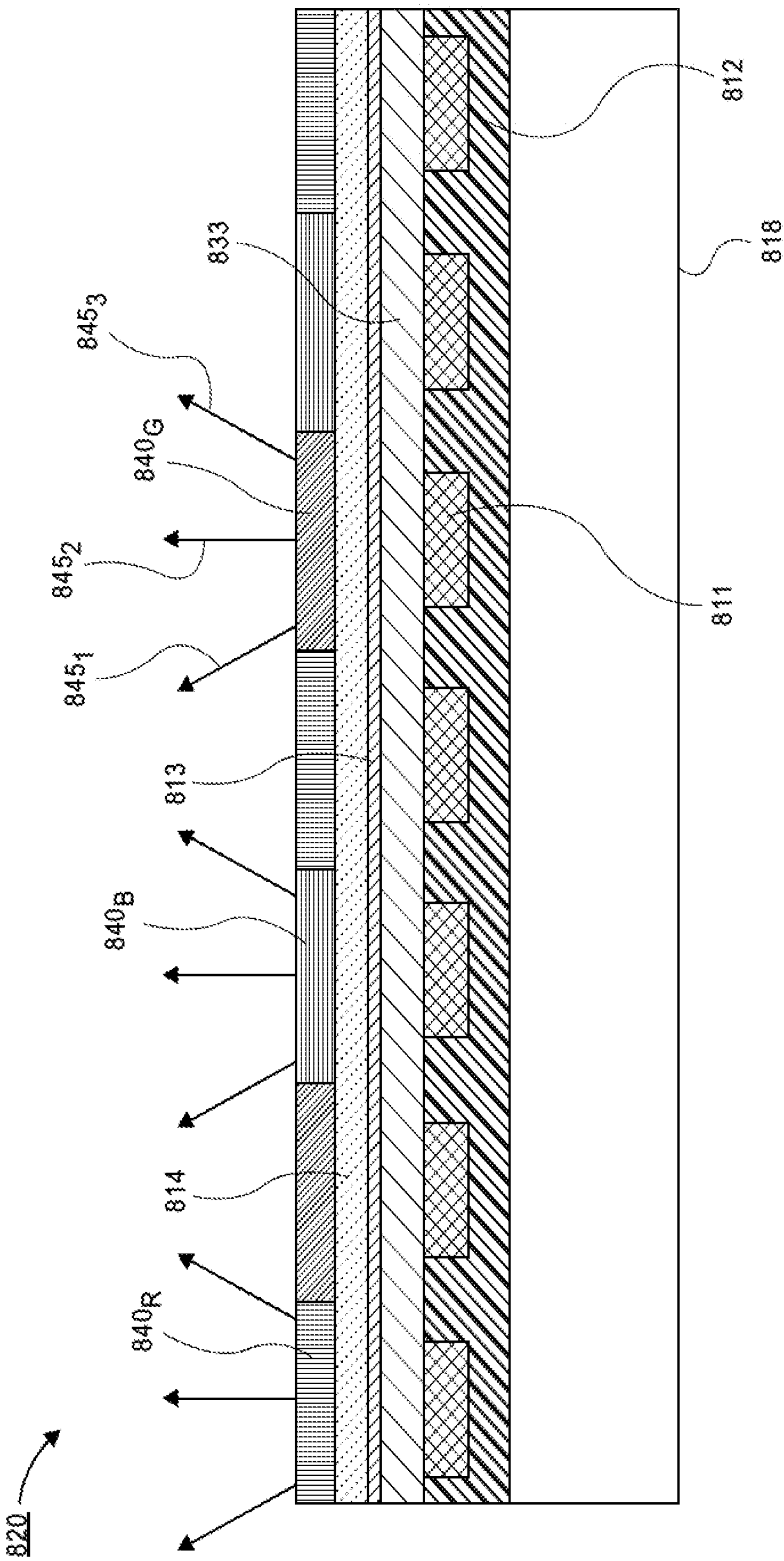


FIG. 8

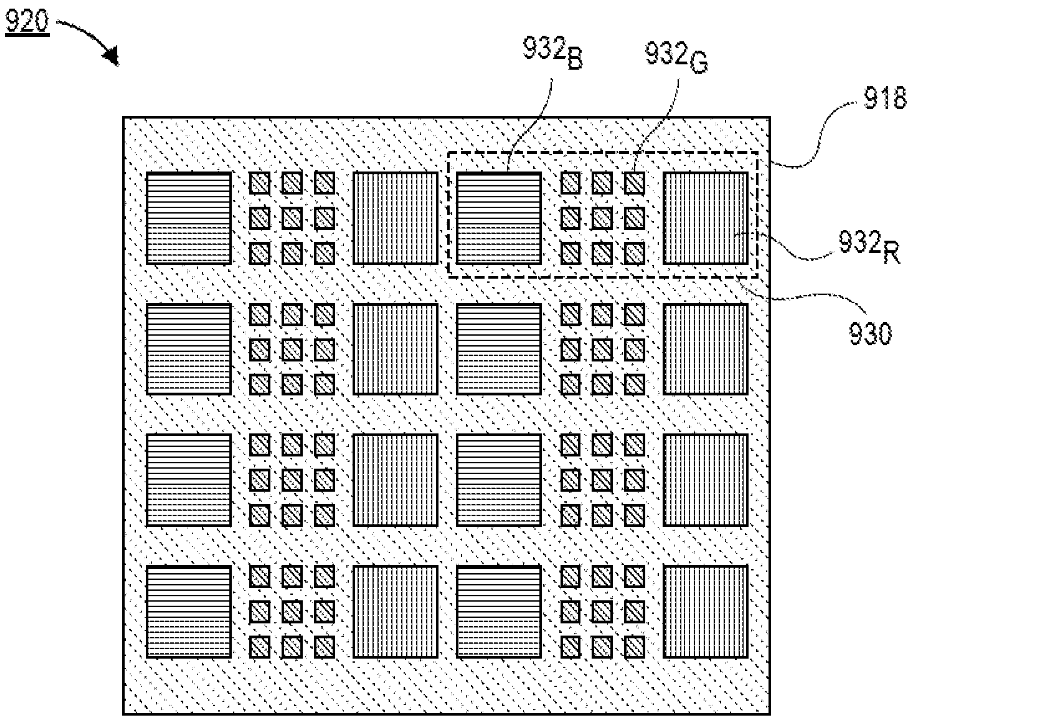

920
932B
932G
918
932R
930

FIG. 9A

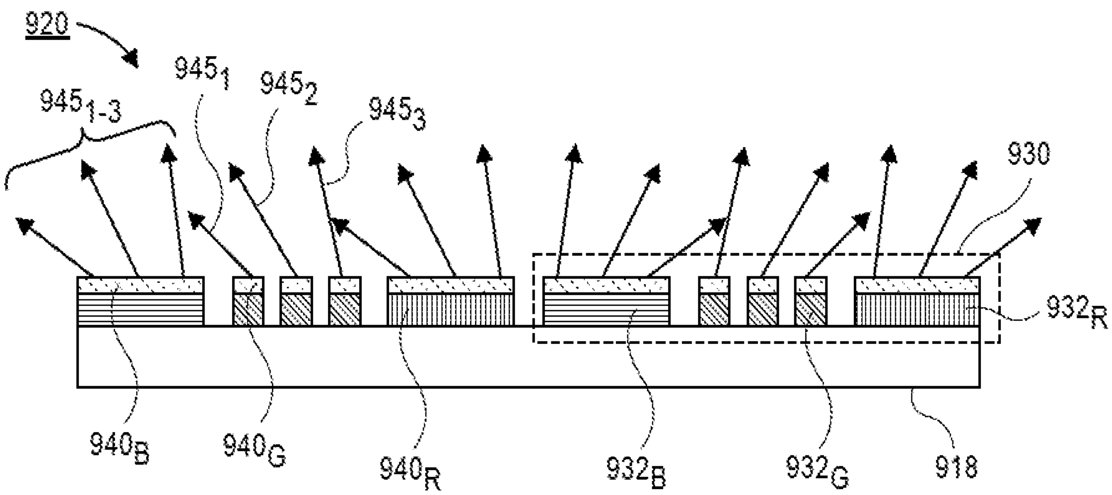

920
945_1
945_2
945_3
945_1-3
930
932R
940B
940G
940R
932B
932G
918

FIG. 9B

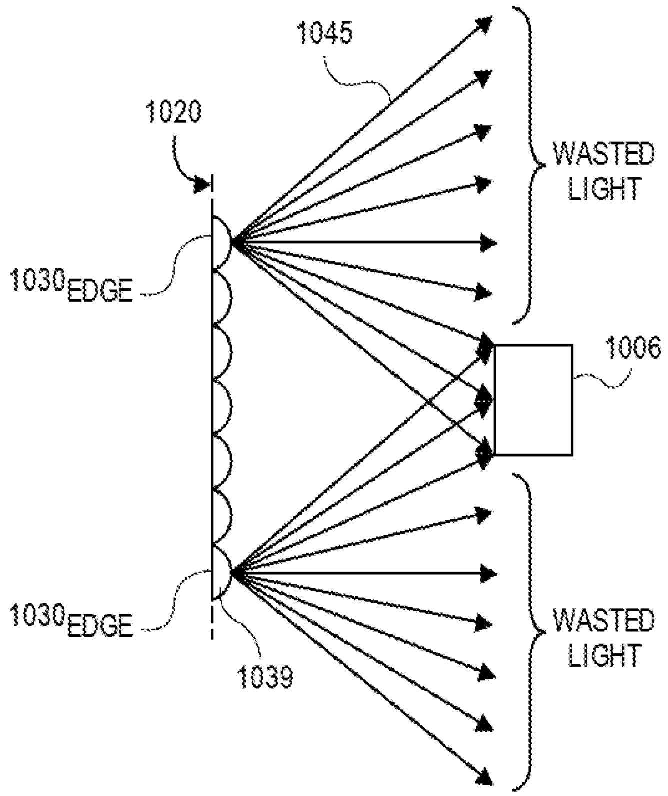


FIG. 10A

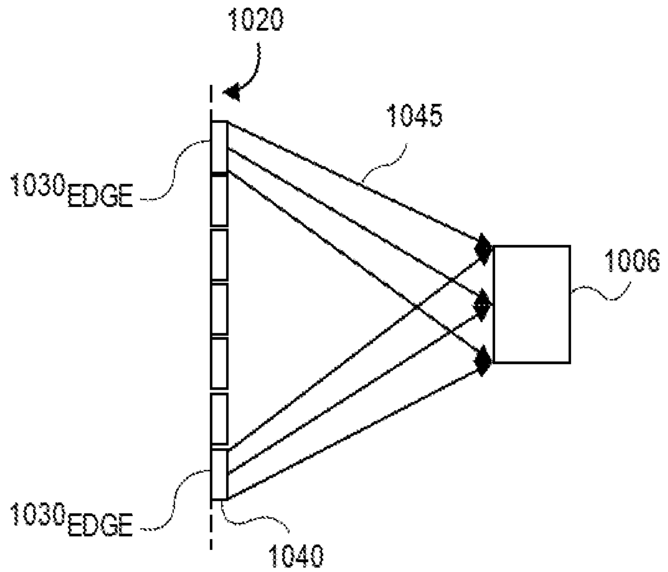


FIG. 10B

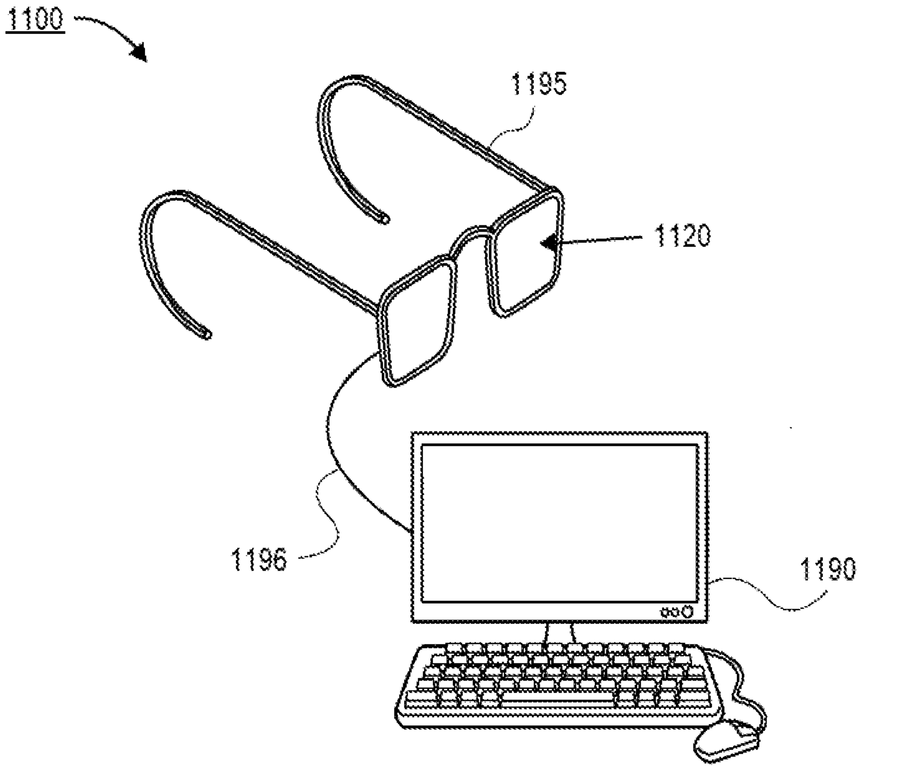


FIG. 11A

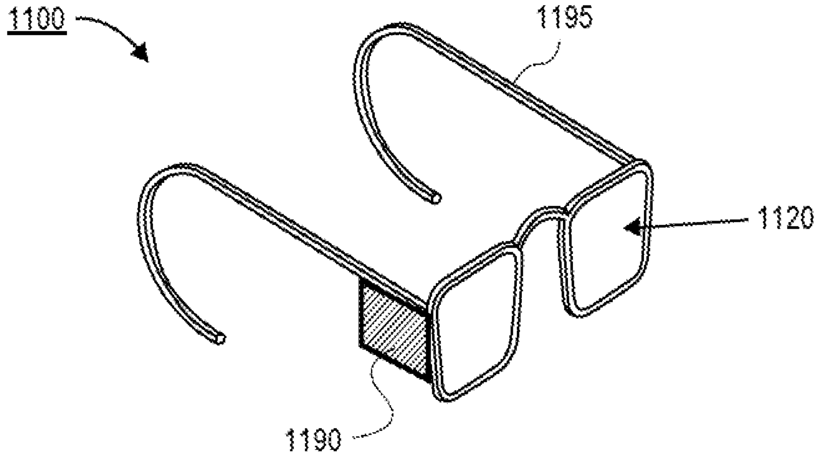


FIG. 11B

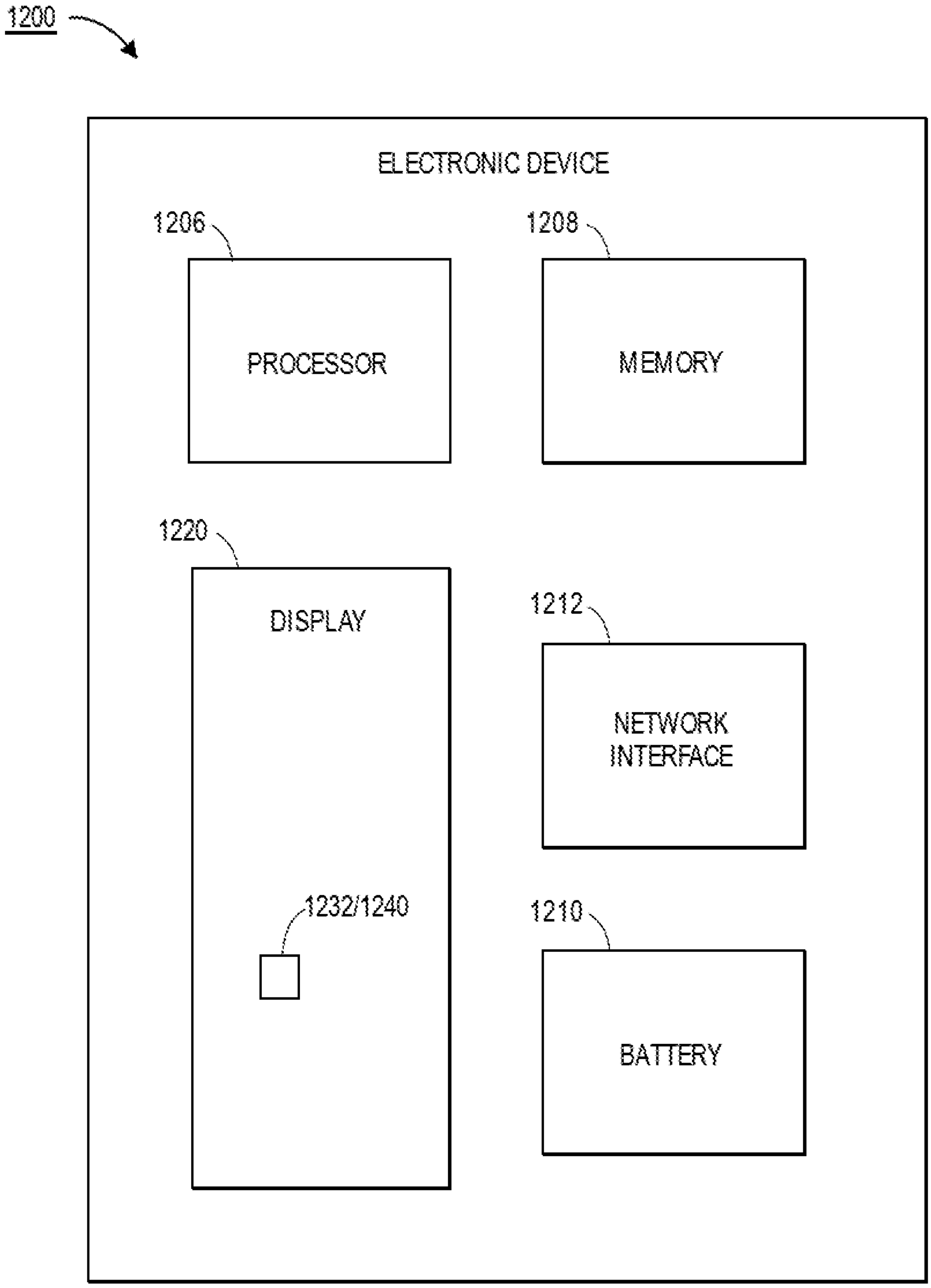

1200
ELECTRONIC DEVICE
1206
PROCESSOR
1208
MEMORY
1220
DISPLAY
1232/1240
1212
NETWORK INTERFACE
1210
BATTERY

FIG. 12

LIGHT FIELD DISPLAY FOR HEAD MOUNTED APPARATUS USING METAPIXELS

TECHNICAL FIELD

[0001] Embodiments of the disclosure are in the field of three-dimensional (3D) displays.

BACKGROUND

[0002] Despite the increased demand for virtual reality systems, the technology is still bulky and does not provide correct focus cues to the visual system. Currently available head-mounted displays generally rely on stereoscopic displays. Stereoscopic displays create 3D images by showing the left eye and right eye images that are slightly offset—the more offset, the closer an object appears. An example of a stereoscopic display is shown in FIG. **1**.

[0003] In FIG. **1**, a virtual image **125** is generated by the display **120** by delivering a first image **102**L to the left eye **105**L and a second image **1028** to the right eye **105**R. In such systems, the eyes are accommodating a screen that is 40 mm to 60 mm from the eyes **105** (i.e., the accommodation distance) while at the same time converging to a virtual plane of the virtual image **125** that is much further away (i.e., the convergence distance). This phenomena is called the "vergence-accommodation conflict" or convergence-accommodation mismatch. The vergence-accommodation conflict may cause eye fatigue and discomfort. In some users, the vergence-accommodation conflict may also contribute to virtual reality sickness.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] FIG. **1** is a schematic illustration of a stereoscopic three-dimension (3D) display.

