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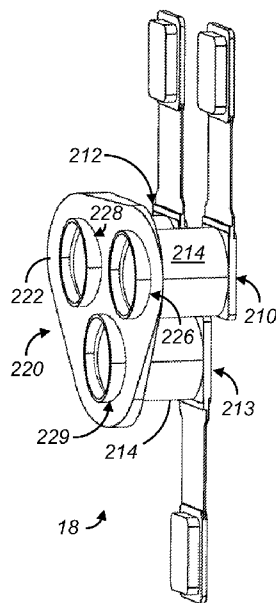


FIG. 5A

(57) Abstract: An image light guide system for generating angularly encoded image-bearing light beams, including an image source system having a first wavelength source; a second wavelength source; and an alignment plate configured to secure a relative arrangement of the first wavelength source and the second wavelength source, wherein a portion of the first wavelength source overlaps a portion of the second wavelength source.



IMAGE LIGHT GUIDE PROJECTOR SYSTEM ALIGNMENT

TECHNICAL FIELD

[0001] The present disclosure generally relates to electronic displays, and more particularly to image light guide systems designed to produce virtual images by micro-display engines configured and arranged for near-eye viewing within a head-mounted display.

BACKGROUND

[0002] Head-Mounted Displays (HMDs) are being developed for a range of diverse uses, including military, commercial, industrial, firefighting, and entertainment applications. For many of these applications, there is value in forming a virtual image that can be visually superimposed over the real-world image that lies in the field of view of the HMD user. An optical image light guide may convey image-bearing light to a viewer in a narrow space for directing the virtual image to the viewer's pupil and enabling this superposition function.

[0003] In general, HMD optics must meet a number of basic requirements for viewer acceptance, including pupil size and field of view (FOV). Pupil size requirements are based on physiological differences in viewer face structure as well as on gaze direction during viewing. A minimum entrance pupil diameter of approximately 10 mm has been found to be desirable for general viewers. A wide FOV is preferable for many tasks and operations. Further, the virtual image that is generated should have sufficient brightness for visibility and viewer comfort.

[0004] In addition to optical requirements, HMD designs must also address practical factors such as acceptable form factor with expectations of reduced size for wearing comfort, weight, cost, and ease of use. There is thus a need for an image light guide system providing an increased FOV and brightness while maintaining a small form factor.

SUMMARY

[0005] The present disclosure provides an image light guide system for generating angularly encoded image-bearing light beams, including an image source system having a first wavelength source; a second wavelength source; and an alignment plate configured to secure a relative arrangement of the first wavelength source and the second wavelength source, wherein a portion of the first wavelength source overlaps a portion of the second wavelength source.

[0006] In a another embodiment, the present disclosure provides an image light guide system for generating angularly encoded image-bearing light beams, including an image source system having a first wavelength source, a second wavelength source, and an alignment plate configured to secure a relative arrangement of the first wavelength source and the second wavelength source, wherein the alignment plate comprises a first surface and a second surface arranged at an acute

angle relative to the first surface, wherein a portion of the first wavelength source overlaps a portion of the second wavelength source; and an image light guide having a first surface and a second surface, wherein the first surface of the image light guide is arranged parallel with the second surface of the alignment plate.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[0007] The accompanying drawings are incorporated herein as part of the specification. The drawings described herein illustrate embodiments of the presently disclosed subject matter and are illustrative of selected principles and teachings of the present disclosure. However, the drawings do not illustrate all possible implementations of the presently disclosed subject matter and are not intended to limit the scope of the present disclosure in any way.

[0008] FIG. 1 is a top view of an image light guide with an exaggerated thickness for showing the propagation of light from an image source along the image light guide to an eyebox within which the virtual image can be viewed.

[0009] FIG. 2 is a perspective view of an image light guide including an in-coupling diffractive optic, a turning diffractive optic, and out-coupling diffractive optic for managing the propagation of image-bearing light beams.

[0010] FIG. 3A is a schematic perspective view of an image source system according to an exemplary embodiment of the present disclosure.

[0011] FIG. 3B is a cross-sectional view of a portion of the image source system according to FIG. 3A.

[0012] FIG. 3C is a cross-sectional view of a portion of another image source system according to FIG. 3A.

[0013] FIG. 3D is a cross-sectional view of a portion of another image source system according to FIG. 3A.

[0014] FIG. 3E is a cross-sectional view of a portion of another image source system according to FIG. 3A.

[0015] FIG. 4A is a top view of an image light guide system with an image source system according to an exemplary embodiment of the present disclosure.

[0016] FIG. 4B is a schematic of image-bearing light refracting through an optical wedge according to FIG. 4A.

[0017] FIG. 5A is a perspective view of an image source system according to an exemplary embodiment of the present disclosure.

[0018] FIG. 5B is a right side view of the image source system according to FIG. 5A.

[0019] FIG. 5C is a left side view of the image source system according to FIG. 5A.

[0020] FIG. 6 is a top view of an image light guide system with an image source system according to an exemplary embodiment of the present disclosure.

[0021] FIG. 7 is a top view of an image light guide system with an image source system according to an exemplary embodiment of the present disclosure.

[0022] FIG. 8 is a top view of an image light guide system with an image source system according to an exemplary embodiment of the present disclosure.

[0023] FIG. 9 is a top view of an image light guide system with an image source system according to an exemplary embodiment of the present disclosure.

[0024] FIG. 10A is a perspective view of a binocular image light guide system according to an exemplary embodiment of the present disclosure.

[0025] FIG. 10B is a top view of a portion of the binocular image light guide system according to FIG. 10A.

[0026] FIG. 11 is a front view of the binocular image light guide system according to FIG. 10A.

[0027] FIG. 12 is a bottom view of the binocular image light guide system according to FIG. 10A.

[0028] FIG. 13 is a perspective view of a binocular image light guide system according to an exemplary embodiment of the present disclosure.

[0029] FIG. 14 is a perspective view of a binocular image light guide system according to an exemplary embodiment of the present disclosure.

DETAILED DESCRIPTION

[0030] It is to be understood that the invention may assume various alternative orientations and step sequences, except where expressly specified to the contrary. It is also to be understood that the specific assemblies and systems illustrated in the attached drawings and described in the following specification are simply exemplary embodiments of the inventive concepts defined herein. Hence, specific dimensions, directions, or other physical characteristics relating to the embodiments disclosed are not to be considered as limiting, unless expressly stated otherwise. Also, although they may not be, like elements in various embodiments described herein may be commonly referred to with like reference numerals within this section of the application.

[0031] Where they are used herein, the terms “first”, “second”, and so on, do not necessarily denote any ordinal, sequential, or priority relation, but are simply used to more clearly distinguish one element or set of elements from another, unless specified otherwise.

[0032] Where they are used herein, the terms “viewer”, “operator”, “observer”, and “user” are considered to be equivalent and refer to the person who views the virtual images through a near-eye viewing device.

[0033] Where used herein, the term “projector” refers to an optical device that emits image-bearing light, and can include additional optical components beyond the display or display panel, e.g., collimating/focusing optics.

[0034] Where used herein, the term “about” when applied to a value is intended to mean within the tolerance range of the equipment used to produce the value, or, in some examples, is intended to mean plus or minus 10%, or plus or minus 5%, or plus or minus 1%, unless otherwise expressly specified.

[0035] Where used herein, the term “substantially” is intended to mean within the tolerance range of the equipment used to produce the value, or, in some examples, is intended to mean plus or minus 10%, or plus or minus 5%, or plus or minus 1%, unless otherwise expressly specified.

[0036] Where used herein, the term “exemplary” is intended to mean “an example of,” “serving as an example,” or “illustrative,” and does not denote any preference or requirement with respect to a disclosed aspect or embodiment.

[0037] An optical system, such as a HMD, can produce a virtual image. In contrast to methods for forming a real image, a virtual image is not formed on a display surface. That is, if a display surface were positioned at the perceived location of a virtual image, no image would be formed on that surface. Virtual images have a number of inherent advantages for augmented reality presentation. For example, the apparent size of a virtual image is not limited by the size or location of a display surface. Additionally, the source object for a virtual image may be small; for example, a magnifying glass provides a virtual image of an object. In comparison with systems that project a real image, a more realistic viewing experience can be provided by forming a virtual image that appears to be some distance away. Providing a virtual image also obviates the need to compensate for screen artifacts, as may be necessary when projecting a real image.

[0038] FIG. 1 is a schematic diagram showing a simplified cross-sectional view of one conventional configuration of an image light guide system 10. Image light guide system 10 includes a planar image light guide 12, an in-coupling diffractive optic IDO, and an out-coupling diffractive optic ODO. The image light guide 12 includes a transparent substrate S, which can be

made of optical glass or plastic, with plane-parallel front and back surfaces 14 and 16. In this example, the in-coupling diffractive optic IDO is shown as a transmissive-type diffraction grating arranged on, in, or otherwise engaged with the front surface 14 of the image light guide 12. However, in-coupling diffractive optic IDO could alternately be a reflective-type diffraction grating or other type of diffractive optic, such as a volume hologram or other holographic diffraction element, that diffracts incoming image-bearing light beams WI into the image light guide 12. The in-coupling diffractive optic IDO can be located on, in, or otherwise engaged with front surface 14 or back surface 16 of the image light guide 12 and can be of a transmissive or reflective-type in a combination that depends upon the direction from which the image-bearing light beams WI approach the image light guide 12.

[0039] When used as a part of a near-eye or head-mounted display system, the in-coupling diffractive optic IDO of the conventional image light guide system 10 couples the image-bearing light beams WI from a real, virtual or hybrid image source system 18 into the substrate S of the image light guide 12. Any real image or image dimension formed by the image source system 18 is first converted into an array of overlapping, angularly related, collimated beams encoding the different positions within a virtual image for presentation to the in-coupling diffractive optic IDO. Typically, the rays within each bundle forming one of the angularly related beams extend in parallel, but the angularly related beams are relatively inclined to each other through angles that can be defined in two angular dimensions corresponding to linear dimensions of the image.

[0040] Once the angularly related beams engage with the in-coupling diffractive optic IDO, at least a portion of the image-bearing light beams WI are diffracted (generally through a first diffraction order) and thereby redirected by in-coupling diffractive optic IDO into the planar image light guide 12 as angularly encoded image-bearing light beams WG for further propagation along a length dimension x of the image light guide 12 by total internal reflection (TIR) between the plane-parallel front and back surfaces 14 and 16. Although diffracted into a different combination of angularly related beams in keeping with the boundaries set by TIR, the image-bearing light beams WG preserve the image information in an angularly encoded form that is derivable from the parameters of the in-coupling diffractive optic IDO. The out-coupling diffractive optic ODO receives the encoded image-bearing light beams WG and diffracts (also generally through a first diffraction order) at least a portion of the image-bearing light beams WG out of the image light guide 12, as image-bearing light beams WO, toward a nearby region of space referred to as an eyebox E, within which the transmitted virtual image can be seen by a viewer's eye or other optical component. The out-coupling diffractive optic ODO can be designed symmetrically with respect to the in-coupling diffractive optic IDO to restore the original angular

relationships of the image-bearing light beams WI among outputted angularly related beams of the image-bearing light beams WO. In addition, the out-coupling diffractive optic ODO can modify the original field points' positional angular relationships producing an output virtual image at a finite focusing distance.

[0041] However, to increase one dimension of overlap among the angularly related beams populating the eyebox E (defining the size of the region within which the virtual image can be seen), the out-coupling diffractive optic ODO is arranged together with a limited thickness T of the image light guide 12 to encounter the image-bearing light beams WG multiple times and to diffract only a portion of the image-bearing light beams WG upon each encounter. The multiple encounters along the length (e.g., a first direction) of the out-coupling diffractive optic ODO have the effect of replicating the image-bearing light beams WG and enlarging or expanding at least one dimension of the eyebox E where the replicated beams overlap. The expanded eyebox E decreases sensitivity to the position of a viewer's eye for viewing the virtual image.

