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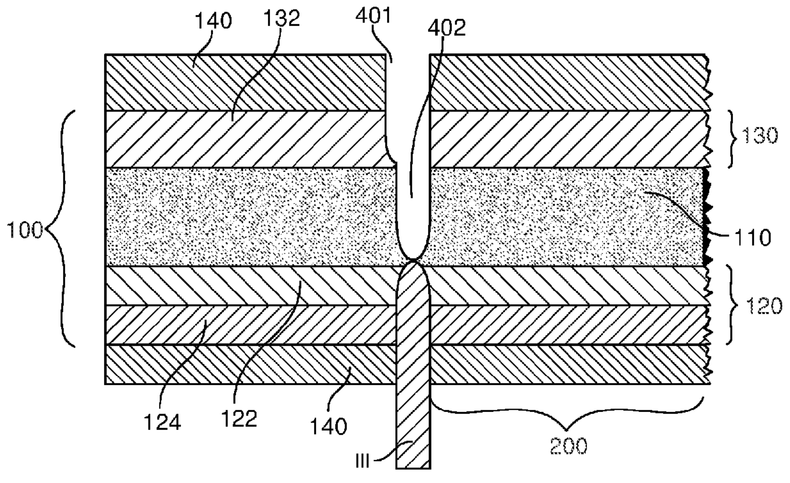

FIG. 4

(57) Abstract: A method of manufacturing an optical element includes forming a first optical layer assembly over a first surface of a planar glass substrate, forming a second optical layer assembly over a second surface of the planar glass substrate, laser cutting entirely through the first optical layer assembly from a first side of the planar glass substrate to form an optical element pattern in the first optical layer assembly, laser cutting entirely through the planar glass substrate from the first side of the planar glass substrate to form the optical element pattern in the planar glass substrate, and laser cutting entirely through the second optical layer assembly from a second side of the planar glass substrate to form the optical element having the optical element pattern.

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GLASS-FILM LAMINATION AND CUTTING METHOD TO MITIGATE ORANGE PEEL

TECHNICAL FIELD

[0001] The present disclosure is generally directed to the formation of optical elements, and more particularly to lamination and cutting methods for forming substantially defect-free polarizing thin films.

BACKGROUND

[0002] Polymer and other organic materials may be incorporated into a variety of different optic and electro-optic device architectures, including passive and active optics and electroactive devices. Lightweight and conformable, one or more polymer/organic solid layers may be incorporated into wearable devices such as smart glasses and are attractive candidates for emerging technologies including virtual reality/augmented reality devices where a comfortable, adjustable form factor is desired.

[0003] Virtual reality (VR) and augmented reality (AR) eyewear devices or headsets, for instance, may enable users to experience events, such as interactions with people in a computer-generated simulation of a three-dimensional world or viewing data superimposed on a real-world view. By way of example, superimposing information onto a field of view may be achieved through an optical head-mounted display (OHMD) or by using embedded wireless glasses with a transparent heads-up display (HUD) or augmented reality (AR) overlay. VR/AR eyewear devices and headsets may be used for a variety of purposes. For example, governments may use such devices for military training, medical professionals may use such devices to simulate surgery, and engineers may use such devices as design visualization aids.

[0004] For use in various optical systems, lenses and other optical devices may be co-integrated with one or more optically active polymer/organic layers that are configured to manipulate light that is incident upon the device. One or more optically active polymer/organic-containing layers may be laminated to a surface of a lens, for example, using a suitable adhesive. Example optically active layers may include diffraction gratings and optical filters such as polarizing thin films (e.g., linear polarizers, circular polarizers, reflective polarizers, transmissive polarizers, quarter waveplates, half waveplates, and the like). Herein, the terms "optically active layer" and "optical layer" may be used interchangeably and relate generally to one or more layers configured to modify a characteristic of light, such as its polarization.

[0005] The act of lamination, particularly over a curved surface of a lens, may introduce defects in the applied polymer/organic-containing layer(s). Unwanted defects may include pin holes, ripples, surface roughness, and other localized distortions/surface phenomena such as orange peel effects. Notwithstanding recent developments, it would be advantageous to provide a method of forming optical elements, as well as optical devices co-integrated with such optical elements that are free or substantially free of these and other defects.

SUMMARY

[0006] According to a first aspect, there is provided a method comprising: forming a first optical layer assembly over a first surface of a planar glass substrate; forming a second optical layer assembly over a second surface of the planar glass substrate; laser cutting entirely through the first optical layer assembly from a first side of the planar glass substrate to form an optical element pattern in the first optical layer assembly; laser cutting entirely through the planar glass substrate from the first side of the planar glass substrate to form the optical element pattern in the planar glass substrate; and laser cutting entirely through the second optical layer assembly from a second side of the planar glass substrate to form an optical element having the optical element pattern.

[0007] The planar glass substrate may be optically transparent.

[0008] The first optical layer assembly may comprise one or more optical layers selected from the group consisting of a linear polarizer, a circular polarizer, a reflective polarizer, a transmissive polarizer, a quarter waveplate, and a half waveplate.

[0009] The second optical layer assembly may comprise one or more optical layers selected from the group consisting of a linear polarizer, a circular polarizer, a reflective polarizer, a transmissive polarizer, a quarter waveplate, and a half waveplate.

[0010] The first optical layer assembly may comprise a linear polarizer and a quarter waveplate, and the second optical layer assembly may comprise a reflective polarizer.

[0011] Forming the first optical layer assembly may comprise laminating one or more first optical layers over the first surface of the planar glass substrate, and forming the second optical layer assembly may comprise laminating one or more second optical layers over the second surface of the planar glass substrate.