[0005] FIG. **2** is a perspective view illustration of a display with subpixels that generate a multi-view light field, in accordance with an embodiment.

[0006] FIG. **3**A is a perspective view illustration of a subpixel with a meta-surface that provides a single view light field, in accordance with an embodiment.

[0007] FIG. **3**B is a perspective view illustration of a subpixel with a meta-surface that has a plurality of regions that generates a multi-view light field, in accordance with an embodiment.

[0008] FIG. **4** is a schematic illustration of a display that provides three light field views to an eye, in accordance with an embodiment.

[0009] FIGS. **5**A-**5**C are cross-sectional illustrations that depict a method of forming a display with a meta-surface over each subpixel, in accordance with an embodiment.

[0010] FIGS. **6**A-**6**C are perspective view illustrations of nano-features that may be used to form meta-surfaces, in accordance with an embodiment.

[0011] FIGS. **6**D-**6**I are perspective view and cross-sectional illustrations of nano-features that comprise a core and a coating, in accordance with an embodiment.

[0012] FIG. **7** is a perspective illustration of an exemplary meta-surface, in accordance with an embodiment.

[0013] FIG. **8** is a cross-sectional illustration of a display with meta-surfaces that are also color conversion devices, in accordance with an embodiment.

[0014] FIG. **9**A is a plan view illustration of a display with pixels that have more green subpixels than red subpixels or blue subpixels, in accordance with an embodiment.

[0015] FIG. **9**B is a cross-sectional illustration of the display in FIG. **9**A that illustrates the meta-surfaces, in accordance with an embodiment.