[0042] The out-coupling diffractive optic ODO is shown as a transmissive-type diffraction grating arranged on or secured to the front surface 14 of the image light guide 12. However, like the in-coupling diffractive optic IDO, the out-coupling diffractive optic ODO can be located on, in, or otherwise engaged with the front or back surface 14 or 16 of the image light guide 12 and can be of a transmissive or reflective-type in a combination that depends upon the direction through which the image-bearing light beams WG is intended to exit the image light guide 12. In addition, the out-coupling diffractive optic ODO could be formed as another type of diffractive optic, such as a volume hologram or other holographic diffraction element, that diffracts propagating image-bearing light beams WG from the image light guide 12 as the image-bearing light beams WO propagating toward the eyebox E.

[0043] FIG. 2 illustrates a perspective view of a conventional image light guide system 10 arranged for expanding the eyebox E in two dimensions, i.e., along both x- and y-axes of the intended image. To achieve a second dimension of eyebox expansion, the in-coupling diffractive optic IDO is oriented to diffract at least a portion of image-bearing light beams WG along a grating vector k_1 along the image light guide 12 toward an intermediate turning optic TO, whose grating vector k_2 is oriented to diffract at least a portion of the image-bearing light beams WG in a reflective mode along the image light guide 12 toward the out-coupling diffractive optic ODO. It should be appreciated that only a portion of the image-bearing light beams WG are diffracted by each of the multiple encounters with intermediate turning optic TO, thereby laterally replicating each of the angularly related beams of the image-bearing light beams WG as they approach the out-coupling diffractive optic ODO. The intermediate turning optic TO redirects the image-

bearing light beams WG toward the out-coupling diffractive optic ODO (having a grating vector k_3) for longitudinally replicating the angularly related beams of the image-bearing light beams WG in a second direction before exiting the image light guide 12 as the image-bearing light beams WO. Grating vectors, such as the depicted grating vectors k_1 , k_2 , and k_3 , extend within a parallel plane of the image light guide 12 in respective directions that are normal to the diffractive features (e.g., grooves, lines, or rulings) of the diffractive optics and have respective magnitudes inverse to the period or pitch d (i.e., the on-center distance between the diffractive features) of the diffractive optics IDO, TO, and ODO.

[0044] As shown in FIG. 2, in-coupling diffractive optic IDO receives the incoming image-bearing light beams WI containing a set of angularly related beams corresponding to individual pixels or equivalent locations within an image generated by the image source 18. A full range of angularly encoded beams for producing a virtual image can be generated by a real display together with collimating optics or other optical components, by a beam scanner for more directly setting the angles of the beams, or by a combination such as a one-dimensional real display used with a scanner. In the configuration shown in FIG. 2, the image light guide 12 outputs a replicated set of angularly related beams (replicated in two dimensions) by providing multiple encounters of the image-bearing light beams WG with both the intermediate turning optic TO and the out-coupling diffractive optic ODO in different orientations. In the depicted orientation of the image light guide 12, the intermediate turning optic TO provides eyebox expansion in a first dimension, e.g., the y-axis direction, and the out-coupling diffractive optic ODO provides a similar eyebox expansion in a second dimension, e.g., the x-axis direction. The relative orientations and respective periods d of the diffractive features of the in-coupling optic IDO, intermediate turning optic TO, and out-coupling diffractive optic ODO provide for eyebox expansion in two dimensions while preserving the intended relationships among the angularly related beams of the image-bearing light beams WI that are output from the image light guide system 10 as the image-bearing light beams WO. It should be appreciated that the periods d of the in-coupling diffractive optic IDO, the intermediate turning optic TO, and the out-coupling diffractive optic ODO, can each include diffractive features having a common pitch d , where the common pitch d of each optic can be different.

[0045] In the configuration shown, while the image-bearing light beams WI input into the image light guide 12 are encoded into a different set of angularly related beams by the in-coupling diffractive optic IDO, the information required to reconstruct the image is preserved by accounting for the systematic effects of the in-coupling diffractive optic IDO. The intermediate turning optic TO, located in an intermediate position between the in-coupling and out-coupling diffractive

optics IDO and ODO, can be arranged so that it does not induce significant changes to the encoding of the image-bearing light beams WG. As such, the out-coupling diffractive optic ODO can be arranged in a symmetric fashion with respect to the in-coupling diffractive optic IDO, e.g., including diffractive features sharing the same period d . Similarly, the period of the intermediate turning optic TO can also match the common period of the in-coupling and out-coupling diffractive optics IDO and ODO. Although the grating vector k_2 of the intermediate turning optic TO is shown oriented at 45 degrees with respect to the other grating vectors, which remains a possible orientation, the grating vector k_2 of the intermediate turning optic TO can be oriented at 60 degrees to the grating vectors k_1 and k_3 of the in-coupling and out-coupling diffractive optics IDO and ODO in such a way that the image-bearing light beams WG are turned 120 degrees. By orienting the grating vector k_2 of the intermediate turning optic TO at 60 degrees with respect to the grating vectors k_1 and k_3 of the in-coupling and out-coupling diffractive optics IDO and ODO, the grating vectors k_1 and k_3 of the in-coupling and out-coupling diffractive optics IDO and ODO are also oriented at 60 degrees with respect to each other. By basing the grating vector magnitudes on the common pitch shared by the in-coupling, intermediate turning, and out-coupling diffractive optics IDO, TO, and ODO, the three grating vectors k_1 , k_2 , and k_3 (as directed line segments) form an equilateral triangle and sum to a zero vector magnitude, which avoids asymmetric effects that could introduce unwanted aberrations including chromatic dispersion. Such asymmetric effects can also be avoided by grating vectors k_1 , k_2 , and k_3 that have unequal magnitudes in relative orientations at which the three grating vectors k_1 , k_2 , and k_3 sum to a zero vector magnitude.

[0046] In a broader sense, the image-bearing light beams WI that are directed into the image light guide 12 are effectively encoded by the in-coupling diffractive optic IDO, whether the in-coupling optic IDO uses gratings, holograms, prisms, mirrors, or some other mechanism. Any reflection, refraction, and/or diffraction of light that takes place at the input should be correspondingly decoded by the output to re-form the virtual image that is presented to the viewer. Whether any symmetries are maintained among the intermediate turning optic TO, the in-coupling optic IDO, and out-coupling diffractive optic ODO, or whether any change to the encoding of the angularly related beams of the image-bearing light beams WI takes place along the image light guide 12, the intermediate turning optic TO and the in-coupling and out-coupling diffractive optics IDO and ODO can be related so that the image-bearing light beams WO that are output from the image light guide 12 preserve or otherwise maintain the original or desired form of the image-bearing light beams WI for producing the intended virtual image.

[0047] As shown in FIG. 2, the letter “R” represents the orientation of the virtual image that is visible to the viewer whose eye is positioned within the eyebox E. As shown, the orientation of the letter “R” in the represented virtual image matches the orientation of the letter “R” as encoded by the image-bearing light beams WI. A change in the rotation about the z axis or angular orientation of incoming image-bearing light beams WI with respect to the x-y plane causes a corresponding symmetric change in rotation or angular orientation of outgoing light from out-coupling diffractive optic (ODO). From the aspect of image orientation, the intermediate turning optic TO simply acts as a type of optical relay, providing one dimension of eyebox expansion through replication of the angularly encoded beams of the image-bearing light beams WG along one axis (e.g., along the y-axis) of the image. Out-coupling diffractive optic ODO further provides a second dimension of eyebox expansion through replication of the angularly encoded beams along another axis (e.g., along the x-axis) while maintaining the original orientation of the virtual image encoded by the image-bearing light beams WI. The intermediate turning optic TO is typically a slanted or square grating or, alternately, can be a blazed grating and is typically arranged on one of the plane-parallel front and back surfaces of the image light guide 12. It should be appreciated that the representation of the virtual image “R” as created by an image source is comprised of infinitely focused light that requires a lens (e.g., the lens in the human eye) to focus the image so that the orientations discussed above can be detected.

[0048] Together, the in-coupling, turning, and out-coupling diffractive optics IDO, TO, and ODO preferably preserve the angular relationships among beams of different wavelengths defining a virtual image upon conveyance by image light guide 12 from an offset position to a near-eye position of the viewer. While doing so, the in-coupling, turning, and out-coupling diffractive optics IDO, TO, and ODO can be relatively positioned and oriented in different ways to control the overall shape of the image light guide 12 as well as the overall orientations at which the angularly related beams can be directed into and out of the image light guide 12.

[0049] HMDs may utilize one or more image source systems 18 when generating image content to generate monochromatic or polychromatic images. For example, the image source systems 18 may utilize technology conventionally referred to as a projector, e.g., a Liquid Crystal Display (LCD), a Liquid Crystal on Silicon (LCoS) display, or a Digital Light Processing (DLP) display. Each of these image source systems 18 can utilize one or more light sources, usually Light Emitting Diodes (LEDs) or Organic LEDs (OLEDs) to generate monochromatic or polychromatic light that will be modulated by each display system. As each of these image source systems 18 modulates light created by a separate source, these types of systems are sometimes also referred to as Spatial Light Modulators (SLMs) or attenuating projectors. Transmissive SLMs, e.g., LCD

display systems, can be optically inefficient thereby increasing power requirements of the light source. Consequently, illumination sources such as LEDs must be driven with higher currents, increasing power consumption and heat production. Reflective SLMs such as LCoS or DLP displays can be optically more efficient and are used in a number of applications such as digital projectors. However, because these systems modulate incident light rather than emit light directly, they require additional optics that project, condense, and split output beams from the LED sources. Additionally, because these image source systems 18 only modulate incident light, the light source must remain turned on regardless of image content. For example, a bright full-screen virtual image and a simple arrow that takes up only 5% of the display pixels will consume approximately the same power. Alternatively, HMDs may utilize an image source system comprising a self-emitting display projector when generating image content. Self-emitting displays may include an array of LEDs or OLEDs that generate a collective image by turning on, off, or dimming respective LEDs.

[0050] Referring now to FIGS. 3A-3C, in an example embodiment, the image source system 18 is a self-emitting microLED display projector that includes a self-emitting microLED display panel 100. MicroLED may also be referred to as μ LED herein. In other exemplary embodiments, the image source system 18 includes an LCoS or DLP display. In an example embodiment, as illustrated in FIG. 3B, which shows a cross-sectional view of a portion of the self-emitting microLED display panel 100 shown in FIG. 3A, the self-emitting microLED display panel 100 includes a substrate 102, an electrode layer 104, a microLED array 106, and a front layer 108. For example, each microLED 106R, 106G, 106B is an individually addressable component of the self-emitting microLED display panel 100, emitting a first wavelength range (e.g., red light in a wavelength range of 620 - 750 nm), a second wavelength range (e.g., green light in a wavelength range of 500 - 565 nm), and a third wavelength range (e.g., blue light in a wavelength range of 450 - 495 nm), respectively. In this example, the microLED array 106R, 106G, 106B is fully interleaved, providing polychromatic light.

[0051] In another example embodiment, as illustrated in FIG. 3C, the microLED array 106 includes only microLEDs 106R emitting a first wavelength range (e.g., red light in a wavelength range of 620 - 750 nm). Similarly, as illustrated in FIGS. 3D and 3E, other microLED arrays 106 may include only microLEDs 106G emitting a second wavelength range (e.g., green light in a wavelength range of 500 - 565 nm) or only microLEDs 106B emitting a third wavelength range (e.g., blue light in a wavelength range of 450 - 495 nm). As described in additional detail herein, a microLED array 106 including only microLEDs 106R, a microLED array 106 including only microLEDs 106G, and a microLED array 106 including only microLEDs 106B may be utilized in one image source system 18 to provide polychromatic images. Each microLED 106 corresponds

to one or more pixels in a projected image. In an example embodiment, the microLED array 106 is configured to emit light as a function of power applied to each self-emitting light source.

[0052] Referring now to FIGS. 4A and 4B, in an exemplary embodiment, an image light guide system 200 includes at least one image source system 18 and a stack of image light guides 202, 204. For example, image light guides 202, 204 each include a first surface 203 and a second surface 205. In an example embodiment, the first surface 203 is positioned generally parallel with the second surface 205. A first in-coupling diffractive optic IDO1 is located on, in, or engaged with the first surface 203 or the second surface 205 of the first image light guide 202. Additionally, one or more out-coupling diffractive optics are formed on, in, or engaged with the first surface 203 or the second surface 205 of the first image light guide 202. A second in-coupling diffractive optic IDO2 is located on, in, or engaged with the first surface 203 or the second surface 205 of the second image light guide 204. Additionally, one or more out-coupling diffractive optics are formed on, in, or engaged with the first surface 203 and/or the second surface 205 of the second image light guide 204. It should be noted that image light guides 202, 204 can be replaced by a single double-sided image light guide having two or more in-coupling diffractive optics formed on, in, or engaged with the first surface 203 and/or the second surface 205 of the image light guide and one or more out-coupling diffractive optics formed on, in, or engaged with the first surface 203 and/or the second surface 205 of the image light guide.