[0012] The method may further comprise forming a first protective thin film over the first optical layer assembly prior to laser cutting the first optical layer assembly, and forming a second protective thin film over the second optical layer assembly prior to laser cutting the second optical layer assembly.

[0013] Laser cutting the first optical layer assembly may comprise first laser parameters, laser cutting the second optical layer assembly may comprise second laser parameters, and laser cutting the planar glass substrate may comprise laser parameters different than the first and second laser parameters.

[0014] A laser power for laser cutting the planar glass substrate may be greater than a laser power for laser cutting either the first optical layer assembly or the second optical layer assembly.

[0015] Forming the first optical layer assembly over the first surface of the planar glass substrate and forming the second optical layer assembly over the second surface of the planar glass substrate may create a laminate sheet. A plurality of optical elements having the optical element pattern may be cut from the laminate sheet.

[0016] The method may further comprise forming the optical element over a planar surface of a lens having the optical element pattern.

[0017] The method may further comprise forming the optical element over a planar surface of a lens. The optical element may comprise, from top to bottom or from one side to another side, a reflective polarizer, the planar glass substrate, a linear polarizer, and a quarter waveplate, wherein the quarter waveplate is located adjacent to the planar surface of the lens.

[0018] According to a second aspect, there is provided a method comprising: forming an optical element pattern in a first optical layer assembly disposed over a first surface of a planar glass substrate by laser cutting entirely through the first optical layer assembly from a first side of the planar glass substrate; forming the optical element pattern in the planar glass substrate by laser cutting entirely through the planar glass substrate from the first side of the planar glass substrate; and forming an optical element having the optical element pattern by laser cutting entirely through a second optical layer assembly from a second side of the planar glass substrate, the second optical layer assembly disposed over a second surface of the planar glass substrate.

[0019] The planar glass substrate may be optically transparent.

[0020] The first optical layer assembly may comprise one or more optical layers selected from the group consisting of a linear polarizer, a circular polarizer, a reflective polarizer, a transmissive polarizer, a quarter waveplate, and a half waveplate.

[0021] The second optical layer assembly may comprise one or more optical layers selected from the group consisting of a linear polarizer, a circular polarizer, a reflective polarizer, a transmissive polarizer, a quarter waveplate, and a half waveplate.

[0022] The first optical layer assembly may comprise a linear polarizer and a quarter waveplate, and the second optical layer assembly may comprise a reflective polarizer.

[0023] A laser power for laser cutting the planar glass substrate may be different than a laser power for laser cutting either the first optical layer assembly or the second optical layer assembly.

[0024] According to a third aspect, there is provided a method comprising: laminating a first optical layer assembly over a first surface of a transparent planar glass substrate; laminating a second optical layer assembly over a second surface of the transparent planar glass substrate; laser cutting through the first optical layer assembly from a first side of the transparent planar glass substrate to form an optical element pattern in the first optical layer assembly; laser cutting through the transparent planar glass substrate from the first side of the transparent planar glass substrate to form the optical element pattern in the transparent planar glass substrate; and laser cutting through the second optical layer assembly from a second side of the transparent planar glass substrate to form an optical element having the optical element pattern.

[0025] The method may further comprise forming a first protective thin film over the first optical layer assembly prior to laser cutting the first optical layer assembly, and forming a second protective thin film over the second optical layer assembly prior to laser cutting the second optical layer assembly.

[0026] The presently defined method includes forming a first optical layer assembly over a first surface of a planar glass substrate and forming a second optical layer assembly over a second surface of the planar glass substrate to form a laminate sheet. The independent acts of forming the first and second optical layer assemblies may include orienting and laminating respective optical layers within each assembly of optical layers. The formation of the first and second optical layers over a planar glass substrate may significantly inhibit the generation of orange peel or other surface phenomena during lamination.

[0027] As used herein, "lamination" may, in some examples, refer to a process through which two or more layers (e.g., optical layers) are brought together and attached using an intervening layer of adhesive. In a lamination step, the adhesive may be applied to an optical layer to form an application layer, and the application layer may be contacted with a glass substrate, lens, or another optical layer to form the laminate. An adhesive may include a layer of optical adhesive tape or a pressure sensitive adhesive, for example. In some examples, the adhesive may be cured to form an adhesive layer between the adjacent layers.

[0028] After the lamination process, the optical element may be visually inspected, for example, for bubbles, scratches, or other defects. In some examples, a method may be partially or fully automated. For instance, a lamination process may be performed under computer control.

[0029] Plural laser cutting steps are used to separately cut the glass substrate and the first and second optical layer assemblies according to a pre-selected shape. That is, a first laser cutting step is used to cut entirely through the first optical layer assembly from a first side of the planar glass substrate to form an optical element pattern in the first optical layer assembly. A second laser cutting step is used to cut entirely through the planar glass substrate from the first side of the planar glass substrate to form the optical element pattern in the planar glass substrate. A third laser cutting step is used to cut entirely through the second optical layer assembly from a second side of the planar glass substrate to form an optical element having the optical element pattern. A pattern recognition paradigm may be used to align the first side cut shape with the second side cut shape.

[0030] By separately targeting and successively cutting the first optical layer assembly, the glass substrate, and the second optical layer assembly, laser cutting parameters may be independently set for each material layer being cut, which may mitigate damage to non-targeted layers during the cutting process. For example, a laser power used to cut softer polymer/organic optical layers may be less than a laser power used to cut a harder glass substrate. For a given layer, a cutting rate, cut profile, and the propensity of laser-induced damage may be individually controlled. The avoidance of damage to one or more optical layers and/or the glass substrate may result in improved pattern fidelity, greater throughput, and enhanced performance.