[0016] FIG. **10**A is a schematic of a display with lenses where light from the edge pixels is projected outside of an eye-box.

[0017] FIG. **10**B is a schematic of a display with meta-surfaces that direct light from the edge of the display into the eye-box, in accordance with an embodiment.

[0018] FIG. **11**A is a schematic of a head mounted display with a wired connection to a computing system, in accordance with an embodiment.

[0019] FIG. **11**B is a schematic of a head mounted display with an integrated computing system, in accordance with an embodiment.

[0020] FIG. **12** is an electronic device having a display, in accordance with embodiments of the present disclosure.

DESCRIPTION OF THE EMBODIMENTS

[0021] A display for providing multi-view light fields and methods of fabricating such displays are described. In the following description, numerous specific details are set forth, such as specific material and structural regimes, in order to provide a thorough understanding of embodiments of the present disclosure. It will be apparent to one skilled in the art that embodiments of the present disclosure may be practiced without these specific details. In other instances, well-known features, such as single or dual damascene processing, are not described in detail in order to not unnecessarily obscure embodiments of the present disclosure. Furthermore, it is to be understood that the various embodiments shown in the Figures are illustrative representations and are not necessarily drawn to scale. In some cases, various operations will be described as multiple discrete operations, in turn, in a manner that is most helpful in understanding the present disclosure, however, the order of description should not be construed to imply that these operations are necessarily order dependent. In particular, these operations need not be performed in the order of presentation.