[0053] In an example embodiment, the image source system 18 includes a first wavelength source 210 and a second wavelength source 212. For example, the first wavelength source 210 includes a microLED array 106R and the second wavelength source 212 includes a microLED array 106B as described above. Each of the first wavelength source 210 and the second wavelength source 212 include a lens barrel 214 housing collimating optics. The image source system 18 further includes an alignment plate 220 having a first surface 222 and a second parallel surface 224. A first through-bore 226 and a second through-bore 228 are disposed through the first and second surfaces 222, 224 of the alignment plate 220, wherein the lens barrel 214 of the first wavelength source 210 is arranged through the first through-bore 226 and the lens barrel 214 of the second wavelength source 212 is arranged through the second through-bore 228. The alignment plate 220 is configured to secure relative alignment of the first wavelength source 210 and the second wavelength source 212.

[0054] As illustrated in FIG. 4A, in an example embodiment, a first optical wedge 230 is arranged between the first wavelength source 210 and the first image light guide 202, and a second optical wedge 232 is arranged between the second wavelength source 212 and the first image light guide 202. Each of the first and second optical wedges 230, 232 have a first surface 234 and a second

surface 236, wherein the second surface 236 is arranged at an acute angle with the first surface 234. For example, the first optical wedge 230 and the second optical wedge 232 may be optically or physically connected with the ends of the respective lens barrels 214. In an example embodiment, the first surface 234 of the first and second optical wedges 230, 232 is arranged parallel to the first surface 222 of the alignment plate 220, and the second surface 236 of the first and second optical wedges 230, 232 is arranged parallel to the first surface 203 of the image light guide 202.

[0055] Referring now to FIG. 4B, in an example embodiment, the first and second optical wedges 230, 232 are configured to induce a change in the angle of incidence of the image-bearing light on the in-coupling diffractive optics IDO1, IDO2 as a product of refraction in the first and second optical wedges 230, 232. Conventionally, the angle of incidence of the image-bearing light is configured so that rays enter and exit a prism at the same angular relationship to the surface normal so that there is not chromatic dispersion. With the first and second optical wedges 230, 232, this symmetry is intentionally broken, and the first and second optical wedges 230, 232 increase the angle of incidence of the image-bearing light according to Snell's law. In an example embodiment, to reduce chromatic dispersion, the first and second wavelength sources 210, 212 have relatively narrow bandwidths. When combined with physically angling the first and second wavelength sources 210, 212 relative to the image light guides 202, 204, large angles of incidence of the image-bearing light can be achieved with minimal impact to form factor of a HMD. As illustrated in FIG. 4B, a 12-degree tilt of the first and second wavelength sources 210, 212 relative to a normal to the image light guides 202, 204, with the first and second optical wedges 230, 232 having an index of refraction of $n=1.9$, provides a 23.27-degree angles of incidence of the image-bearing light relative to a normal to the image light guides 202, 204. Thus, an incident angle of 23.27-degrees is achieved with only a 12-degree tilt of the first and second wavelength sources 210, 212. This reduces form factor requirements and allows for a more compact image source system 18 which is increasingly important in HMD systems.

[0056] Referring now to FIGS. 5A-C, in an example embodiment, the image source system 18 includes a first wavelength source 210, a second wavelength source 212, and a third wavelength source 213. For example, the first wavelength source 210 includes a microLED array 106R, the second wavelength source 212 includes a microLED array 106B, and the third wavelength source 213 includes a microLED array 106G as described above. Each of the first, second, and third wavelength sources 210, 212, 213 include a lens barrel 214 housing collimating optics. The image source system 18 further includes an alignment plate 220 having a first surface 222 and a second parallel surface 224, wherein the first surface 222 is arranged at an acute angle (e.g., 10-degrees)

with the second surface 224. A first through-bore 226, a second through-bore 228, and a third through-bore 229 are disposed through the first and second surfaces 222, 224 of the alignment plate 220, wherein the lens barrel 214 of the first wavelength source 210 is arranged through the first through-bore 226, the lens barrel 214 of the second wavelength source 212 is arranged through the second through-bore 228, and the lens barrel 214 of the third wavelength source 213 is arranged through the third through-bore 229. The alignment plate 220 is configured to ensure relative alignment of the first, second, and third wavelength sources 210, 212, 213. In an example embodiment, the wavelength sources 210, 212, 213 are positioned within the alignment plate such that the distance in the z-axis direction between the first, second, and third wavelength sources 210, 212, 213 are all different. With square or rectangular arrays, e.g., arrays 106A-106G, the ability to stagger the z-axis position of the arrays allows for some overlap in a plane parallel to the second surface 224 of the alignment plate 220. In other words, the first, second, and third wavelength sources 210, 212, 213 may therefore be arranged such that they at least partially overlap in at least one dimension.

[0057] As illustrated in FIG. 6, in an example embodiment, the first surface 222 of the alignment plate 220 is arranged parallel with the first surface 203 of the image light guides 202, 204. The first surface 222 of the alignment plate 220 serves to provide constant angular alignment of the first, second, and third wavelength sources 210, 212, 213 relative to the surfaces 203, 205 of image light guides 202, 204.

[0058] As illustrated in FIG. 7, in an example embodiment, a first optical wedge 230 is arranged between the first wavelength source 210 and the first image light guide 202, a second optical wedge 232 is arranged between the second wavelength source 212 and the first image light guide 202, and a third optical wedge 233 is arranged between the third wavelength source 213 and the first image light guide 202. Each of the first, second, and third optical wedges 230, 232, 233 have a first surface 234 and a second surface 236, wherein the second surface 236 is arranged at an acute angle with the first surface 234. For example, the first, second, and third optical wedges 230, 232, 233 may be optically or physically connected with the ends of the respective lens barrels 214. In an example embodiment, the first surface 234 of the first, second, and third optical wedges 230, 232, 233 is arranged parallel to the first surface 222 of the alignment plate 220, and the second surface 236 of the first, second, and third optical wedges 230, 232, 233 is arranged parallel to the first surface 203 of the image light guides 202, 204.

[0059] As illustrated in FIG. 8, in an example embodiment, the first, second, and third optical wedges 230, 232, 233 may be arranged within the lens barrels 214 to save space and minimize form factor and decrease the distance between the image source system 18 and the image light

guides 202, 204. As illustrated in FIG. 9, in an example embodiment, the first, second, and third optical wedges 230, 232, 233 may be arranged within the through-bores 226, 228, 229 of the alignment plate to minimize form factor and decrease the distance between the image source system 18 and the image light guides 202, 204.

[0060] As illustrated in FIGS. 10A-12, in an example embodiment, a binocular image light guide system 300 includes two image light guide systems 200 and four image source systems 18 (e.g., two image source systems 18 per image light guide system 200) according to at least one of the embodiments described above. As shown in FIGS. 10A and 10B, in an example embodiment, image light guides 202, 204 include an at least partially transparent substrate with parallel front and back surfaces 203, 205. For example, the image light guides 202, 204 may be made of optical glass, fused quartz, or a polymer. In an example embodiment, the image light guide 202 includes a first in-coupling diffractive optic IDO1 arranged along the front surface 203 and a third in-coupling diffractive optic IDO3 arranged along the back surface 205 and adjacent a first side of the image light guide 204 in the x-direction. The image light guide 204 includes a second in-coupling diffractive optic IDO2 arranged along the front surface 203 adjacent a first side of the image light guide 202 in the x-direction. As illustrated in FIG. 10B, this arrangement of the first, second, and third in-coupling diffractive optics IDO1, IDO2, IDO3 is also provided a second side of the image light guide system 200 opposite the first side in the x-direction.

[0061] Referring now to FIG. 10A, at least one out-coupling diffractive optic ODO1, IDO2 is arranged along a front surface 203 or back surface 205 of each of the image light guides 202, 204. In an exemplary embodiment, the out-coupling diffractive optics ODO1, ODO2 span substantially the width of the image light guides 202, 204 in the x-direction. For example, the out-coupling diffractive optic ODO1 can span at least 90% of the width of the image light guide 202. The image light guide 202 may also include separate or discrete intermediate diffractive optics TO1 and TO4 arranged along the front or back surface 203, 205, and the image light guide 204 may include separate or discrete intermediate diffractive optics TO2 and TO3 arranged along the front or back surface 203, 205.

[0062] As illustrated in FIG. 13, in an example embodiment, the image source systems 18 include a single fully interleaved microLED array 106R, 106G, 106B, providing polychromatic light. For example, a binocular image light guide system 300 includes two image light guide systems 200 and four image source systems 18 (e.g., two image source systems 18 per image light guide system 200). The first, second, and third in-coupling diffractive optics IDO1, IDO2, IDO3 may be arranged generally coaxially along an imaginary-axis arranged substantially parallel to a normal to the front and back surface 203, 205. In another example, the first, second, and third in-coupling

diffractive optics IDO1, IDO2, IDO3 may be arranged generally coaxially along an imaginary-axis arranged substantially parallel to a central ray of image-bearing light emitted by the image source system 18.

[0063] As illustrated in FIG. 14, in an example embodiment, the image source systems 18 include LCOS projectors. For example, two projected virtual images are combined in each double-sided image light guide 202, 204 to produce the required FOV. The image source systems 18 are placed on either side of the image light guide stacks 200, in the z-direction, for a compact configuration.

DISPLAYS/PROJECTORS:

[0064] Example of image source systems include, without limitation, OLEDs, μ LEDs, LCOS, LCD and DLP image source systems, including conventional LCOS or DLP projectors, discrete RGB μ LED projectors, and single fully interleaved μ LED projectors. To achieve the desired field of view (“FOV”), there are advantages to using two projectors combined in one monocular waveguide subsystem to achieve increased performance, efficiency, color uniformity, and brightness uniformity over a smaller FOV. As FOV is increased, efficiency scales proportionally with the virtual image area. Larger FOV image source systems are less efficient, more complex, and pose a larger risk. In example embodiments, the image source systems 18 described above minimize this risk, and function more efficiently by limiting the individual image source FOV to 50-degrees diagonal.

[0065] μ LEDs have the advantage of high brightness and, being self-emitters, have lower power draw and better contrast. μ LEDs also allow for much more compact solutions because they do not require separate front or rear illumination optics. For example, a DLP projector system could be replaced with a similarly performing μ LED system at 1/3 the volume and power budget.

WAVEGUIDES:

[0066] Image light guides, or waveguides, are thin transparent substrates that laterally translate virtual images to the eye from compact projection optics, while expanding the exit pupil to form large exit apertures (i.e., large eye relief and eye-motion box) that support a wide range of users without the need for active adjustments. Image light guides provide a compact, transparent, lightweight solution. Waveguides, similar to projectors, benefit from operating over a more limited FOV. Material changes (increasing the refractive index) only increase the waveguide angular bandwidth by a limited amount. Different grating paths would be required for different angular subsections of the FOV. It is effectively less risk for the waveguide development effort to split the total FOV into separate projectors.

WAVEGUIDE/PROJECTOR SUBSYSTEM SOLUTIONS:

[0067] As shown to in FIGS. 10-12, discrete red, green, and blue μ LED projectors minimize color crosstalk by isolating the individual color channels in the system. Because of the pupil expanding nature of the waveguides, the lateral positioning of the individual projectors does not impact their overlap. Single high resolution μ LED projectors with interleaved red, blue, and green pixels provide a compact and efficient system. Overlapped grating patterns and double-sided waveguide designs produce a system that is largely driven by the eye motion box required to support the FOV.

LIGHT SECURITY:

[0068] Forward light mitigation through grating designs that limit the forward light to 1/10th of the light emitted towards the eye may be incorporated into the image light guide systems. The μ LED systems described can operate at faster frame rates than conventional solutions. This is advantageous because these projectors are efficient and fast enough to support a duty cycle where the display is off the majority of the individual frame rate. This is advantageous, because a compact shutter can be incorporated that blocks light only during the portion of the duty cycle when the projector is illuminating. The majority of the time the system will be largely transparent, with the switching speeds being at 120 Hz or less and not visible to the user. Light emitted from the system would not be visible from a distance.