[0031] A picosecond or femto second green laser, for instance, may be used to cut each respective layer in a glass-film laminate to form an optical element having a desired form factor. Laser cutting parameters may be chosen to effectively cut each successive layer without creating damage in the target layer or any layers adjacent to the target layer. The laser cutting process may separate an optical element from a glass-film laminate in a controllable fashion with negligible debris, minimal induced defects, and low subsurface damage, preserving strength and geometric fidelity. A laser cutting method may be tuned and configured to enable manual or mechanical separation, i.e., partial separation or complete separation of an optical element from the laminate sheet.

[0032] According to further embodiments, an optical element may be laminated to a planar surface of a lens to form an optical device. That is, an optical element having an optical element pattern may be laminated to a planar surface of a lens having the equivalent or substantially equivalent optical element pattern to form the optical device.

[0033] As disclosed herein, a glass-film laminate may be formed from a plurality of optically active layers that are located over opposing sides of a flat glass substrate. Example optically active layers include diffraction gratings and optical filters such as polarizing thin films (e.g., linear polarizers, circular polarizers, reflective polarizers, transmissive polarizers, quarter waveplates, half waveplates, and the like). The formation of one or more optically active layers over a flat substrate may decrease the propensity for wrinkling or the generation of uneven, rough irregularities (i.e., orange peel) in one or more surfaces of the glass-film laminate. A multitude of optical elements may be harvested from the glass-film laminate using a sequence of laser cutting steps that independently and successively cut through the optically active layers and the glass substrate.

[0034] According to particular embodiments, a first laser cutting step may be used to cut one or more optically active layers located on one side of the glass substrate and a second laser cutting step may be used to cut the glass substrate. The partially cut glass-film laminate may be flipped over and a third laser cutting step may be used to cut one or more optically active layers located on the other side of the glass substrate. A pattern recognition scheme may be used to align the front and back-side cutting to produce a desired form factor and avoid laser-induced damage to one or more of the optically active layers. The alignment accuracy of one or more polarization layers within each optical element may be improved by harvesting multiple pre-aligned optical elements from a single glass-film laminate. An optical element may be sized and dimensioned to overlie a planar surface of a lens, for example, which may be incorporated into various optical systems, such as AR/VR devices and headsets.

[0035] An optical element may include a glass substrate and one or more optical layers disposed over each of the major surfaces of the glass substrate. One or more lamination steps may be used to form such a multilayer stack, and a laser may be used to cut through the stack and define an optical element having a desired form factor. The optical element may be affixed to a planar surface of a transparent optical device, such as a lens.

[0036] A material or element that is "transparent" or "optically transparent" may, for a given thickness, have a transmissivity within the visible light spectrum of at least approximately 80%, e.g., approximately 80, 90, 95, 97, 98, 99, or 99.5%, including ranges between any of the foregoing values, and less than approximately 5% bulk haze, e.g., approximately 0.1, 0.2, 0.5, 1, 2, or 5% bulk haze, including ranges between any of the foregoing values. Transparent materials will typically exhibit very low optical absorption and minimal optical scattering.

[0037] As used herein, the terms "haze" and "clarity" may refer to an optical phenomenon associated with the transmission of light through a material, and may be attributed, for example, to the refraction of light within the material, e.g., due to secondary phases or porosity and/or the reflection of light from one or more surfaces of the material. As will be appreciated by those skilled in the art, haze may be associated with an amount of light that is subject to wide angle scattering (i.e., at an angle greater than 2.5° from normal) and a corresponding loss of transmissive contrast, whereas clarity may relate to an amount of light that is subject to narrow angle scattering (i.e., at an angle less than 2.5° from normal) and an attendant loss of optical sharpness or "see through quality."

[0038] A multilayer laminate sheet may include a transparent glass substrate, a first optical layer assembly disposed over a first surface of the transparent glass substrate, and a second optical layer assembly disposed over a second surface of the transparent glass substrate opposite to the first surface. Each optical layer assembly may independently include one or more optically active layers. As used herein, a "laminate" or a "laminate sheet" may, in some examples, refer to a composite structure that includes two or more bonded thin films or layers. In some embodiments, a "glass-film laminate" may include a glass substrate and one or more optical layers laminated over one or both of the major surfaces of the glass substrate. In some embodiments, plural optical elements may be harvested from a single laminate sheet.

[0039] A glass substrate may be configured to provide mechanical support for an optical element and may include any suitable organic or inorganic material. For instance, a glass substrate may include silicon dioxide. By way of example, a silicon dioxide-containing glass having high light transmittance across the visible spectrum may include, in addition to silicon dioxide (SiO_2), sodium oxide (Na_2O) and calcium oxide (CaO), a low amount of iron oxide coupled with zinc oxide and/or erbium oxide.

[0040] A glass substrate may have planar and parallel major surfaces. A planar glass substrate may be regarded as being flat or approximately flat and characterized by opposing major surfaces each having a surface roughness (R_a) of less than approximately 1 micrometer, e.g., less than approximately 1 micrometer, less than approximately 500 nm, less than approximately 200 nm, less than approximately 100 nm, less than approximately 50 nm, less than approximately 20 nm, less than approximately 10 nm, or less than approximately 5 nm, including ranges between any of the foregoing values.

[0041] One or more optically active layers may be disposed over each major surface of the glass substrate. According to some embodiments, each optically active layer may include a single layer or a multilayer stack of one or more polymer or organic materials, such as polyvinylidene fluoride (PVDF) or polyethylene (PE), e.g., ultra-high molecular weight polyethylene (UHMWPE), although additional polymer and organic materials are contemplated. These and other polymer materials may be crystalline (e.g. single crystal), partially crystalline, or amorphous (i.e., glassy).