[0022] Certain terminology may also be used in the following description for the purpose of reference only, and thus are not intended to be limiting. For example, terms such as "upper", "lower", "above", "below," "bottom," and "top" refer to directions in the drawings to which reference is made. Terms such as "front", "back", "rear", and "side" describe the orientation and/or location of portions of the component within a consistent but arbitrary frame of reference which is made clear by reference to the text and the associated drawings describing the component under discussion. Such terminology may include the words specifically mentioned above, derivatives thereof, and words of similar import.

[0023] As noted above, the vergence-accommodation conflict currently results in discomfort when viewing stereoscopic 3D images. Accordingly, embodiments disclosed herein include a display that generates 3D images through the use of light fields. Instead of flat images, light fields that mimic the angles of light that bounce off objects in the real world are used. Such light field images have been shown to minimize or eliminate the vergence-accommodation conflict.

[0024] In 3D displays, the intensity and color of light and the direction of the light rays need to be reproduced. The term "light field" is used herein to refer to the field of light either represented by a set of light rays or a wavefront (holography). Ideally, a perfect 3D display would reproduce a set of all the light rays (or light field) from a 3D scene. Although standard holography can perform this task well, the recording of a holographic medium is too slow to permit real-time operation. Auto-stereoscopic multi-view 3D displays can be realized using pure geometrical optics techniques, such as multi-projector, parallax barrier, integral imaging, or a combination of these. Multi-projector solutions have been demonstrated, but they are difficult to implement on a virtual reality device. Near-eye light field displays with microlens optical designs have also been demonstrated. However, the resolution tradeoff is directly proportional to the number of angular views provided. Additionally, some of the views are subject to absorption, scattering, and aberrations—particularly in the boundaries between the lenses.

[0025] Accordingly, embodiments disclosed herein include displays that comprise meta-surfaces over the subpixels for steering the emitted light instead of optical lenses. The small size of features (e.g., sub-wavelength) on the meta-surfaces allow for unique subpixel arrangements of different sizes and spacing, where each subpixel has its own angular meta-surface. The use of on-subpixel-meta-surfaces to control viewpoints in a light field display offers unique trade-offs between spatial resolution and viewpoints. For example, the number of views for green subpixels (i.e., luminance information) may be greater than the number of views for red and blue subpixels (i.e., chrominance information). Additionally, viewpoints may be tuned to expected eye-box locations in order to improve perceived resolution.

[0026] Referring now to FIG. **2**, a schematic illustration of a display **200** is shown, in accordance with an embodiment. In an embodiment, the display **200** may comprise a plurality of pixels **230**. The pixels **230** include subpixels **232**. In the illustrated embodiment, each pixel **230** includes twelve subpixels **232** (e.g., three each of red subpixels **232**, green subpixels **232**, blue subpixels **232**, and yellow subpixels **232**). However, it is to be appreciated that any number of subpixels **232**, any arrangement of subpixels **232**, and/or any color combinations may be chosen for the pixels **230**. Alternative subpixel configurations are described in greater detail below with respect to FIGS. **9**A and **9**B.

[0027] In an embodiment, each subpixel **232** may comprise a meta-surface that modifies the path of light **254** emitted by the respective subpixel **232**. For clarity, the meta-surfaces are not depicted in FIG. **2**. The meta-surfaces may be chosen to direct light at a chosen angle in order to generate a light field that is used to generate a 3D image. In an embodiment, each pixel **230** may comprise a plurality of views represented by light paths **254** of different angles. For example, a first view is provided by the light path $\mathbf{254}_1$, a second view is provided by the light path $\mathbf{254}_2$, and a third view is provided by path $\mathbf{254}_3$.

[0028] Referring now to FIG. **3**A, a perspective view of a subpixel **332** is shown, in accordance with an embodiment. In an embodiment, a meta-surface **340** may be positioned over the surface of the subpixel **332**. In the illustrated embodiment, the meta-surface **340** is directly over a top surface of the subpixel **332**. However, in some embodiments, one or more layers (e.g., transparent conductors or dielectrics) may be formed between the subpixel **332** and the meta-surface **340**.

[0029] In an embodiment, the meta-surface **340** is a material layer that is fabricated with features that are smaller than the wavelength of the light emitted by the subpixel **332**. The features of the meta-surface **340** modify the path of the light **345** in a predictable manner. The meta-surface **340** is described in greater detail below. In FIG. **3**A the entire meta-surface **340** provides a uniform modification of the path of the light **345**. That is, the angle of the emitted light **345** is uniform across the meta-surface **340**. However, embodiments are not limited to such configurations, and the meta-surface **340** may include a non-uniform meta-surface **340**.

[0030] An example of an embodiment with a non-uniform meta-surface **340** is shown in FIG. **3**B. As shown, a plurality of meta-surface regions **340**A-**340**D may be formed over a single subpixel **332**. Each of the meta-surface regions **340**A-**340**D may provide different angles to the emitted light **345**. As shown, emitted light **345**A in meta-surface region **340**A has a first angle, emitted light **345**B in meta-surface region **340**B has a second angle, emitted light **345***c* in meta-surface region **340***c* has a third angle, and emitted light **345**D in meta-surface region **340**D has a fourth angle. Accordingly, a plurality of views may be obtained from a single subpixel **332**.

[0031] Referring now to FIG. **4**, a schematic of a display system **400** with a display **420** emitting light towards an eye-box **406** in front of a user's pupil **405** is shown, in accordance with an embodiment. As shown, a single pixel (e.g., comprising subpixels $\mathbf{432}_G$, $\mathbf{432}_B$, $\mathbf{432}_R$, and $\mathbf{432}_Y$) is capable of providing a plurality of views $\mathbf{445}_1$-$\mathbf{445}_3$. For example, each subpixel **432** may emit light $\mathbf{445}_{1\text{-}3}$ that contributes to the one of the three views seen by the pupil **405**. While not shown in FIG. **4**, it is to be appreciated that a meta-surface may be formed over each of the subpixels **432** in order to modify the light **445** to provide the three different views.

[0032] Referring now to FIGS. **5**A-**5**C, a series of cross-sectional illustrations depict a method of forming a meta-surface over subpixels, in accordance with an embodiment.

[0033] In FIG. **5**A, a cross-sectional illustration of a display **520** with a display backplane **518** that comprises a green subpixel $\mathbf{532}_G$, a blue subpixel $\mathbf{532}_B$, and a red subpixel $\mathbf{532}_R$ is shown, in accordance with an embodiment. While illustrated schematically as a solid block, it is to be appreciated that the display backplane **518** may comprise a substrate (e.g., a glass substrate) with circuitry (e.g., thin film transistors) and data driver and scan driver chips for controlling pixel circuits. The display backplane **518** may also comprise one or more dielectric layers to isolate components, as is known to those skilled in the art.

[0034] In an embodiment, the subpixels **532** on the display backplane **518** may be any suitable light emitting device. In a particular embodiment, the subpixels **532** may be micro light emitting diode (LED) devices. For example, the subpixels **532** may be formed on one or more source wafers (e.g., silicon wafers) and transferred to the display backplane **518** with a pick-and-place process, or a direct transfer from the source wafer to the display backplane **518**. While explicitly disclosing micro LED devices, it is to be appreciated that other light emitting devices, such as organic LEDs (OLEDs) may also be used in accordance with embodiments described herein.

[0035] Referring now to FIG. **5**B, a cross-sectional illustration after a transparent dielectric layer **514** is formed over the subpixels **532** is shown, in accordance with an embodiment. In an embodiment, the transparent dielectric layer **514** may be titanium oxide (TiO_2), hafnium oxide (HfO_2), zirconium oxide (ZrO_2) or the like. The transparent dielectric layer **514** may have a refractive index that is lower than the refractive index of semiconductor material of the subpixels **532** and serve as an index matching layer that reduces total internal reflections of light emitted by the subpixels **532**.