[0069] For situations requiring full brightness from the system, and having less stringent light security requirements, the system can be flipped up out of the way or removed entirely. Alternatively, for very low light situations, overcast starlight, where attenuation of the visible light must be absolutely minimized, it may be preferred to switch to a notch filter that prevents a limited wavelength range from being transmitted. In such a system a red filter combined with a monochrome red image might supply the best overall user experience. Waveguides can also incorporate infrared (“IR”) channels to help illuminate the eyes to support eye tracking systems. Waveguides are a natural solution to generate collimated light to illuminate the pupil for detections by a camera.

[0070] One or more features of the embodiments described herein may be combined to create additional embodiments which are not depicted. While various embodiments have been described in detail above, it should be understood that they have been presented by way of example, and not limitation. It will be apparent to persons skilled in the relevant arts that the disclosed subject matter may be embodied in other specific forms, variations, and modifications without departing from the scope, spirit, or essential characteristics thereof. The embodiments described above are

therefore to be considered in all respects as illustrative, and not restrictive. The scope of the invention is indicated by the appended claims, and all changes that come within the meaning and range of equivalents thereof are intended to be embraced therein.

CLAIMS

What is claimed is:

1. An image light guide system for generating angularly encoded image-bearing light beams, comprising:
 - an image source system, comprising:
 - a first wavelength source;
 - a second wavelength source;
 - an alignment plate configured to secure a relative arrangement of the first wavelength source and the second wavelength source, wherein a portion of the first wavelength source overlaps a portion of the second wavelength source.
2. The image light guide system according to claim 1, wherein the alignment plate further comprises a first surface and a second surface, the second surface arranged at an acute angle relative to the first surface.
3. The image light guide system according to claim 2, wherein the portion of the first wavelength source overlaps the portion of the second wavelength source in a plane parallel to the first surface.
4. The image light guide system according to claim 1, wherein the image source system further comprise a first lens barrel coupled with the first wavelength source and a second lens barrel coupled with the second wavelength source.
5. The image light guide system according to claim 4, wherein the alignment plate further comprises a first through-bore and a second through-bore, wherein the first lens barrel is arranged through the first through-bore and the second lens barrel is arranged through the second through-bore.
6. The image light guide system according to claim 5, wherein the first lens barrel and the second lens barrel extend past a plane of the second surface.
7. The image light guide system according to claim 2, further comprising an image light guide having a first surface and a second surface.
8. The image light guide system according to claim 7, wherein the first surface of the image light guide is arranged parallel with the second surface of the alignment plate.

9. The image light guide system according to claim 7, further comprising a first wedge arranged between the first wavelength source and the image light guide, wherein a first surface of the first wedge is arranged parallel to the second surface of the alignment plate and a second surface of the first wedge is arranged parallel to the first surface of the image light guide.

10. The image light guide system according to claim 9, wherein a principal ray emitted from the first wavelength source is arranged at a first angle relative to the first surface of the image light guide, and wherein the principal ray enters the first wedge at the first angle and exits the first wedge at a second angle relative to the first surface of the image light guide, wherein the second angle is greater than the first angle.

11. An image light guide system for generating angularly encoded image-bearing light beams, comprising:

an image source system, comprising:

a first wavelength source;

a second wavelength source;

an alignment plate configured to secure a relative arrangement of the first wavelength source and the second wavelength source, wherein the alignment plate comprises a first surface and a second surface arranged at an acute angle relative to the first surface, wherein a portion of the first wavelength source overlaps a portion of the second wavelength source;

an image light guide having a first surface and a second surface, wherein the first surface of the image light guide is arranged parallel with the second surface of the alignment plate.

12. The image light guide system according to claim 11, further comprising an optical wedge arranged between the first wavelength source and the image light guide.

13. The image light guide system according to claim 12, wherein a first surface of the optical wedge is arranged parallel to the second surface of the alignment plate, and a second surface of the optical wedge is arranged parallel to the first surface of the image light guide.

14. The image light guide system according to claim 13, wherein a principal ray emitted from the first wavelength source is arranged at a first angle relative to the first surface of the image light guide, and wherein the principal ray enters the optical wedge at the first angle and exits the optical wedge at a second angle relative to the first surface of the image light guide, wherein the second angle is greater than the first angle.

15. The image light guide system according to claim 12, wherein the optical wedge is a first optical wedge, further comprising a second optical wedge arranged between the second wavelength source and the image light guide.

16. The image light guide system according to claim 15, wherein a first surface of the second optical wedge is arranged parallel to the second surface of the alignment plate, and a second surface of the second optical wedge is arranged parallel to the first surface of the image light guide.

17. The image light guide system according to claim 11, further comprising a third wavelength source, wherein the first, second, and third wavelength sources at least partially overlap in at least one dimension.

18. The image light guide system according to claim 17, further comprising a first optical wedge arranged between the first wavelength source and the image light guide, a second optical wedge arranged between the second wavelength source and the image light guide, and a third optical wedge arranged between the third wavelength source and the image light guide.

19. The image light guide system according to claim 18, wherein a first surface of each optical wedge is arranged parallel to the second surface of the alignment plate, and a second surface of each optical wedge is arranged parallel to the first surface of the image light guide.

20. The image light guide system according to claim 18, wherein the image source system further comprise a first lens barrel coupled with the first wavelength source, a second lens barrel coupled with the second wavelength source, and a third lens barrel coupled with the third wavelength source, wherein the alignment plate comprises a first through-bore, a second through-bore, and a third through-bore, wherein the first lens barrel is arranged through the first through-bore, the second lens barrel is arranged through the second through-bore, and the third lens barrel is arranged through the third through-bore, wherein the first lens barrel, the second lens barrel, and the third lens barrel extend past a plane of the second surface.

21. The image light guide system according to claim 20, wherein the first, second, and third optical wedges are arranged within the first, second, and third lens barrels, respectively.

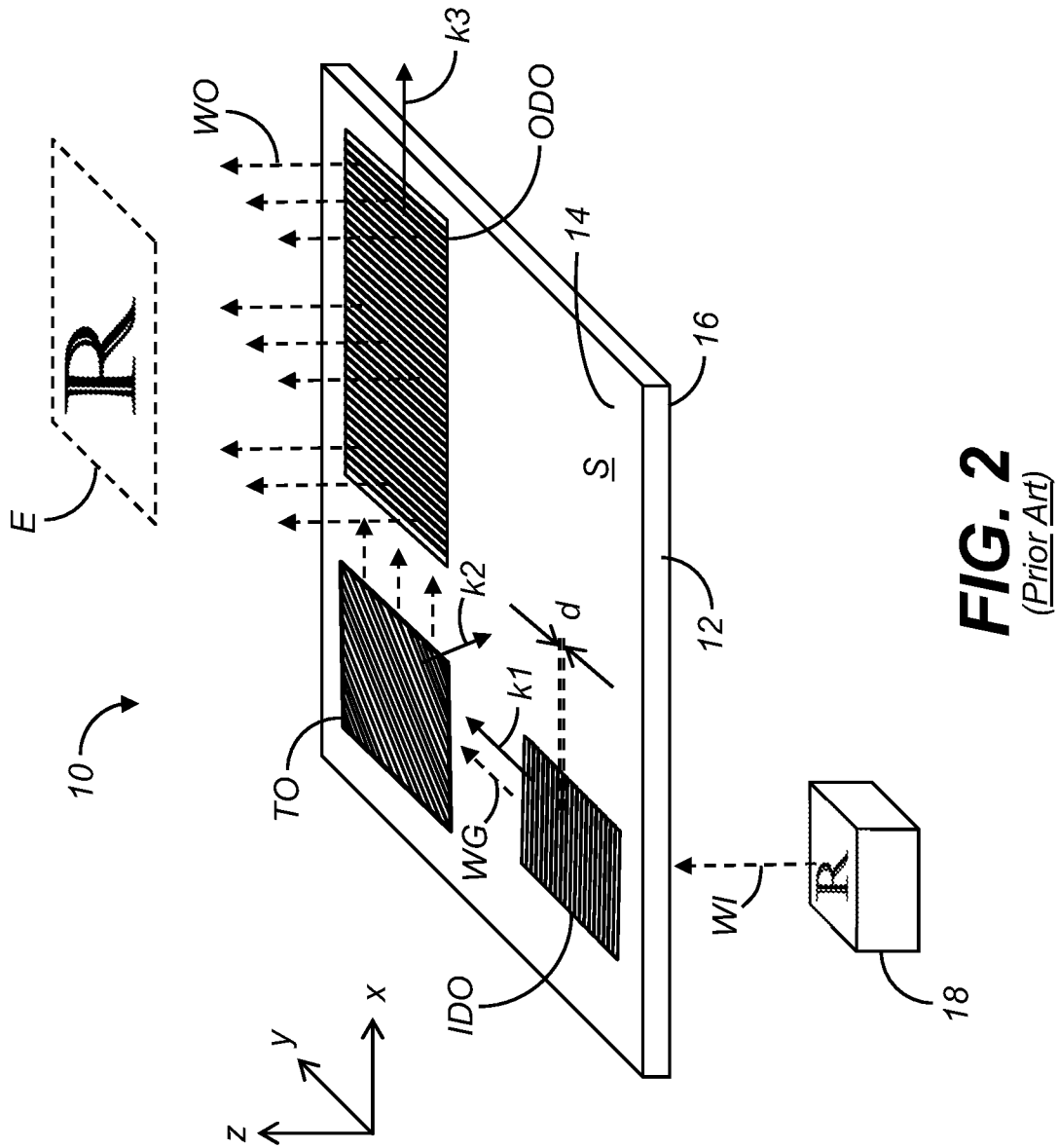


FIG. 2
(Prior Art)