[0042] The one or more optically active layers may include polarizing thin films, and may include linear polarizers, circular polarizers, reflective polarizers, transmissive polarizers, quarter waveplates, half waveplates, and the like.

[0043] Linear polarizers can be divided into two general categories. In an absorptive polarizer, unwanted polarization states are absorbed by the optical layer. In a beam-splitting polarizer, on the other hand, an unpolarized beam of light may be split into two beams with opposite polarization states.

[0044] Circular polarizers can be used to create circularly polarized light or, alternatively, to selectively absorb or pass clockwise and counter-clockwise circularly polarized light.

[0045] A reflective polarizer may be configured to reflect light of one polarization and transmit light having the orthogonal polarization. In pancake VR optics and polarization recycling, for instance, broadband circular reflective polarizers are typically core components where the reflective polarizer quality may impact the display viewing experience of a user or the recycling efficiency of the device.

[0046] Example reflective polarizers include, without limitation, cholesteric reflective polarizers (CLCs) and/or multilayer birefringent reflective polarizers. In some examples, a reflective polarizer may be fabricated by forming an alignment layer (e.g., a polymer layer or grating) and forming at least one layer of a cholesteric liquid crystal (CLC) over the alignment layer that is at least partially aligned to the alignment layer. The alignment layer may include a photoalignment material (PAM) that may be formed over a substrate. A desired molecular orientation may be obtained by exposing the PAM to polarized light (such as ultraviolet (UV) and/or visible light). A CLC may be further processed to stabilize the molecular alignment of a CLC within a solid material, for example, to provide a chiral material such as a chiral solid. A CLC may be polymerized, cross-linked, and/or a polymer network may be formed through the CLC to fix or set the alignment. In some examples, a CLC may be formed using an effective concentration of a chiral dopant within a nematic liquid crystal, and the chiral nematic (cholesteric) mixture may further include polymerizable materials.

[0047] In some examples, a reflective polarizer may include a chiral material, such as a material having molecular ordering similar to that of a cholesteric liquid crystal, and may include a solid material derived from cooling, polymerizing, cross-linking, or otherwise stabilizing the molecular order of a cholesteric liquid crystal. By way of example, a chiral solid may have a helical optical structure similar to that of a cholesteric liquid crystal, where a direction of maximum refractive index may describe a helix around a normal to the local direction of molecular orientation.

[0048] A reflective polarizer may itself include one or more polymer or organic solid thin film layers that are stacked to form a multilayer. A multilayer thin film may be formed by clocking and stacking individual layers. That is, in an example "clocked" multilayer stack, an angle of refractive index misorientation between successive layers may range from approximately 1° to approximately 90°, e.g., 1, 2, 5, 10, 20, 30, 40, 45, 50, 60, 70, 80, or 90°, including ranges between any of the foregoing values.

[0049] A circular reflective polarizer may include a linear reflective polarizer and quarter waveplate, where the linear reflective polarizer may be formed from one or more polymer materials, such as PEN. A circular reflective polarizer can also be made using cholesteric materials, such as a cholesteric liquid crystal (CLC).

[0050] A waveplate, or retarder, is an optical device that may be configured to alter the polarization state of a light wave travelling through it. Two common types of waveplates are a half-wave plate, which shifts the polarization direction of linearly polarized light, and a quarter-wave plate, which may convert linearly polarized light into circularly polarized light or vice versa.

[0051] Within a laminate sheet, i.e., a glass-film laminate, the configuration of one or more optically active layers, e.g., the orientation between adjacent optically active layers, may be arranged to provide desired performance or function. For example, a linear polarizer and a quarter waveplate may be adjacent and mutually oriented within an optical element to produce circularly polarized light. With the present methods, a desired orientational relationship between optically active layers may be pre-set at the laminate sheet level for a plurality of optical elements, obviating the need to orient two or more layers for each individual optical element, and thus improving angle alignment accuracy.

[0052] Features from any of the embodiments described herein may be used in combination with one another in accordance with the general principles described herein. These and other embodiments, features, and advantages will be more fully understood upon reading the following detailed description in conjunction with the accompanying drawings and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0053] The accompanying drawings illustrate a number of examples and are a part of the specification. Together with the following description, these drawings demonstrate and explain various principles of the present disclosure.

[0054] FIG. 1 shows cross-sectional views of (A) a glass-film laminate and (B) a glass-film laminate including a protective layer disposed over opposing major surfaces.

[0055] FIG. 2 is a top-down plan view of a glass-film laminate illustrating an optical element harvest architecture.

[0056] FIG. 3 illustrates a multi-step laser cutting method for forming an optical element from a glass-film laminate.

[0057] FIG. 4 illustrates the formation of an optical element from a glass-film laminate at an intermediate stage of fabrication.

[0058] FIG. 5 shows the harvesting of an optical element from a glass-film laminate.

[0059] FIG. 6 is a cross-sectional schematic view of an optical element integrated with a lens.

[0060] FIG. 7 is an illustration of exemplary augmented-reality glasses that may be used in connection with embodiments of this disclosure.

[0061] FIG. 8 is an illustration of an exemplary virtual-reality headset that may be used in connection with embodiments of this disclosure.

[0062] Throughout the drawings, identical reference characters and descriptions indicate similar, but not necessarily identical, elements. While the examples described herein are susceptible to various modifications and alternative forms, specific examples have been shown in the drawings and will be described in detail herein. However, the examples described herein are not intended to be limited to the particular forms disclosed. Rather, the present disclosure covers all modifications, equivalents, and alternatives falling within the scope of the appended claims.