[0036] Referring now to FIG. **5**C, a cross-sectional illustration after the meta-surfaces **540** are positioned over the subpixels **532** is shown, in accordance with an embodiment. In an embodiment, a first meta-surface $\mathbf{540}_G$ may be positioned over the first subpixel $\mathbf{532}_G$, a second meta-surface $\mathbf{540}_B$ may be positioned over the second subpixel $\mathbf{532}_B$, and a third meta-surface $\mathbf{540}_R$ may be positioned over the third subpixel $\mathbf{532}_R$ in order to form a pixel **530**. In FIG. **5**C, the pixel **530** is shown with three different colors (e.g., the first subpixel $\mathbf{532}_G$ is green, the second subpixel $\mathbf{532}_B$ is blue, and the third subpixel $\mathbf{532}_R$ is red). However, it is to be appreciated that the pixel **530** may be formed with any combination of colors, and any number of each color. Furthermore, while the cross-sectional illustration depicts the three subpixels in a row, other embodiments may include subpixels arranged in a 2×2, 3×3, etc. configuration.

[0037] In an embodiment, each meta-surface **540** may modify the light **545** emitted by the underlying subpixel **532**. For example, each meta-surface **540** may provide a uniform modification of the light **545** (i.e., similar to what is shown in FIG. **3**A) in order to provide a single view, or each meta-surface **540** may provide a plurality of different modifications to the light **545** (i.e., similar to what is shown in FIG. **3**B) in order to provide a plurality of views. In the embodiment illustrated in FIG. **5**C, each of the meta-surfaces **540** provide light $\mathbf{545}_1$ at a first angle, light $\mathbf{545}_2$ at a second angle, and light **5453** at a third angle.

[0038] In an embodiment, the meta-surfaces **540** in the pixel **530** may provide the same angle (or angles) of light **545** emitted by all of the subpixels **532** within the pixel **530**. Different pixels **530** may provide different angles (i.e., the meta-surface provides a desired angle of light **545** that depends on the location of the pixel **530** on the display backplane **518**). While all meta-surfaces **540** within a given pixel may provide the same angle of emitted light **545**, it is to be appreciated that the meta-surfaces **540** may not all be the same. Particularly, the angle of the emitted light **545** is partially dependent on the wavelength of the light. That is, for a given meta-surface **540**, the angle of the emitted light **545** will be different for a green subpixel $\mathbf{532}_G$, a blue subpixel $\mathbf{532}_B$, and a red subpixel $\mathbf{532}_R$. Accordingly, the first meta-surface $\mathbf{540}_G$ may be designed to steer light emitted by the first color subpixel $\mathbf{532}_G$, the second meta-surface **540**E may be designed to steer light emitted by the second color subpixel $\mathbf{532}_B$, and the third meta-surface **5408** may be designed to steer light emitted by the third color subpixel $\mathbf{532}_R$.

[0039] In an embodiment, the meta-surfaces **540** may be placed over the respective subpixels **532** with a transfer process. That is, the meta-surfaces **540** may be fabricated on one or more source substrates and subsequently transferred to the display backplane **518**. For example, a meta-surface material layer (e.g., a transparent dielectric, such as TiO_2) may be deposited over a substrate. Features with a dimension less than the wavelength of the light emitted by the subpixel may then be patterned into the meta-surface material layer (e.g., with 193 nm immersion ArF laser steppers or nanoimprint lithography). Examples of features suitable to form meta-surfaces are described in greater detail below with respect to FIGS. **6**A-**6**C.

[0040] The ability to steer the light emitted by the subpixels is provided by controlling the phase distribution of the light waves. In meta-surfaces such as those described herein, the required phase distribution is realized by controlling the size and distribution of nano-features of the meta-surface. In an embodiment, the meta-surface device may comprise an array of nano-features that are formed of a material that has a low loss for visible light (e.g., TiO_2, GaP, $ZrTiO_4$, $HfTiO_4$, or the like).

[0041] Referring now to FIGS. **6**A-**6**C, cross-sectional illustrations of exemplary nano-features are shown, in accordance with embodiments. In FIG. **6**A, the nano-feature **648** comprises a post **646** over a substrate **647**. The post **646** may have a diameter D that is less than the wavelength of the light emitted by an underlying subpixel. The post **646** may have a height H that is approximately 300 nm or less. In FIG. **6**B, the nano-feature **648** comprises a shell **644** formed over the substrate **647**. The shell **644** may have an opening **649** formed through its center. In FIG. **6**C, the nano-feature **648** comprises a shell **644** with a post **646** in the opening **649**. A meta-surface with a plurality of different types of nano-features **648** provides improved flexibility in the design of the meta-surface since the different types of nano-features provide different phase dispersions. For example, nano-features **648** that comprises a pillar **646** are highly dispersive (i.e., the pillars cause larger phase delays for light with shorter wavelengths), and nano-features **648** that comprise a shell **644** are less dispersive.

[0042] In FIGS. **6**A-**6**C, the nano-features **648** are all illustrated as monolithic features formed from a single material. However, it is to be appreciated that material limitations in such embodiments may not provide a desired light extraction efficiency. Such nano-features are typically formed with exceptionally high refractive index materials (e.g., greater than 3.0). For example, meta-surfaces for beam shaping have been developed for near-infrared light using high refractive index material such as silicon. These silicon-based meta-surface structures, however, absorb an undesirably large percentage of impinging light (e.g., 40% or more) in the visible range (e.g. red, green and blue). Visible wavelength transparent materials, such as silicon nitride (Si_3N_4) with a refractive index of about 2.0, have not been considered to have a sufficiently high refractive index to support the optical resonance desired to effectively manipulate optical wave-fronts. The use of titanium oxide (TiO_2) with refractive index of approximately 2.4-2.6 has been proposed for meta-surfaces operating with visible lights. However, the lower refractive index contrast compared to silicon of nanostructures formed with TiO_2 require very high aspect ratios (e.g., 5-10), which makes the fabrication very challenging. For example, the deposition of approximately 600 nm of TiO_2 using atomic layer deposition (ALD) is very expensive because of the small deposition rate of ALD process (e.g., approximately 0.05 nm/s).

[0043] It is generally believed that meta-surfaces require sufficiently large dielectric contrast relative to their background environment to enable the confinement and manipulation of light within nanoscale structures. For visible light, the highest index materials (Si or Ge) suffer from large optical loss due to small band gap (≤1.12 eV). Accordingly, embodiments disclosed herein include nano-features **648** that combine materials with high light confinement and low optical absorption in the visible range, while achieving high manufacturing throughput which is essential for low manufacturing cost. Examples of such nano-features are illustrated in FIGS. **6**D-**6**I.

[0044] Referring now to FIG. **6**D, a perspective view illustration of a nano-feature **648** with a core **646** and a coating **643** over a substrate **647** is shown in accordance with an embodiment. As shown, the nano-feature **648** may comprise a core material **646** that is covered by a coating **643**. In an embodiment, the core **646** may be cylindrical, though other shaped cores **646** are possible. In an embodiment, the core **646** may be a material with relatively low refractive index. For example, the core **646** may be Si_3N_4. In an embodiment, the core **646** may be surrounded by an ultrathin coating material **643** with high refractive index. For example, the coating **643** may be TiO_2 or Si). The thin dimension of the coating **636** layer enables a small optical path to minimize optical loss. Furthermore, it is to be appreciated that such a nano-feature **648** improves manufacturability. For example, the deposition rate of the thick core **646** (e.g., Si_3N_4) may be much higher than that of the coating (e.g., TiO_2), enabling high throughput. The thin TiO_2 or Si "coating" may be deposited using ALD which provides excellent thickness control and the required conformality around the core.