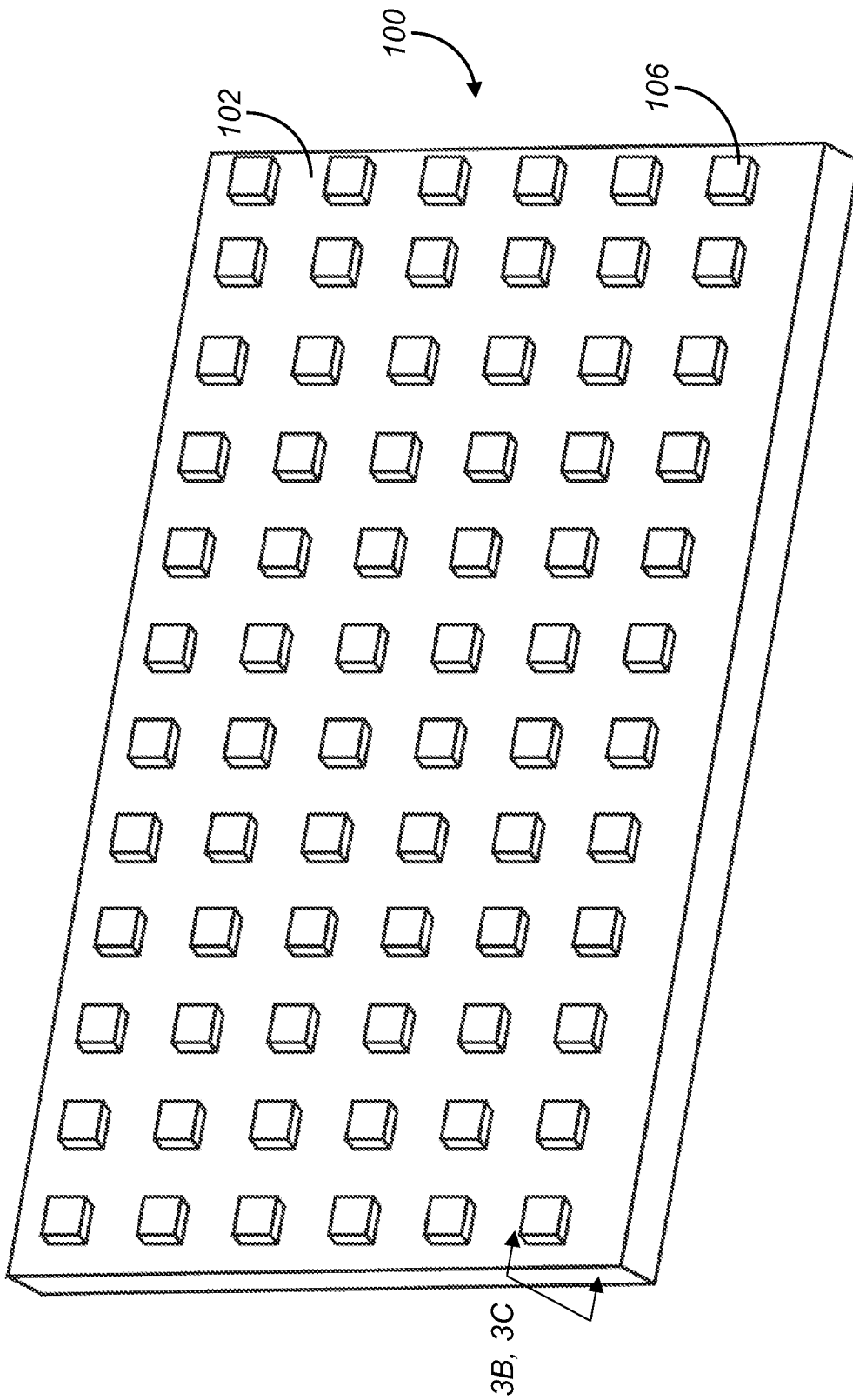


FIG. 3A

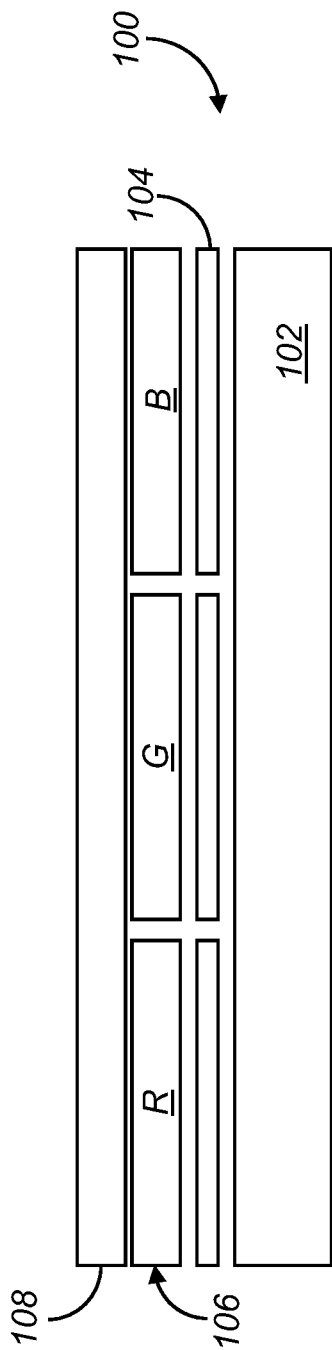


FIG. 3B

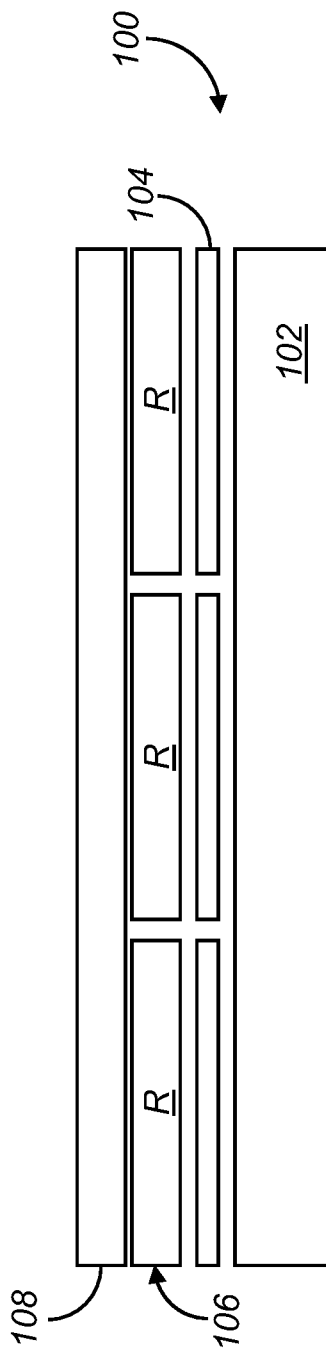


FIG. 3C

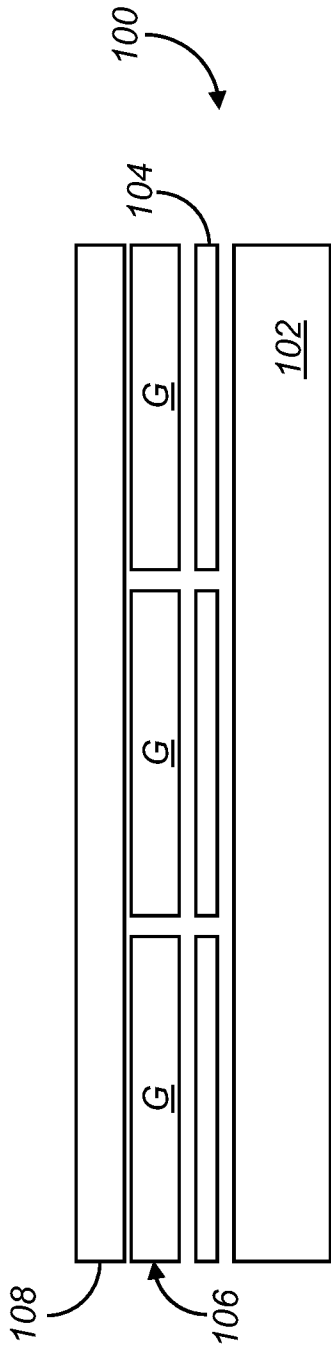


FIG. 3D

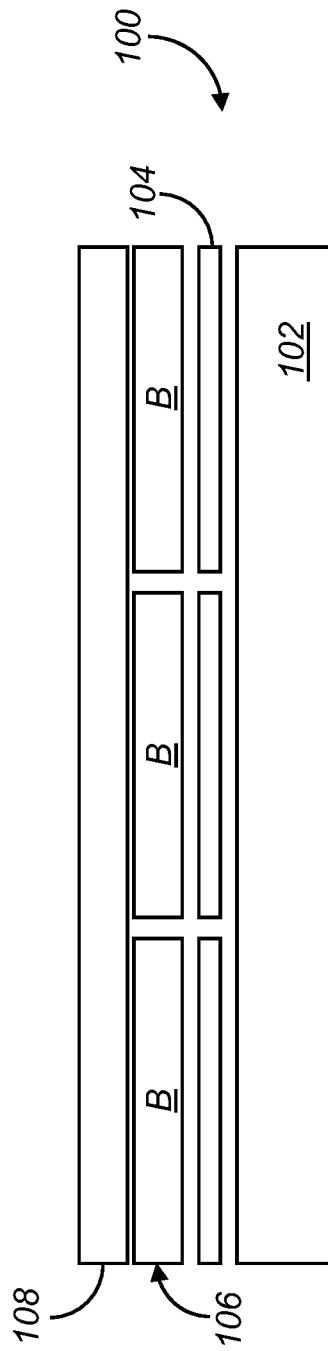


FIG. 3E