DETAILED DESCRIPTION

[0063] The following will provide, with reference to FIGS. 1-8, detailed descriptions of methods for cutting a glass-film laminate (i.e., a laminate sheet) to form an optical element. The discussion associated with FIGS. 1-6 includes a description of methods of forming a glass-film laminate and the resulting structure, and laser cutting methods for harvesting plural optical elements from the laminate that avoid the creation of damage such as ablation and/or orange peel in the polymer/organic thin film layers and/or cracking or spalling of the glass substrate. The discussion associated with FIGS. 7 and 8 relates to exemplary virtual reality and augmented reality devices that may include one or more optical elements as disclosed herein.

[0064] Referring to FIG. 1, illustrated is a cross-sectional view of a glass-film laminate. Shown in FIG. 1A, glass-film laminate 100 includes a glass substrate 110, a first optical layer assembly 120 disposed over a first surface of the glass substrate 110, and a second optical layer assembly 130 disposed over a second surface of the glass substrate 110. First optical layer assembly 120 may include, for example, a linear polarizer layer 122 laminated to the first surface of the glass substrate 110, and a quarter waveplate 124 laminated to the linear polarizer 122. Second optical layer assembly 130 may include a reflective polarizer 132.

[0065] Referring to FIG. 1B, a protective thin film 140 may be laminated over exposed surfaces of the first and second optical layer assemblies. During laser cutting, a protective thin film may decrease the propensity for laser-induced damage to one or more layers within the laminate. In the various examples disclosed herein, the adhesive layer(s) forming a laminate, such as glass-film laminate 100, are not illustrated so as to not distract from the principles of the disclosure.

[0066] Turning to FIG. 2, shown is a top-down plan view of glass-film laminate 100. Illustrated are the locations of plural optical elements 200, which are arranged to be defined using a multi-step laser cutting process and harvested from laminate 100.

[0067] An example multi-step laser cutting process is illustrated schematically in FIG. 3, where successive laser cutting steps I, II, and III are configured to cut entirely through second optical layer assembly 130, glass substrate 110, and first optical layer assembly 120, respectively. For instance, and with reference to FIG. 4, an example process may include laser cutting entirely through the second optical layer assembly 130 from a second side of the glass substrate 110 to form an optical element pattern 401 in the second optical layer assembly, laser cutting entirely through the glass substrate 110 from the second side of the glass substrate 110 to form the optical element pattern 402 in the glass substrate 110, and laser cutting entirely through the first optical layer assembly 120 from a first side of the glass substrate to form an optical element 200 having the optical element pattern. FIG. 4 shows laminate 100 following laser cutting of the second optical layer assembly 130 and the glass substrate 110, and prior to laser cutting the first optical layer assembly 120. The laser cutting and harvesting of an optical element 200 from a glass-film laminate 100 is shown in FIG. 5.

[0068] Referring to FIG. 6, optical element 200 may be disposed over and laminated to a planar surface of an optical device such as lens 600. In the illustrated example, optical element 200 may be arranged such that the first optical layer assembly 120, including the linear polarizer layer 122 and the quarter waveplate 124, is located proximate to lens 600.

[0069] Embodiments of the present disclosure may include or be implemented in conjunction with various types of artificial-reality systems. Artificial reality is a form of reality that has been adjusted in some manner before presentation to a user, which may include, for example, a virtual reality, an augmented reality, a mixed reality, a hybrid reality, or some combination and/or derivative thereof. Artificial-reality content may include completely computer-generated content or computer-generated content combined with captured (e.g., real-world) content. The artificial-reality content may include video, audio, haptic feedback, or some combination thereof, any of which may be presented in a single channel or in multiple channels (such as stereo video that produces a three-dimensional (3D) effect to the viewer). Additionally, in some embodiments, artificial reality may also be associated with applications, products, accessories, services, or some combination thereof, that are used to, for example, create content in an artificial reality and/or are otherwise used in (e.g., to perform activities in) an artificial reality.

[0070] Artificial-reality systems may be implemented in a variety of different form factors and configurations. Some artificial-reality systems may be designed to work without near-eye displays (NEDs). Other artificial-reality systems may include an NED that also provides visibility into the real world (e.g., augmented-reality system 700 in FIG. 7) or that visually immerses a user in an artificial reality (e.g., virtual-reality system 800 in FIG. 8). While some artificial-reality devices may be self-contained systems, other artificial-reality devices may communicate and/or coordinate with external devices to provide an artificial-reality experience to a user. Examples of such external devices include handheld controllers, mobile devices, desktop computers, devices worn by a user, devices worn by one or more other users, and/or any other suitable external system.

[0071] Turning to FIG. 7, augmented-reality system 700 may include an eyewear device 702 with a frame 710 configured to hold a left display device 715(A) and a right display device 715(B) in front of a user's eyes. Display devices 715(A) and 715(B) may act together or independently to present an image or series of images to a user. While augmented-reality system 700 includes two displays, embodiments of this disclosure may be implemented in augmented-reality systems with a single NED or more than two NEDs.

[0072] In some examples, augmented-reality system 700 may include one or more sensors, such as sensor 740. Sensor 740 may generate measurement signals in response to motion of augmented-reality system 700 and may be located on substantially any portion of frame 710. Sensor 740 may represent a position sensor, an inertial measurement unit (IMU), a depth camera assembly, a structured light emitter and/or detector, or any combination thereof. In some examples, augmented-reality system 700 may or may not include sensor 740 or may include more than one sensor. In examples in which sensor 740 includes an IMU, the IMU may generate calibration data based on measurement signals from sensor 740. Examples of sensor 740 may include, without limitation, accelerometers, gyroscopes, magnetometers, other suitable types of sensors that detect motion, sensors used for error correction of the IMU, or some combination thereof.