[0045] Referring now to FIG. **6**E, a cross-sectional illustration of a pair of nano-features **648** is shown, in accordance with an embodiment. In an embodiment, the nano-features **648** may comprise a core **646** with a coating **643** surrounding all exposed surfaces. For example, the coating **643** may be formed over the sidewalls **641**A and **641**B, and over the top surface **641***c* of the core **646**. Due to the deposition with an ALD process, the thickness of the coating **643** may be uniform over all surfaces.

[0046] Referring now to FIG. **6**F, a cross-sectional illustration of a pair of nano-features **648** is shown, in accordance with an additional embodiment. In an embodiment, nano-features **648** may be substantially similar to nano-features **648** in FIG. **6**E, with the exception that the coating **643** is omitted from the top surface **641***c* of the core **646**. In some embodiments, the coating **643** may be polished off of the top surface **641***c*. Additional embodiments may include masking the top surface **641***c* to prevent deposition if the coating **643**.

[0047] Referring now to FIG. **6**G, a cross-sectional illustration of a pair of nano-features **648** is shown, in accordance with an additional embodiment. In an embodiment, nano-features **648** may be substantially similar to nano-features **648** in FIG. **6**E with the exception that the coating **643** is also formed over surface **642** of the substrate **647**.

[0048] Referring now to FIGS. **6**H and **61**, cross-sectional illustrations of nano-features **648** are shown in accordance with additional embodiments. In FIGS. **6**H and **61**, one of the two nano-features **648** are shown as having non-uniform cross-sections. That is, a width of the core **646** may be non-uniform. For example, in FIG. **6**H a first width W_1 towards the bottom of the core **646** may be greater than a second width W_2 towards the top of the core **646**. In an alternative embodiment illustrated in FIG. **6**I, the first width W_1 is less than the second width W_2. While embodiments show two distinct widths W_1 and W_2, it is to be appreciated that the core **346** may comprise any number of different widths (e.g., two or more). Additionally, the width may be continuously changing (e.g., sidewalls of the core **346** may be tapered, or the like.

[0049] FIG. **7** provides an example of a meta-surface **740** with an array of nano-features **748**, in accordance with an embodiment. In an embodiment, the positioning and type of nano-features **748** in the array is chosen to provide a desired modification to light emitted by an underlying subpixel. The nano-features **748** may have different diameters and be arranged in a lattice (e.g., a hexagonal lattice). Each of the nano-features **748** may be considered as a short waveguide with circular cross-section truncated on both sides—operating as a low-quality-factor Fabry-Perot resonator. The circular cross-section of the nano-features **748** allows for polarization insensitive operation. Due to the high index contrast between the nano-features **748** and the surrounding, the nano-features **748** behave as independent scatterers with small cross-coupling. The phase and amplitude of the scattered light depends on the diameter of the posts. The phase of the transmitted light, which is the sum of the incident and forward scattered light, can be controlled to take any value in the 0-2π range by properly selecting the post diameter. The local transmission coefficient of an array of nano-features **748** with gradually varying diameters can be approximated by the transmission coefficient of a uniform periodic array of nano-features **748**. The subwavelength lattice constant and the large number of phase steps provided by the continuous post diameter-phase relation, enables accurate implementation of any phase profile optimized for a specific application. To design the proper array, an algorithm may be used to select the best nano-feature **748** from a library (e.g., a library including different nano-features **648**, such as those shown in FIGS. **6**A-**6**C) for each position on the meta-surface based on the required phase dispersion.

[0050] Referring now to FIG. **8**, a cross-sectional illustration of a display **820** that includes meta-surfaces **840** that also function as color conversion devices is shown, in accordance with an additional embodiment. In an embodiment, the display **820** may include a display backplane **818**. A plurality of anodes **811** may be formed in a dielectric layer **812**. In an embodiment, a white OLED **833** may be formed over the anodes **811**. A transparent cathode **813** may be formed over the white OLED **833**. In an embodiment, a passivation layer **814** may be formed over the transparent cathode **813**.

[0051] In an embodiment, a plurality of meta-surfaces **840** may be formed over the white OLED **833**. Each meta-surface **840** may comprise nano-features that provide one or more views of light $\mathbf{845}_1$-$\mathbf{845}_3$. Additionally, the meta-surfaces **840** may be color conversion devices. That is, the meta-surfaces **840** may change the white light emitted by the white OLED **833** to a colored light. For example, meta-surfaces $\mathbf{840}_R$ may convert white light to red light, meta-surfaces $\mathbf{840}_B$ may convert white light to blue light, and meta-surfaces $\mathbf{840}_G$ may convert white light to green light. In an embodiment, the color conversion may be implemented with quantum dots, nanophosphors, or the like.

[0052] In the illustrated embodiment, color light (e.g., green, blue red) is obtained from a single white OLED **833** by three different color changing meta-surfaces $\mathbf{840}_G$, $\mathbf{840}_B$, $\mathbf{840}_R$. However, it is to be appreciated that embodiments may also include color changing devices for one or more of the colors in a pixel. For example, blue micro LEDs may be used as the source for each color, and red color changing meta-surfaces and green color changing meta-surfaces may be used to convert blue light to red light and green light. In some embodiments, only the meta-surface for red subpixels comprises a color changing device.

[0053] The use of meta-surfaces in combination with micro LEDs allows several advantages over other techniques. Placing a unique meta-surface above each subpixel enables independent control of the angle/view of each subpixel. This in combination with the variable pixel size enabled by using micro LEDs allows for unique opportunities for optimization. One optimization includes the trade off of luminance and chrominance resolution in terms of viewpoints. The eye is considerably less sensitive to red and blue light in the visible color space, so optimizing the resolution of green subpixels (i.e., luminance) relative to red and blue subpixels (i.e., chrominance) enables a higher resolution of perceived pixels. A display **920** that takes advantage of this tradeoff is shown in FIGS. **9**A and **9**B.

[0054] As shown in the plan view illustration in FIG. **9**A, a display **920** may comprise a plurality of pixels **930** on a display backplane **918**. Each pixel may comprise a plurality of sub-pixels (e.g., blue subpixels $\mathbf{932}_B$, red subpixels $\mathbf{932}_R$, and green subpixels **932**G). In an embodiment, the number of green subpixels **932**G may be greater than the number of blue subpixels $\mathbf{932}_B$ or red subpixels $\mathbf{932}_R$. For example, there may be nine green subpixels **932**G for every one blue subpixel $\mathbf{932}_B$ or red subpixel $\mathbf{932}_R$.

[0055] Referring now to FIG. **9**B, a cross-sectional view illustrates the light **945** from the subpixels. As shown, each green subpixel **932**G may have a unique path for the light $\mathbf{945}_1$, $\mathbf{945}_2$, or $\mathbf{945}_3$. The same number of views may be spread over each individual blue subpixel $\mathbf{932}_B$ or red subpixel $\mathbf{932}_R$. By implementing different optical functions over the individual pixels, the energy from the red subpixels $\mathbf{932}_R$ and blue subpixels $\mathbf{932}_B$ may be spread over multiple viewpoints. This may reduce the number of pixels required for a given spatial and angular resolution by up to 50%.

[0056] A second non-uniform optimization is illustrated in FIGS. **10**A and **10**B. In cases where the parallax views which need to be supported across the display is significant—which is common in far eye displays or any display with a large field of view and a fixed view point—generating a wide field of viewpoints with a lens array for each set of elemental images under a lens leads to many viewpoints being generated that are not in fact visible to the user.

[0057] For example, in the schematic of a display **1020** with a lens based array, pixels $\mathbf{1030}_{Edge}$ near the edge of the display may have a significant portion of the light **1045** directed outside of the eye-box **1006** by the lenses **1039**. In contrast, FIG. **10**B provides a schematic of a display **1020** with a meta-surfaces based array. The meta-surfaces **1040** allow for all of the light **1045** emitted by the edge pixels $\mathbf{1030}_{Edge}$ to be directed to the eye-box **1006**. Focusing the viewpoints of light **1045** into the eye-box **1006** further improves the spatial versus angular trade off. Placing unique meta-surfaces on each subpixel enables even the edge pixels $\mathbf{1030}_{Edge}$ to contribute to the resolution in the target eye-box, and improvements to the perceived spatial or angular resolution are obtained.