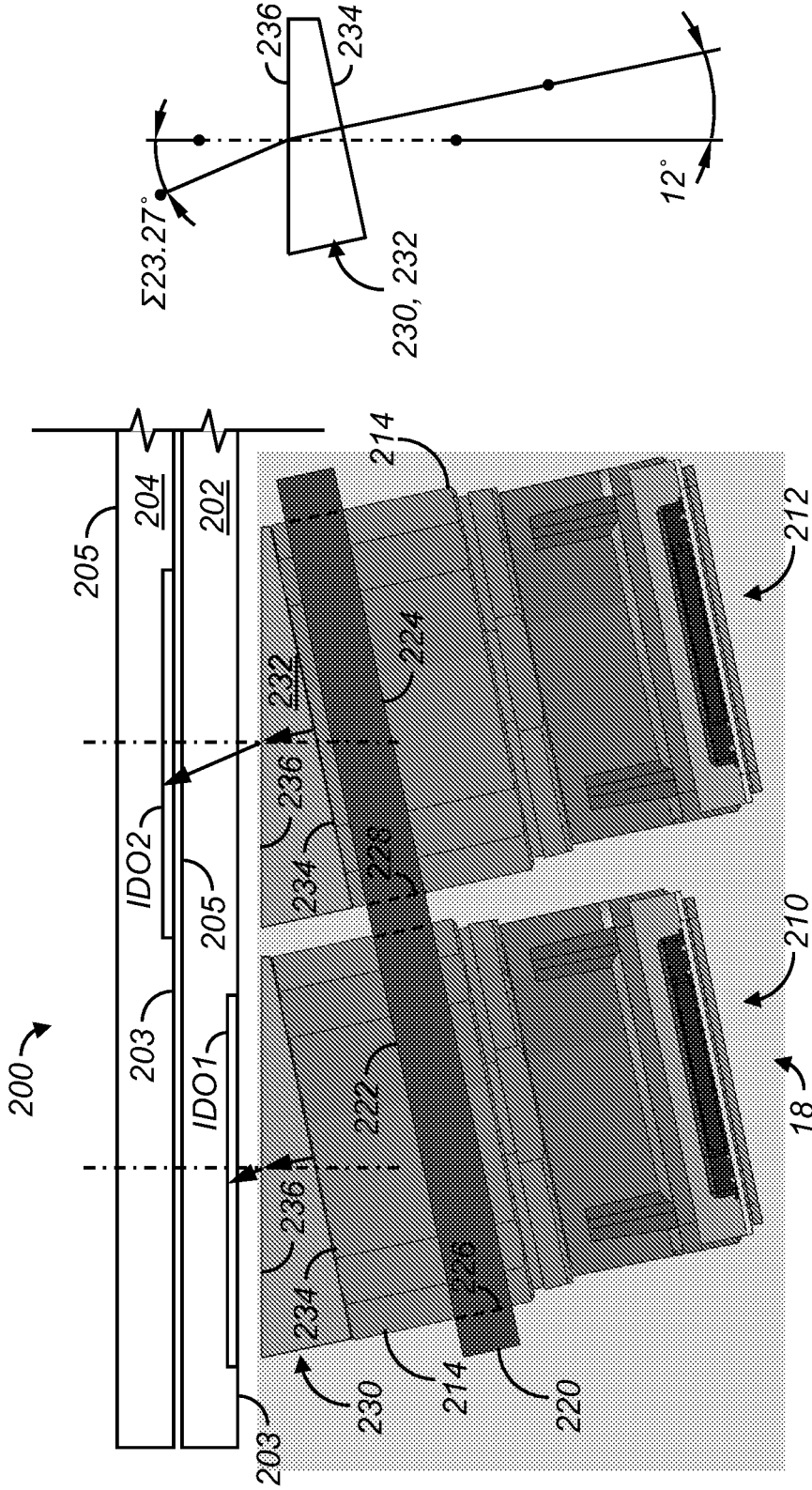


FIG. 4B

FIG. 4A

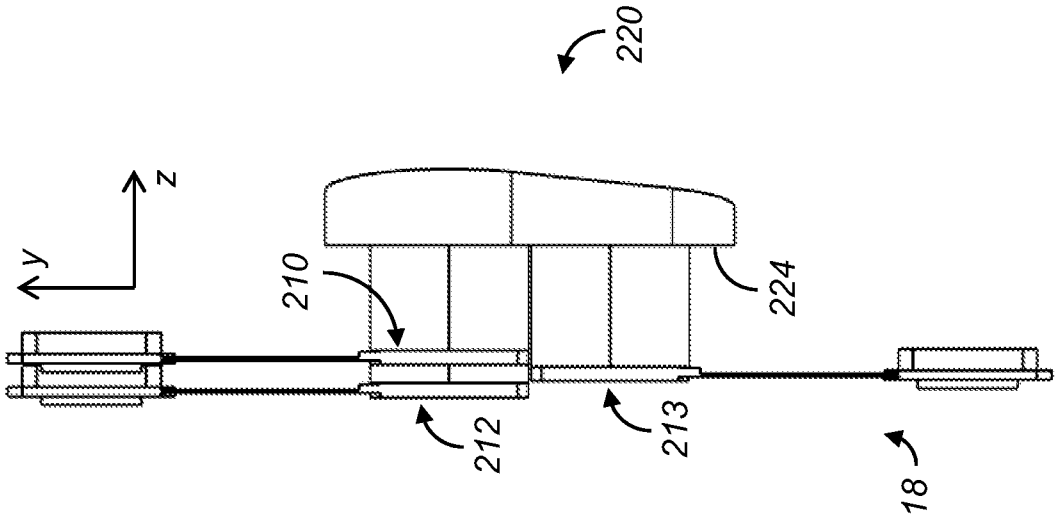


FIG. 5C

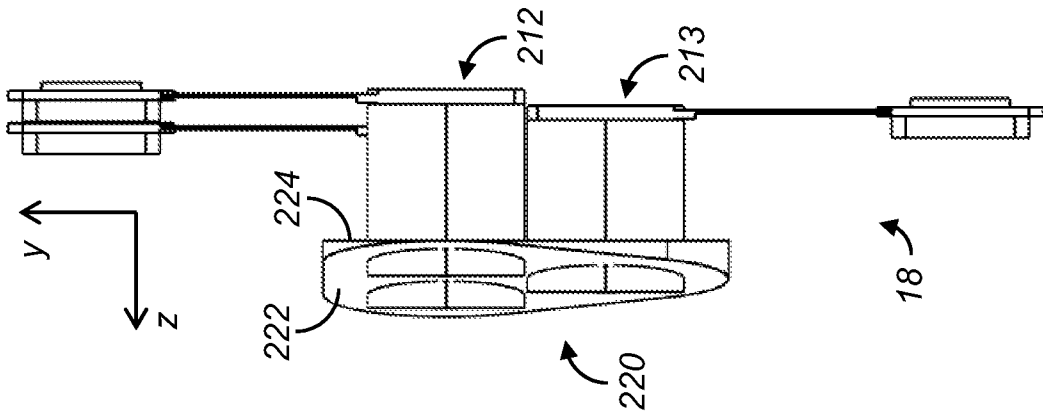


FIG. 5B

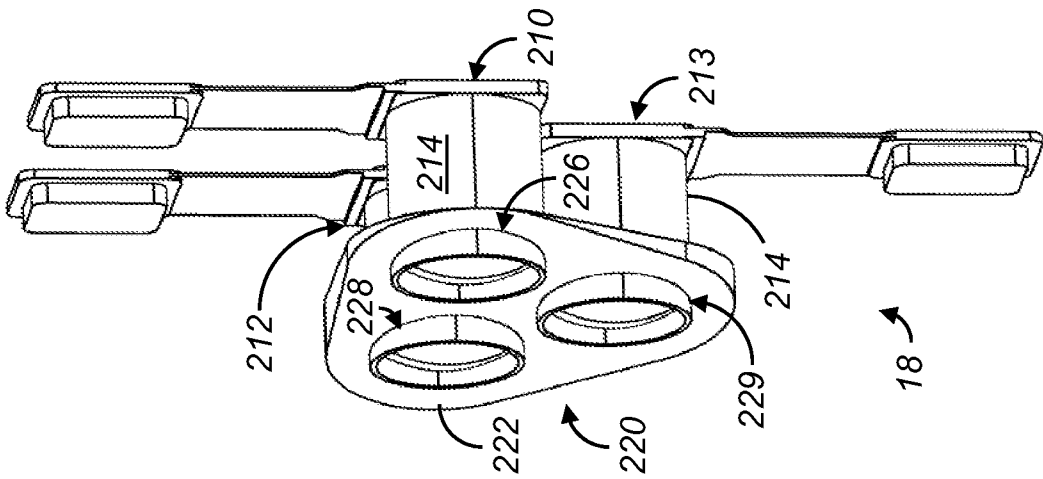


FIG. 5A

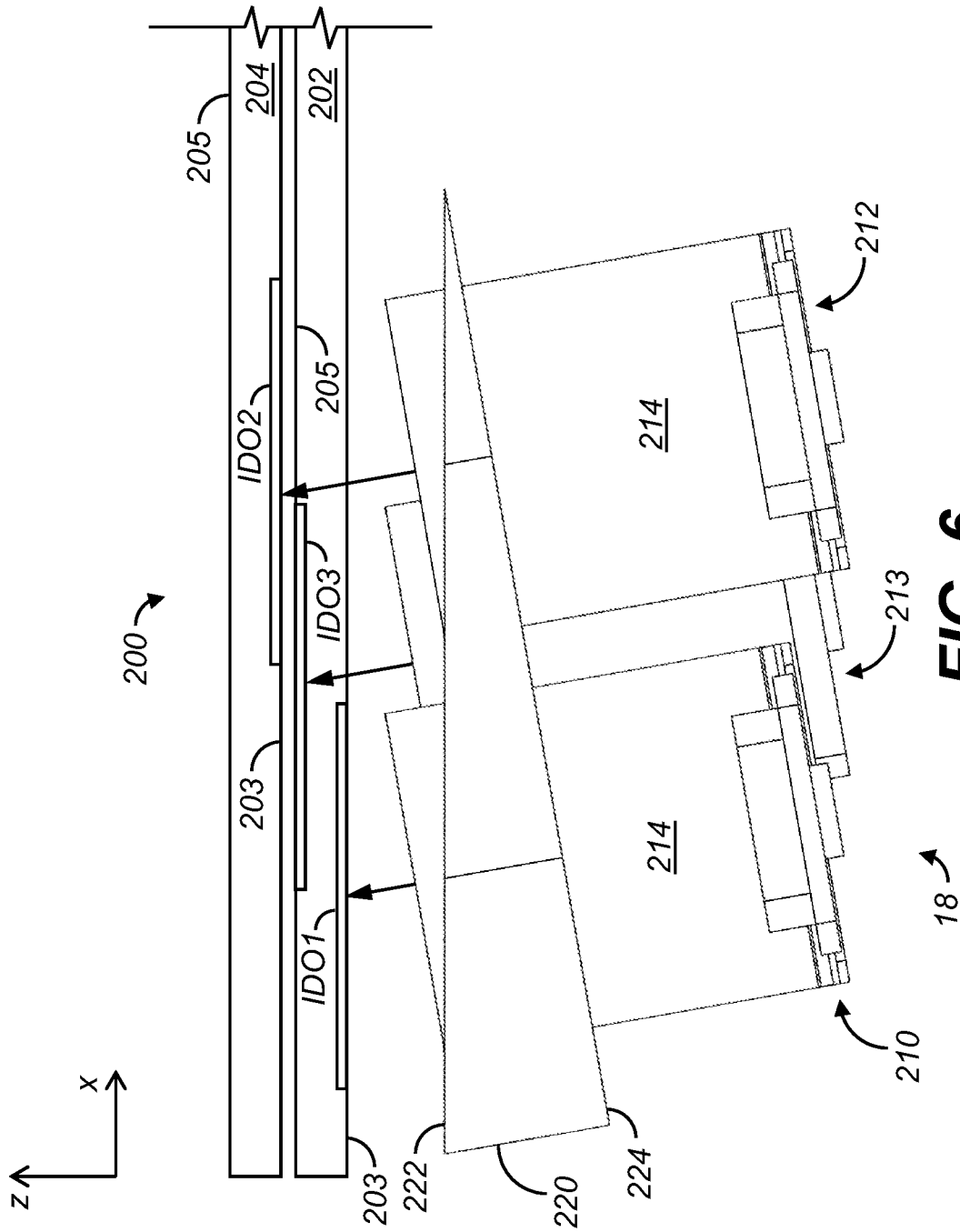
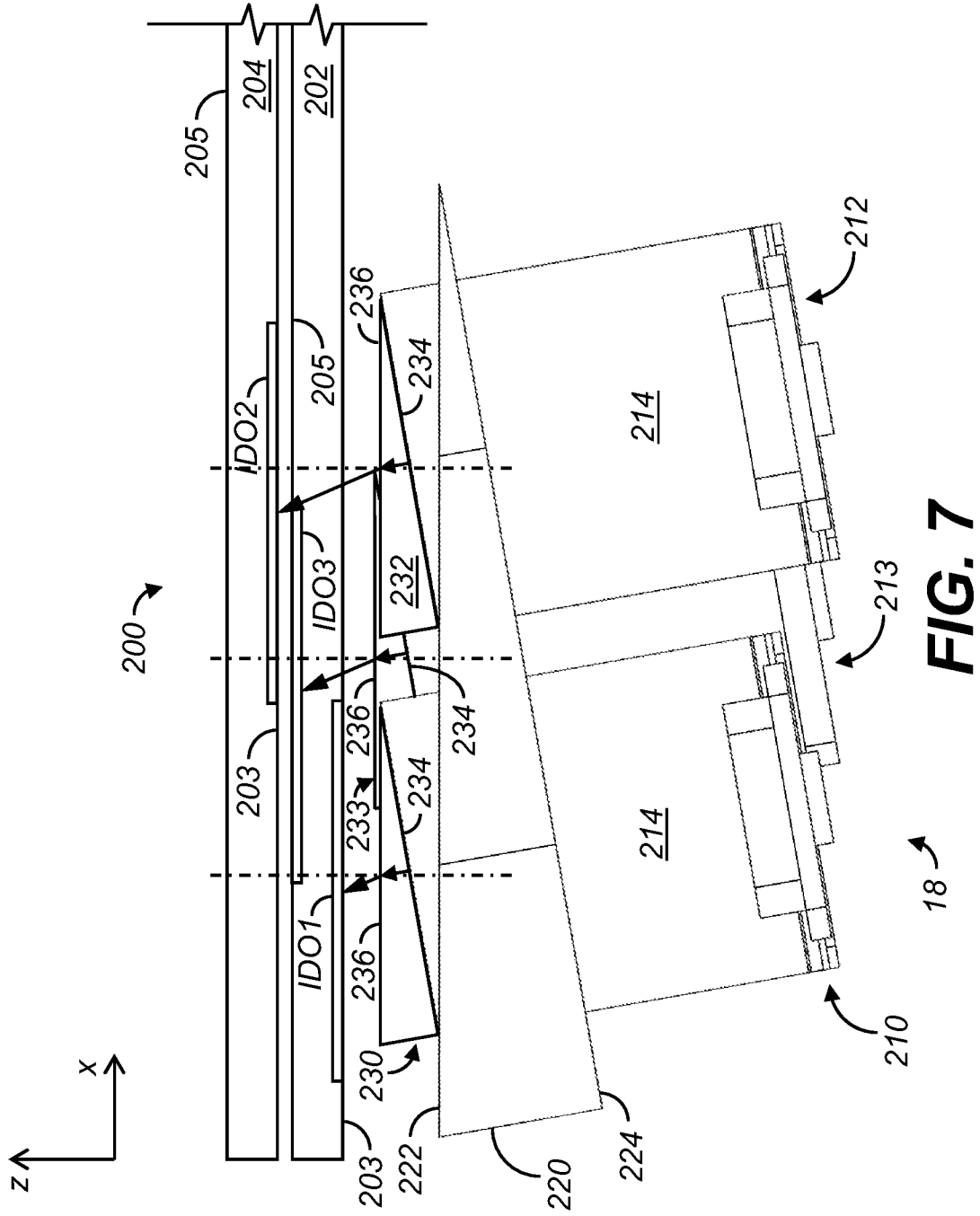