[0073] Augmented-reality system 700 may also include a microphone array with a plurality of acoustic transducers 720(A)-720(J), referred to collectively as acoustic transducers 720. Acoustic transducers 720 may be transducers that detect air pressure variations induced by sound waves. Each acoustic transducer 720 may be configured to detect sound and convert the detected sound into an electronic format (e.g., an analog or digital format). The microphone array in FIG. 7 may include, for example, ten acoustic transducers: 720(A) and 720(B), which may be designed to be placed inside a corresponding ear of the user, acoustic transducers 720(C), 720(D), 720(E), 720(F), 720(G), and 720(H), which may be positioned at various locations on frame 710, and/or acoustic transducers 720(I) and 720(J), which may be positioned on a corresponding neckband 705.

[0074] In some examples, one or more of acoustic transducers 720(A)-(F) may be used as output transducers (e.g., speakers). For example, acoustic transducers 720(A) and/or 720(B) may be earbuds or any other suitable type of headphone or speaker.

[0075] The configuration of acoustic transducers 720 of the microphone array may vary. While augmented-reality system 700 is shown in FIG. 7 as having ten acoustic transducers 720, the number of acoustic transducers 720 may be greater or less than ten. In some examples, using higher numbers of acoustic transducers 720 may increase the amount of audio information collected and/or the sensitivity and accuracy of the audio information. In contrast, using a lower number of acoustic transducers 720 may decrease the computing power required by an associated controller 750 to process the collected audio information. In addition, the position of each acoustic transducer 720 of the microphone array may vary. For example, the position of an acoustic transducer 720 may include a defined position on the user, a defined coordinate on frame 710, an orientation associated with each acoustic transducer 720, or some combination thereof.

[0076] Acoustic transducers 720(A) and 720(B) may be positioned on different parts of the user's ear, such as behind the pinna, behind the tragus, and/or within the auricle or fossa. Or, there may be additional acoustic transducers 720 on or surrounding the ear in addition to acoustic transducers 720 inside the ear canal. Having an acoustic transducer 720 positioned next to an ear canal of a user may enable the microphone array to collect information on how sounds arrive at the ear canal. By positioning at least two of acoustic transducers 720 on either side of a user's head (e.g., as binaural microphones), augmented-reality device 700 may simulate binaural hearing and capture a 3D stereo sound field around about a user's head. In some examples, acoustic transducers 720(A) and 720(B) may be connected to augmented-reality system 700 via a wired connection 730, and in other examples acoustic transducers 720(A) and 720(B) may be connected to augmented-reality system 700 via a wireless connection (e.g., a Bluetooth connection). In still other examples, acoustic transducers 720(A) and 720(B) may not be used at all in conjunction with augmented-reality system 700.

[0077] Acoustic transducers 720 on frame 710 may be positioned along the length of the temples, across the bridge, above or below display devices 715(A) and 715(B), or some combination thereof. Acoustic transducers 720 may be oriented such that the microphone array is able to detect sounds in a wide range of directions surrounding the user wearing the augmented-reality system 700. In some examples, an optimization process may be performed during manufacturing of augmented-reality system 700 to determine relative positioning of each acoustic transducer 720 in the microphone array.

[0078] In some examples, augmented-reality system 700 may include or be connected to an external device (e.g., a paired device), such as neckband 705. Neckband 705 generally represents any type or form of paired device. Thus, the following discussion of neckband 705 may also apply to various other paired devices, such as charging cases, smart watches, smart phones, wrist bands, other wearable devices, hand-held controllers, tablet computers, laptop computers, other external compute devices, etc.

[0079] As shown, neckband 705 may be coupled to eyewear device 702 via one or more connectors. The connectors may be wired or wireless and may include electrical and/or non-electrical (e.g., structural) components. In some cases, eyewear device 702 and neckband 705 may operate independently without any wired or wireless connection between them. While FIG. 7 illustrates the components of eyewear device 702 and neckband 705 in example locations on eyewear device 702 and neckband 705, the components may be located elsewhere and/or distributed differently on eyewear device 702 and/or neckband 705. In some examples, the components of eyewear device 702 and neckband 705 may be located on one or more additional peripheral devices paired with eyewear device 702, neckband 705, or some combination thereof.

[0080] Pairing external devices, such as neckband 705, with augmented-reality eyewear devices may enable the eyewear devices to achieve the form factor of a pair of glasses while still providing sufficient battery and computation power for expanded capabilities. Some or all of the battery power, computational resources, and/or additional features of augmented-reality system 700 may be provided by a paired device or shared between a paired device and an eyewear device, thus reducing the weight, heat profile, and form factor of the eyewear device overall while still retaining desired functionality. For example, neckband 705 may allow components that would otherwise be included on an eyewear device to be included in neckband 705 since users may tolerate a heavier weight load on their shoulders than they would tolerate on their heads. Neckband 705 may also have a larger surface area over which to diffuse and disperse heat to the ambient environment. Thus, neckband 705 may allow for greater battery and computation capacity than might otherwise have been possible on a stand-alone eyewear device. Since weight carried in neckband 705 may be less invasive to a user than weight carried in eyewear device 702, a user may tolerate wearing a lighter eyewear device and carrying or wearing the paired device for greater lengths of time than a user would tolerate wearing a heavy standalone eyewear device, thereby enabling users to more fully incorporate artificial-reality environments into their day-to-day activities.