[0058] In yet another embodiment, adaptive subpixel resolution may be obtained with a pupil tracing device in order to increase the resolution in the foveae region of the eye. For example, some of the green subpixels of pixel (e.g., some of the plurality of green subpixels **932**G in FIG. **9**A) may be reserved for foveated rendering when the eye is known to be in the zone for that view. As such, more luminance and color information can be delivered to the color sensitive cones in the foveae. The computational requirements on the GPU for such a display would not be significant because only a small portion of the display is viewed in the foveated region at a given time.

[0059] Referring now to FIGS. **11**A and **11**B, schematics of a head mounted display **1100** are shown, in accordance with embodiments. In FIG. **11**A, the head mounted display **1100** comprises a display **1120** attached to a frame **1195**. The display **1120** may be any suitable display, such as those described above that include meta-surfaces over subpixels. In the illustrated embodiment, the frame **1195** resembles the frames of glasses, with the display **1120** being positioned where the lenses normally are positioned. However, it is to be appreciated that other frame/display configurations are possible in accordance with various embodiments. In an embodiment, a computer **1190** may be attached to the display **1120** with a cable **1196**. The computer **1190** may provide the processing power (e.g., for graphics rendering, etc.) for the display **1120**. In an additional embodiment, the computer **1190** may be integrated with the frame **1195**, as shown in FIG. **11**B. In such an embodiment, the head mounted display **1100** may be considered a wireless or untethered display.

[0060] While FIGS. **11**A and **11**B illustrate a head mounted display **1100**, it is to be appreciated that embodiments such as those described herein are capable of being integrated into any display technology. For example, 3D displays with meta-surfaces such as those described herein may be used in displays with form-factors for use in mobile devices (e.g., cell phones, tablets, laptop computers, etc.) or in larger form factors (e.g., televisions, computer displays, etc.).

[0061] FIG. **12** is an electronic device having a display, in accordance with embodiments of the present disclosure. Referring to FIG. **12**, an electronic device **1200** has a display or display panel **1220** with a subpixel/meta-surface **1232/1240** combination. The display may also have glass layers and other layers, circuitry, and so forth. The display panel **1220** may be a micro-LED display panel. As should be apparent, only one subpixel/meta-surface **1232/1240** is depicted for clarity, though a display panel **1220** will have an array or arrays of subpixel/meta-surface **1232/1240** combinations.

[0062] The electronic device **1200** may be a mobile device such as smartphone, tablet, notebook, smartwatch, and so forth. The electronic device **1200** may be a computing device, stand-alone display, television, display monitor, vehicle computer display, the like. Indeed, the electronic device **1200** may generally be any electronic device having a display or display panel.

[0063] The electronic device **1200** may include a processor **1206** (e.g., a central processing unit or CPU) and memory **1208**. The memory **1208** may include volatile memory and nonvolatile memory. The processor **1206** or other controller, along with executable code store in the memory **1208**, may provide for touchscreen control of the display and well as for other features and actions of the electronic device **1200**.

[0064] In addition, the electronic device **1200** may include a battery **1210** that powers the electronic device including the display panel **1202**. The device **1200** may also include a network interface **1212** to provide for wired or wireless coupling of the electronic to a network or the internet. Wireless protocols may include Wi-Fi (e.g., via an access point or AP), Wireless Direct®, Bluetooth®, and the like. Lastly, as is apparent, the electronic device **1200** may include additional components including circuitry and other components.

[0065] Thus, embodiments described herein include micro light-emitting diode (LED) fabrication and assembly.

[0066] The above description of illustrated implementations of embodiments of the disclosure, including what is described in the Abstract, is not intended to be exhaustive or to limit the disclosure to the precise forms disclosed. While specific implementations of, and examples for, the disclosure are described herein for illustrative purposes, various equivalent modifications are possible within the scope of the disclosure, as those skilled in the relevant art will recognize.

[0067] These modifications may be made to the disclosure in light of the above detailed description. The terms used in the following claims should not be construed to limit the disclosure to the specific implementations disclosed in the specification and the claims. Rather, the scope of the disclosure is to be determined entirely by the following claims, which are to be construed in accordance with established doctrines of claim interpretation.

[0068] Example 1: a display, comprising: a display backplane substrate; a light emission source on the display backplane substrate; and a meta-surface over the light emission source, wherein the meta-surface comprises a plurality of nano-features for modifying a path of light emitted by the light emission source.

[0069] Example 2: the display of Example 1, wherein the meta-surface is separated from the light emission source by a dielectric layer.

[0070] Example 3: the display of Example 1 or Example 2, wherein the meta-surface comprises TiO_2.

[0071] Example 4: the display of Examples 1-3, light emission source is a micro light emitting diode (LED).

[0072] Example 5: the display of Examples 1-4, wherein the micro LED emits white light, and wherein the meta-surface further comprises a color changing device that converts the white light to red light, blue light, or green light.

[0073] Example 6: the display of Examples 1-5, wherein the meta-surface comprises a plurality of regions, wherein each region provides a different modification of the path of light emitted by the emission source.

[0074] Example 7: the display of Examples 1-6, wherein the nano-features comprise one or more of a post, a shell, or a post surrounded by a shell.

[0075] Example 8: the display of Examples 1-7, wherein a dimension of the nano-features is less than the wavelength of the light emitted by the light emission source.

[0076] Example 9: the display of Examples 1-8, wherein the nano-features comprise a core and a coating surrounding the core.

[0077] Example 10: the display of Examples 1-9, wherein the coating surrounds sidewall surfaces of the core, or the coating surrounds sidewall surfaces and a top surface of the core.

[0078] Example 11: the display of Examples 1-10, wherein the core has a non-uniform width.

[0079] Example 12: the display of Examples 1-11, wherein the core is Si_3N_4 and the coating is Si or TiO_2.

[0080] Example 13: a three-dimensional (3D) display, comprising: a display backplane substrate; and a plurality of pixels on the display backplane substrate, wherein each of the pixels comprises: a first subpixel, wherein a first meta-surface is positioned over the first subpixel, the first meta-surface having a plurality of nano-features for modifying a path of light emitted by the first subpixel; a second subpixel, wherein a second meta-surface is positioned over the second subpixel, the second meta-surface having a plurality of nano-features for modifying a path of light emitted by the second subpixel; and a third subpixel, wherein a third meta-surface is positioned over the third subpixel, the third meta-surface having a plurality of nano-features for modifying a path of light emitted by the third subpixel.

[0081] Example 14: the 3D display of Example 13, wherein the first subpixel emits green light, the second subpixel emits red light, and the third subpixel emits blue light.

[0082] Example 15: the 3D display of Example 13 or Example 14, wherein the first meta-surface modifies light emitted by the first subpixel by a first angle, the second meta-surface modifies light emitted by the second subpixel by a second angle, and the third meta-surface modifies light emitted by the third subpixel by a third angle.

[0083] Example 16: the 3D display of Examples 13-15, wherein, within each pixel, the first angle, the second angle, and the third angle of each pixel are equal to each other.

[0084] Example 17: the 3D display of Examples 13-16, wherein the each of the first meta-surface, the second meta-surface, and the third meta-surface comprise a plurality of regions, wherein each region provides a different modification of the path of light emitted by the respective subpixels.

[0085] Example 18: the 3D display of Examples 13-17, wherein the first subpixel is a blue subpixel, the second subpixel is a red subpixel, and the third subpixel is a green subpixel.