FIG. 6



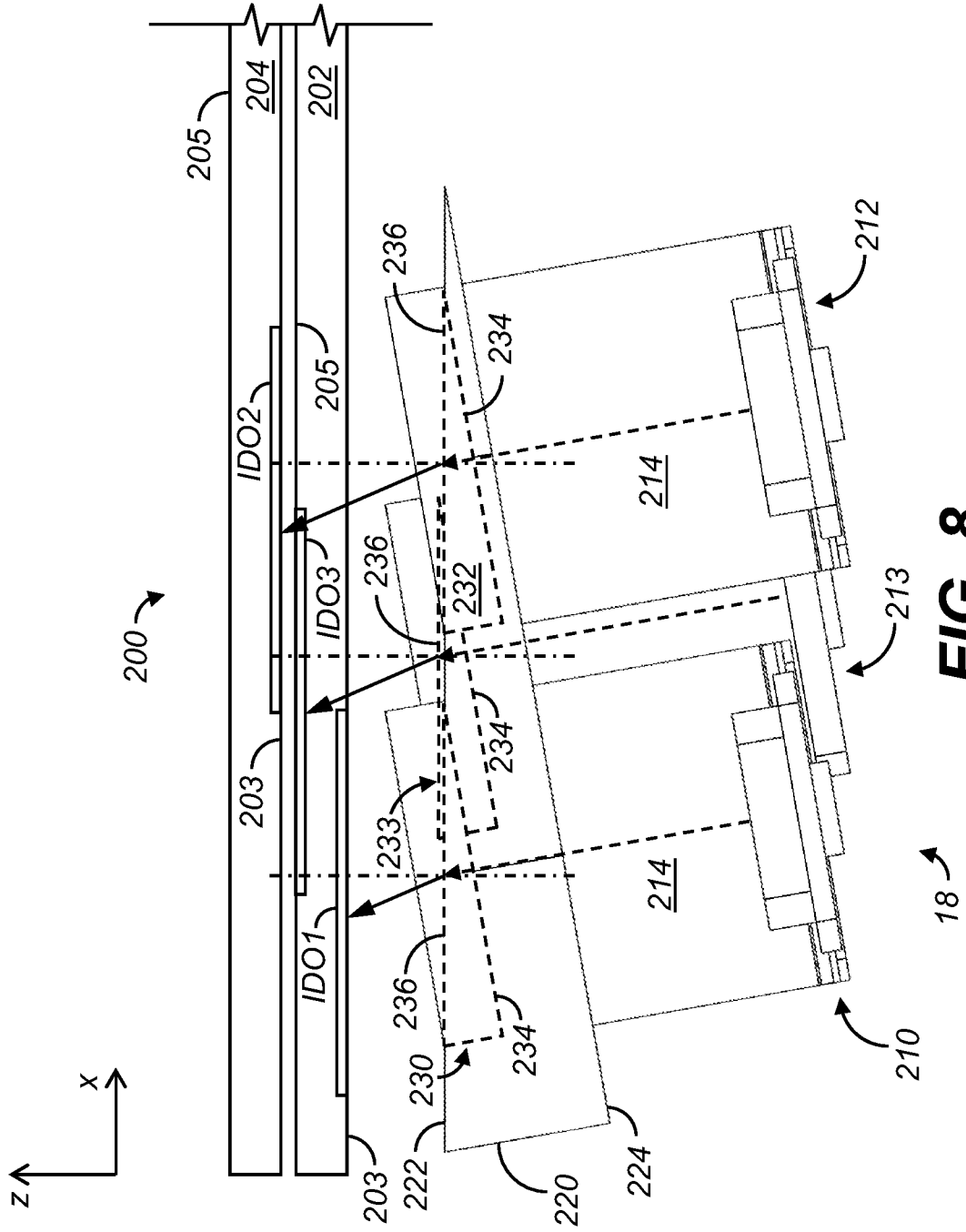


FIG. 8

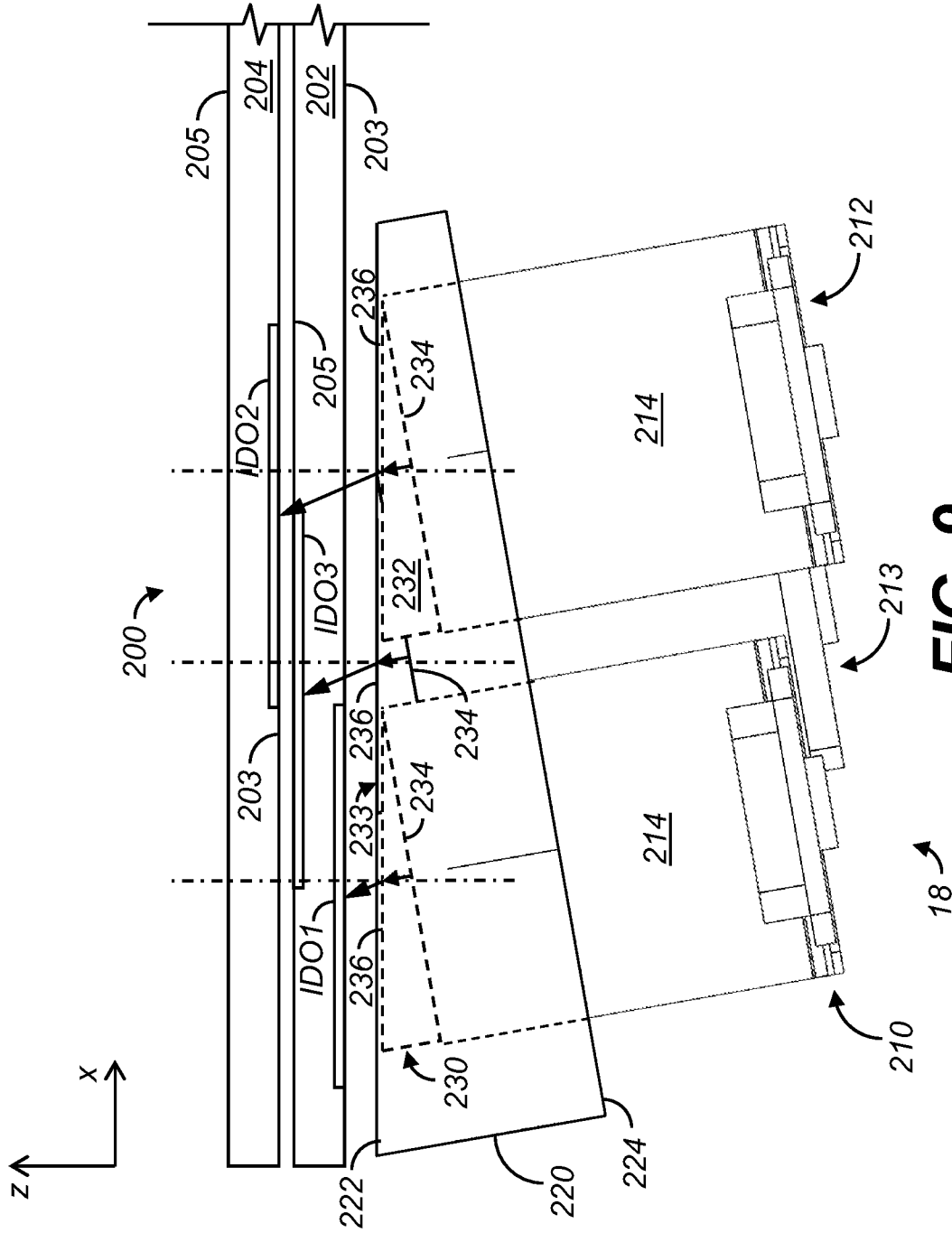


FIG. 9

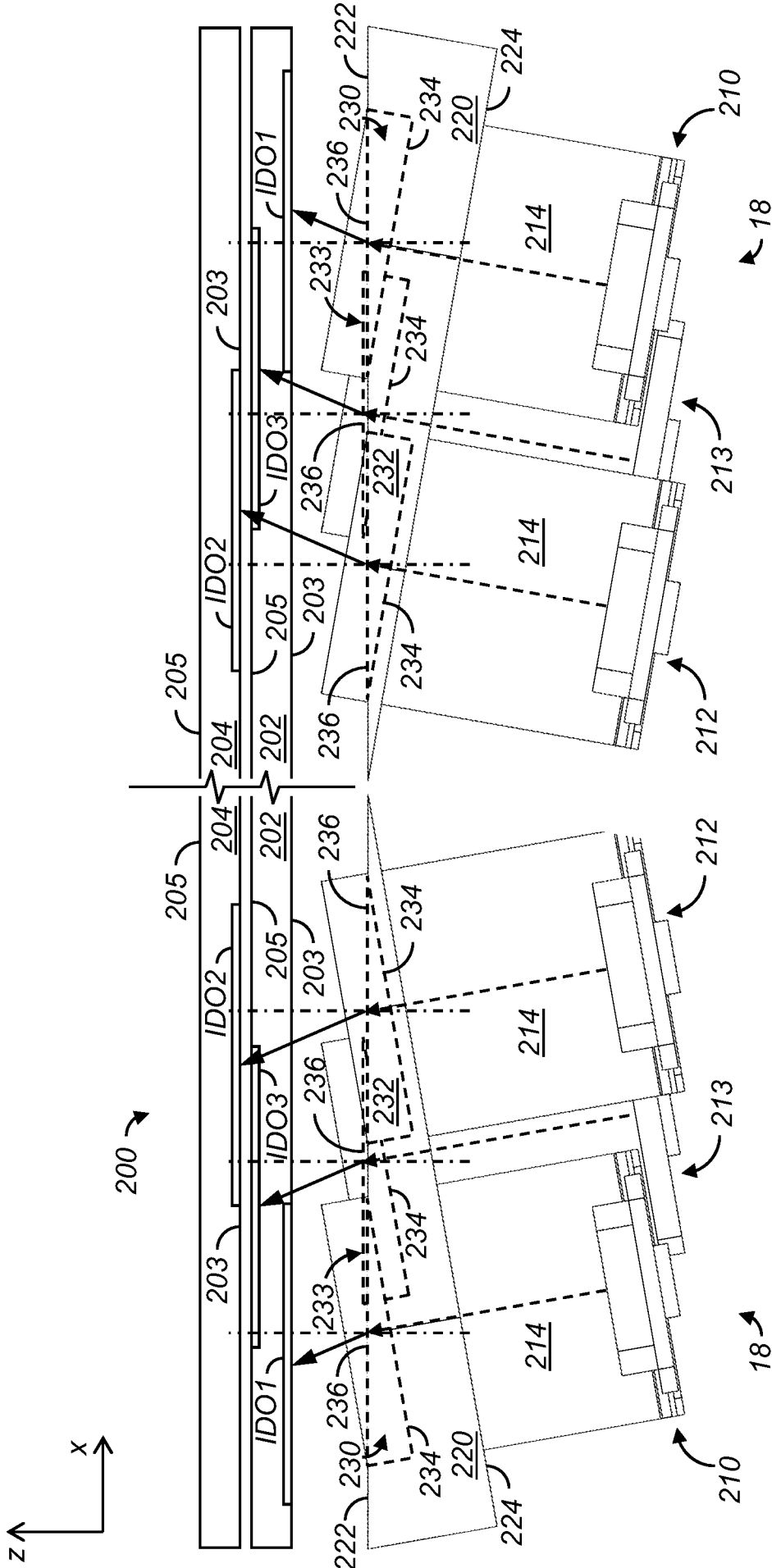


FIG. 10B

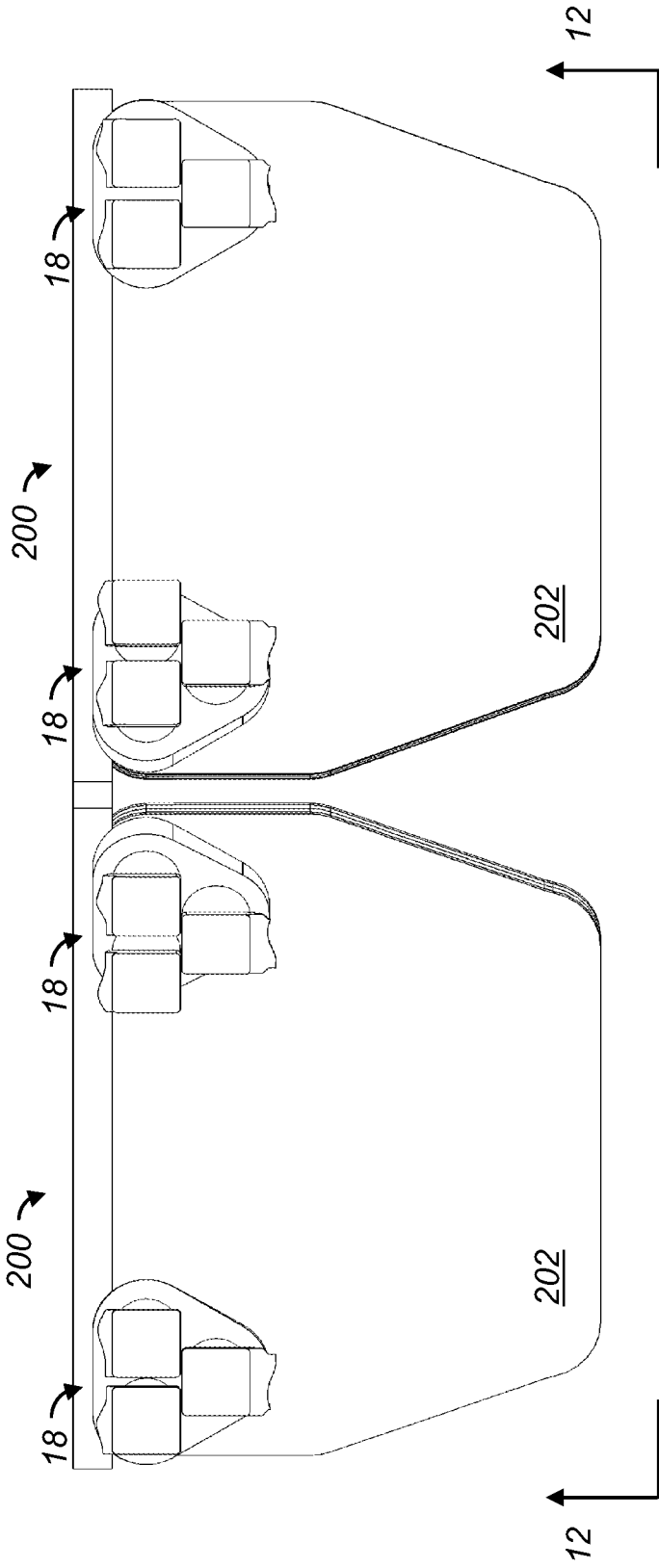


FIG. 11

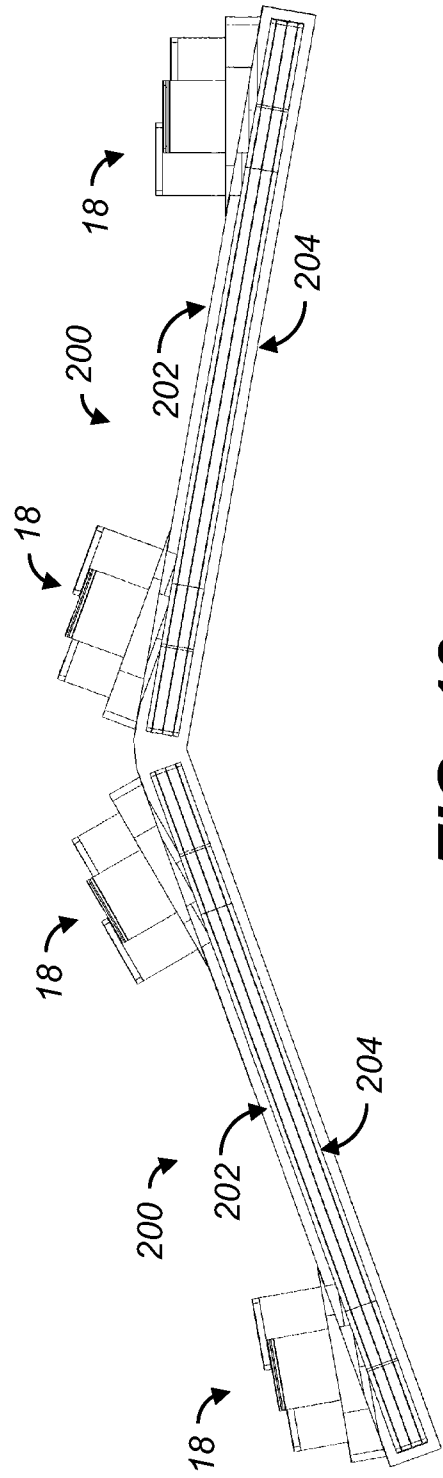


FIG. 12

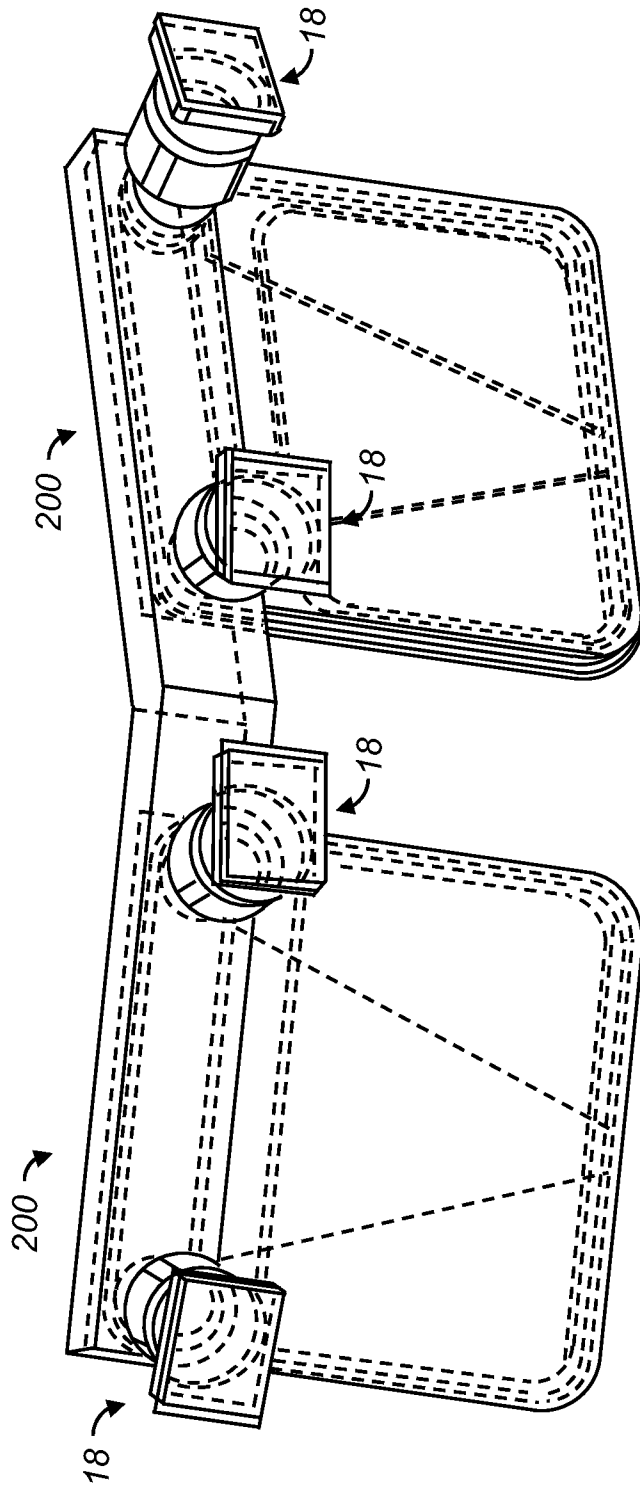


FIG. 13

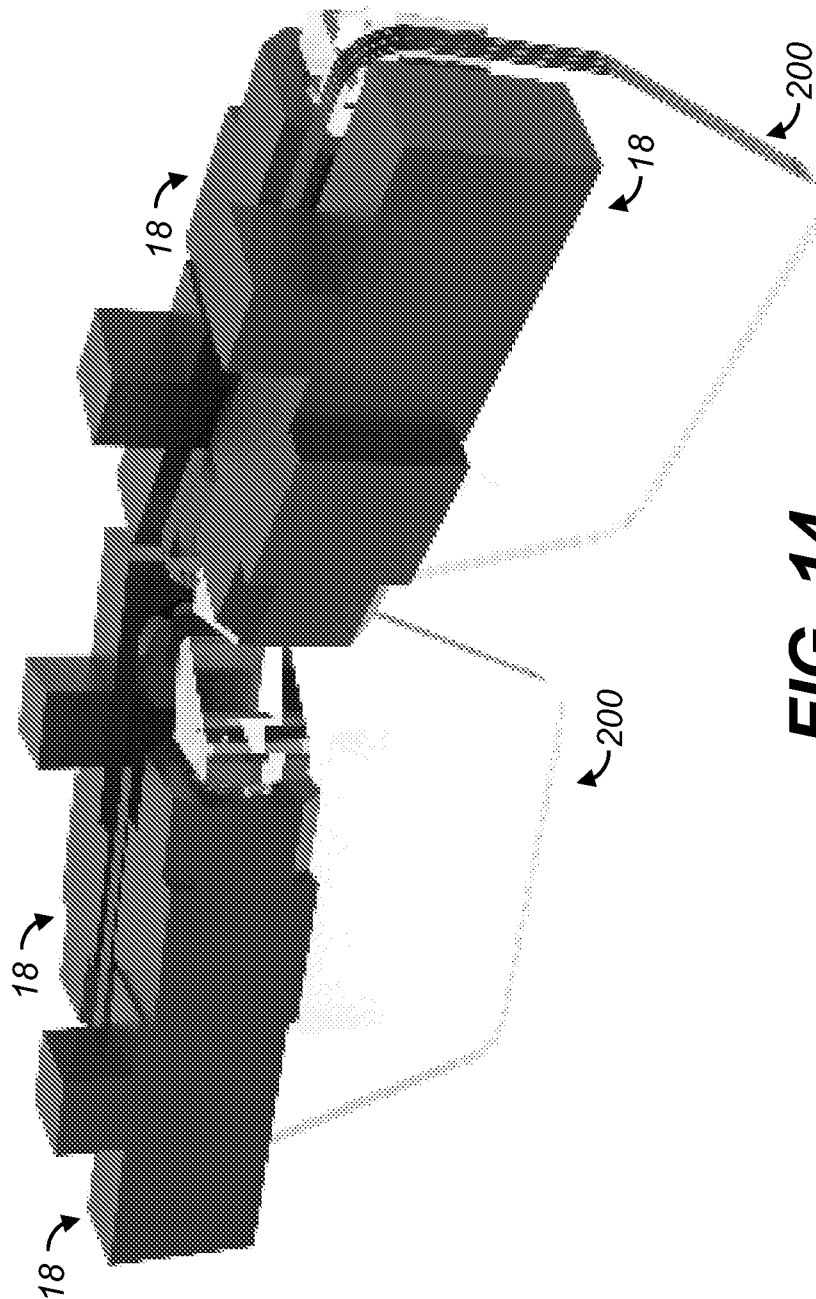


FIG. 14

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2024/036310

A. CLASSIFICATION OF SUBJECT MATTER IPC - INV. G02B 6/00; G02B 6/43; G02B 27/01 (2024.01) ADD. CPC - INV. G02B 6/0091; G02B 6/0046; G02B 6/43; G02B 27/0176 ADD. G02B 6/008; G02B 6/4204; G02B 2027/0123 According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) See Search History document Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched See Search History document Electronic database consulted during the international search (name of database and, where practicable, search terms used) See Search History document		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y --- A	WO 2022/187664 A1 (VUZIX CORPORATION) 09 September 2022; paragraphs [00037], [0044], [00070]; FIGS. 3A, 8	1 --- 2, 7 --- 3-6, 8-21
Y --- A	US 2010/0202048 A1 (YAAKOV AMITAI, ET AL.) 12 August 2010; Abstract; FIG. 23; paragraphs [0006], [0065], [0093], [0098]	2, 7 --- 1, 3-6, 8-21
A	US 2021/0055561 A1 (LUMUS LTD) 25 February 2021; Figs 5A-C; paragraphs [0066], [0078]	1-21
A	US 2022/0334399 A1 (LUMUS LTD) 20 October 2022; Entire document	1-21
A	US 2022/0099975 A1 (VUZIX CORP) 31 March 2022; Entire document	1-21
<input type="checkbox"/> Further documents are listed in the continuation of Box C. <input type="checkbox"/> See patent family annex.		
* Special categories of cited documents: "A" document defining the general state of the art which is not considered to be of particular relevance "D" document cited by the applicant in the international application "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search 05 September 2024 (05.09.2024)	Date of mailing of the international search report <div style="text-align: center; font-size: 1.2em; font-weight: bold;">OCT 01 2024</div>	
Name and mailing address of the ISA/ Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-8300	Authorized officer <div style="text-align: center; font-weight: bold;">Shane Thomas</div> Telephone No. PCT Helpdesk: 571-272-4300	