[0081] Neckband 705 may be communicatively coupled with eyewear device 702 and/or to other devices. These other devices may provide certain functions (e.g., tracking, localizing, depth mapping, processing, storage, etc.) to augmented-reality system 700. In the example of FIG. 7, neckband 705 may include two acoustic transducers (e.g., 720(I) and 720(J)) that are part of the microphone array (or potentially form their own microphone subarray). Neckband 705 may also include a controller 725 and a power source 735.

[0082] Acoustic transducers 720(I) and 720(J) of neckband 705 may be configured to detect sound and convert the detected sound into an electronic format (analog or digital). In the example of FIG. 7, acoustic transducers 720(I) and 720(J) may be positioned on neckband 705, thereby increasing the distance between the neckband acoustic transducers 720(I) and 720(J) and other acoustic transducers 720 positioned on eyewear device 702. In some cases, increasing the distance between acoustic transducers 720 of the microphone array may improve the accuracy of beamforming performed via the microphone array. For example, if a sound is detected by acoustic transducers 720(C) and 720(D) and the distance between acoustic transducers 720(C) and 720(D) is greater than, e.g., the distance between acoustic transducers 720(D) and 720(E), the determined source location of the detected sound may be more accurate than if the sound had been detected by acoustic transducers 720(D) and 720(E).

[0083] Controller 725 of neckband 705 may process information generated by the sensors on neckband 705 and/or augmented-reality system 700. For example, controller 725 may process information from the microphone array that describes sounds detected by the microphone array. For each detected sound, controller 725 may perform a direction-of-arrival (DOA) estimation to estimate a direction from which the detected sound arrived at the microphone array. As the microphone array detects sounds, controller 725 may populate an audio data set with the information. In examples in which augmented-reality system 700 includes an inertial measurement unit, controller 725 may compute all inertial and spatial calculations from the IMU located on eyewear device 702. A connector may convey information between augmented-reality system 700 and neckband 705 and between augmented-reality system 700 and controller 725. The information may be in the form of optical data, electrical data, wireless data, or any other transmittable data form. Moving the processing of information generated by augmented-reality system 700 to neckband 705 may reduce weight and heat in eyewear device 702, making it more comfortable to the user.

[0084] Power source 735 in neckband 705 may provide power to eyewear device 702 and/or to neckband 705. Power source 735 may include, without limitation, lithium ion batteries, lithium-polymer batteries, primary lithium batteries, alkaline batteries, or any other form of power storage. In some cases, power source 735 may be a wired power source. Including power source 735 on neckband 705 instead of on eyewear device 702 may help better distribute the weight and heat generated by power source 735.

[0085] As noted, some artificial-reality systems may, instead of blending an artificial reality with actual reality, substantially replace one or more of a user's sensory perceptions of the real world with a virtual experience. One example of this type of system is a head-worn display system, such as virtual-reality system 800 in FIG. 8, that mostly or completely covers a user's field of view. Virtual-reality system 800 may include a front rigid body 802 and a band 804 shaped to fit around a user's head. Virtual-reality system 800 may also include output audio transducers 806(A) and 806(B). Furthermore, while not shown in FIG. 8, front rigid body 802 may include one or more electronic elements, including one or more electronic displays, one or more inertial measurement units (IMUs), one or more tracking emitters or detectors, and/or any other suitable device or system for creating an artificial reality experience.

[0086] Artificial-reality systems may include a variety of types of visual feedback mechanisms. For example, display devices in augmented-reality system 700 and/or virtual-reality system 800 may include one or more liquid crystal displays (LCDs), light emitting diode (LED) displays, organic LED (OLED) displays, digital light project (DLP) micro-displays, liquid crystal on silicon (LCoS) micro-displays, and/or any other suitable type of display screen. Artificial-reality systems may include a single display screen for both eyes or may provide a display screen for each eye, which may allow for additional flexibility for varifocal adjustments or for correcting a user's refractive error. Some artificial-reality systems may also include optical subsystems having one or more lenses (e.g., conventional concave or convex lenses, Fresnel lenses, adjustable liquid lenses, etc.) through which a user may view a display screen. These optical subsystems may serve a variety of purposes, including to collimate (e.g., make an object appear at a greater distance than its physical distance), to magnify (e.g., make an object appear larger than its actual size), and/or to relay (to, e.g., the viewer's eyes) light. These optical subsystems may be used in a non-pupil-forming architecture (such as a single lens configuration that directly collimates light but results in so-called pincushion distortion) and/or a pupil-forming architecture (such as a multi-lens configuration that produces so-called barrel distortion to nullify pincushion distortion).

[0087] In addition to or instead of using display screens, some artificial-reality systems may include one or more projection systems. For example, display devices in augmented-reality system 700 and/or virtual-reality system 800 may include micro-LED projectors that project light (using, e.g., a waveguide) into display devices, such as clear combiner lenses that allow ambient light to pass through. The display devices may refract the projected light toward a user's pupil and may enable a user to simultaneously view both artificial-reality content and the real world. The display devices may accomplish this using any of a variety of different optical components, including waveguide components (e.g., holographic, planar, diffractive, polarized, and/or reflective waveguide elements), light-manipulation surfaces and elements (such as diffractive, reflective, and refractive elements and gratings), coupling elements, etc. Artificial-reality systems may also be configured with any other suitable type or form of image projection system, such as retinal projectors used in virtual retina displays.

[0088] Artificial-reality systems may also include various types of computer vision components and subsystems. For example, augmented-reality system 700 and/or virtual-reality system 800 may include one or more optical sensors, such as two-dimensional (2D) or 3D cameras, structured light transmitters and detectors, time-of-flight depth sensors, single-beam or sweeping laser rangefinders, 3D LiDAR sensors, and/or any other suitable type or form of optical sensor. An artificial-reality system may process data from one or more of these sensors to identify a location of a user, to map the real world, to provide a user with context about real-world surroundings, and/or to perform a variety of other functions.