[0086] Example 19: the 3D display of Examples 13-18, wherein each pixel comprises a plurality of third subpixels.

[0087] Example 20: the 3D display of Examples 13-19, wherein each first meta-surface comprises a plurality of regions, wherein each region provides a different modification of the path of light emitted by the respective subpixel, and wherein each second meta surface comprises a plurality of regions, wherein each region provides a different modification of the path of light emitted by the respective subpixel.

[0088] Example 21: the 3D display of Examples 13-20, wherein the subpixels comprise micro light emitting diodes (LEDs).

[0089] Example 22: the 3D display of Examples 13-21, wherein the meta-surfaces comprise TiO_2.

[0090] Example 23: a head mounted three-dimensional (3D) display, comprising: a frame, wherein the frame is supporting the 3D display on a user's head; a display mechanically coupled to the frame, wherein the display provides a multi-view light field to each eye of the user; and a computing device communicatively coupled to the display.

[0091] Example 24: the head mounted 3D display of Example 23, wherein the display comprises: a display backplane substrate; and a plurality of pixels on the display backplane substrate, wherein each of the pixels comprises: a first subpixel, wherein a first meta-surface is positioned over the first subpixel, the first meta-surface having a plurality of nano-features for modifying a path of light emitted by the first subpixel; a second subpixel, wherein a second meta-surface is positioned over the second subpixel, the second meta-surface having a plurality of nano-features for modifying a path of light emitted by the second subpixel; and a third subpixel, wherein a third meta-surface is positioned over the third subpixel, the third meta-surface having a plurality of nano-features for modifying a path of light emitted by the third subpixel.

[0092] Example 25: the head mounted 3D display of Example 23 or Example 24, wherein each of the first meta-surface, the second meta-surface, and the third meta-surface comprise a plurality of regions, wherein each region provides a different modification of the path of light emitted by the respective subpixels in order to generate the multi-view light field.

What is claimed is:

1. A display, comprising:
- a display backplane substrate;
- a light emission source on the display backplane substrate; and
- a meta-surface over the light emission source, wherein the meta-surface comprises a plurality of nano-features for modifying a path of light emitted by the light emission source.

2. The display of claim **1**, wherein the meta-surface is separated from the light emission source by a dielectric layer.

3. The display of claim **1**, wherein the meta-surface comprises TiO_2.

4. The display of claim **1**, light emission source is a micro light emitting diode (LED).

5. The display of claim **4**, wherein the micro LED emits white light, and wherein the meta-surface further comprises a color changing device that converts the white light to red light, blue light, or green light.

6. The display of claim **1**, wherein the meta-surface comprises a plurality of regions, wherein each region provides a different modification of the path of light emitted by the emission source.

7. The display of claim **1**, wherein the nano-features comprise one or more of a post, a shell, or a post surrounded by a shell.

8. The display of claim **7**, wherein a dimension of the nano-features is less than the wavelength of the light emitted by the light emission source.

9. The display of claim **1**, wherein the nano-features comprise a core and a coating surrounding the core.

10. The display of claim **9**, wherein the coating surrounds sidewall surfaces of the core, or the coating surrounds sidewall surfaces and a top surface of the core.

11. The display of claim **9**, wherein the core has a non-uniform width.

12. The display of claim **9**, wherein the core is Si_3N_4 and the coating is Si or TiO_2.

13. A three-dimensional (3D) display, comprising:
- a display backplane substrate; and
- a plurality of pixels on the display backplane substrate, wherein each of the pixels comprises:
  - a first subpixel, wherein a first meta-surface is positioned over the first subpixel, the first meta-surface having a plurality of nano-features for modifying a path of light emitted by the first subpixel;
  - a second subpixel, wherein a second meta-surface is positioned over the second subpixel, the second meta-surface having a plurality of nano-features for modifying a path of light emitted by the second subpixel; and
  - a third subpixel, wherein a third meta-surface is positioned over the third subpixel, the third meta-surface having a plurality of nano-features for modifying a path of light emitted by the third subpixel.

14. The 3D display of claim **13**, wherein the first subpixel emits green light, the second subpixel emits red light, and the third subpixel emits blue light.

15. The 3D display of claim **14**, wherein the first meta-surface modifies light emitted by the first subpixel by a first angle, the second meta-surface modifies light emitted by the second subpixel by a second angle, and the third meta-surface modifies light emitted by the third subpixel by a third angle.

16. The 3D display of claim **15**, wherein, within each pixel, the first angle, the second angle, and the third angle of each pixel are equal to each other.

17. The 3D display of claim **13**, wherein the each of the first meta-surface, the second meta-surface, and the third meta-surface comprise a plurality of regions, wherein each region provides a different modification of the path of light emitted by the respective subpixels.

18. The 3D display of claim **13**, wherein the first subpixel is a blue subpixel, the second subpixel is a red subpixel, and the third subpixel is a green subpixel.

19. The 3D display of claim **18**, wherein each pixel comprises a plurality of third subpixels.

20. The 3D display of claim **19**, wherein each first meta-surface comprises a plurality of regions, wherein each region provides a different modification of the path of light emitted by the respective subpixel, and wherein each second meta surface comprises a plurality of regions, wherein each region provides a different modification of the path of light emitted by the respective subpixel.

21. The 3D display of claim **13**, wherein the subpixels comprise micro light emitting diodes (LEDs).

22. The 3D display of claim **13**, wherein the meta-surfaces comprise TiO_2.

23. A head mounted three-dimensional (3D) display, comprising:
- a frame, wherein the frame is supporting the 3D display on a user's head;
- a display mechanically coupled to the frame, wherein the display provides a multi-view light field to each eye of the user; and
- a computing device communicatively coupled to the display.

24. The head mounted 3D display of claim **23**, wherein the display comprises:
- a display backplane substrate; and
- a plurality of pixels on the display backplane substrate, wherein each of the pixels comprises:

a first subpixel, wherein a first meta-surface is positioned over the first subpixel, the first meta-surface having a plurality of nano-features for modifying a path of light emitted by the first subpixel;

a second subpixel, wherein a second meta-surface is positioned over the second subpixel, the second meta-surface having a plurality of nano-features for modifying a path of light emitted by the second subpixel; and

a third subpixel, wherein a third meta-surface is positioned over the third subpixel, the third meta-surface having a plurality of nano-features for modifying a path of light emitted by the third subpixel.

25. The head mounted 3D display of claim **24**, wherein each of the first meta-surface, the second meta-surface, and the third meta-surface comprise a plurality of regions, wherein each region provides a different modification of the path of light emitted by the respective subpixels in order to generate the multi-view light field.

* * * * *

专利名称(译)	用于使用头像素的头戴式设备的光场显示器		
公开(公告)号	US20200135703A1	公开(公告)日	2020-04-30
申请号	US16/176605	申请日	2018-10-31
[标]申请(专利权)人(译)	英特尔公司		
申请(专利权)人(译)	英特尔公司		
当前申请(专利权)人(译)	英特尔公司		
[标]发明人	AHMED KHALED HICKS RICHMOND HUNTER SETH SUPIKOV ALEXEY JIANG JUN		
发明人	AHMED, KHALED HICKS, RICHMOND HUNTER, SETH SUPIKOV, ALEXEY JIANG, JUN		
IPC分类号	H01L25/075 G02B27/22 H01L33/58		
CPC分类号	G02B30/00 H01L33/58 H01L25/0753 H01L33/56 H01L2933/0083		
外部链接	Espacenet USPTO		

摘要(译)

本文公开的实施例包括具有超表面的3D显示器以及形成这种显示器的方法。 在一个实施例中，显示器可以包括显示器底板基板以及在显示器底板基板上的发光源。 在一个实施例中，可以在发光源上方形成超颖表面。 在一个实施例中，超颖表面包括用于修改由发光源发射的光的路径的多个纳米特征。