[0089] Artificial-reality systems may also include one or more input and/or output audio transducers. In the examples shown in FIG. 8, output audio transducers 806(A) and 806(B) may include voice coil speakers, ribbon speakers, electrostatic speakers, piezoelectric speakers, bone conduction transducers, cartilage conduction transducers, tragus-vibration transducers, and/or any other suitable type or form of audio transducer. Similarly, input audio transducers may include condenser microphones, dynamic microphones, ribbon microphones, and/or any other type or form of input transducer. In some examples, a single transducer may be used for both audio input and audio output.

[0090] While not shown in FIG. 7, artificial-reality systems may include tactile (i.e., haptic) feedback systems, which may be incorporated into headwear, gloves, body suits, handheld controllers, environmental devices (e.g., chairs, floormats, etc.), and/or any other type of device or system. Haptic feedback systems may provide various types of cutaneous feedback, including vibration, force, traction, texture, and/or temperature. Haptic feedback systems may also provide various types of kinesthetic feedback, such as motion and compliance. Haptic feedback may be implemented using motors, piezoelectric actuators, fluidic systems, and/or a variety of other types of feedback mechanisms. Haptic feedback systems may be implemented independent of other artificial-reality devices, within other artificial-reality devices, and/or in conjunction with other artificial-reality devices.

[0091] By providing haptic sensations, audible content, and/or visual content, artificial-reality systems may create an entire virtual experience or enhance a user's real-world experience in a variety of contexts and environments. For instance, artificial-reality systems may assist or extend a user's perception, memory, or cognition within a particular environment. Some systems may enhance a user's interactions with other people in the real world or may enable more immersive interactions with other people in a virtual world. Artificial-reality systems may also be used for educational purposes (e.g., for teaching or training in schools, hospitals, government organizations, military organizations, business enterprises, etc.), entertainment purposes (e.g., for playing video games, listening to music, watching video content, etc.), and/or for accessibility purposes (e.g., as hearing aids, visual aids, etc.). The embodiments disclosed herein may enable or enhance a user's artificial-reality experience in one or more of these contexts and environments and/or in other contexts and environments.

[0092] The process parameters and sequence of the steps described and/or illustrated herein are given by way of example only and can be varied as desired. For example, while the steps illustrated and/or described herein may be shown or discussed in a particular order, these steps do not necessarily need to be performed in the order illustrated or discussed. The various exemplary methods described and/or illustrated herein may also omit one or more of the steps described or illustrated herein or include additional steps in addition to those disclosed.

[0093] The preceding description has been provided to enable others skilled in the art to best utilize various aspects of the examples disclosed herein. This exemplary description is not intended to be exhaustive or to be limited to any precise form disclosed. Many modifications and variations are possible without departing from the scope of the present disclosure. The examples disclosed herein should be considered in all respects illustrative and not restrictive. Reference should be made to the appended claims and their equivalents in determining the scope of the present disclosure.

[0094] Unless otherwise noted, the terms "connected to" and "coupled to" (and their derivatives), as used in the specification and claims, are to be construed as permitting both direct and indirect (i.e., via other elements or components) connection. In addition, the terms "a" or "an," as used in the specification and claims, are to be construed as meaning "at least one of." Finally, for ease of use, the terms "including" and "having" (and their derivatives), as used in the specification and claims, are interchangeable with and have the same meaning as the word "comprising."

[0095] It will be understood that when an element such as a layer or a region is referred to as being formed on, deposited on, or disposed "on" or "over" another element, it may be located directly on at least a portion of the other element, or one or more intervening elements may also be present. In contrast, when an element is referred to as being "directly on" or "directly over" another element, it may be located on at least a portion of the other element, with no intervening elements present.

[0096] As used herein, the term "approximately" in reference to a particular numeric value or range of values may, in certain embodiments, mean and include the stated value as well as all values within 10% of the stated value. Thus, by way of example, reference to the numeric value "50" as "approximately 50" may, in certain embodiments, include values equal to 50±5, i.e., values within the range 45 to 55.

[0097] As used herein, the term "substantially" in reference to a given parameter, property, or condition may mean and include to a degree that one of ordinary skill in the art would understand that the given parameter, property, or condition is met with a small degree of variance, such as within acceptable manufacturing tolerances. By way of example, depending on the particular parameter, property, or condition that is substantially met, the parameter, property, or condition may be at least approximately 90% met, at least approximately 95% met, or even at least approximately 99% met.

[0098] While various features, elements or steps of particular embodiments may be disclosed using the transitional phrase “comprising,” it is to be understood that alternative embodiments, including those that may be described using the transitional phrases “consisting” or “consisting essentially of,” are implied. Thus, for example, implied alternative embodiments to a glass substrate that comprises or includes silicon dioxide include embodiments where a glass substrate consists essentially of silicon dioxide and embodiments where a glass substrate consists of silicon dioxide.

CLAIMS

1. A method comprising:

forming a first optical layer assembly over a first surface of a planar glass substrate;

forming a second optical layer assembly over a second surface of the planar glass substrate;

laser cutting entirely through the first optical layer assembly from a first side of the planar glass substrate to form an optical element pattern in the first optical layer assembly;

laser cutting entirely through the planar glass substrate from the first side of the planar glass substrate to form the optical element pattern in the planar glass substrate; and

laser cutting entirely through the second optical layer assembly from a second side of the planar glass substrate to form an optical element having the optical element pattern.

2. The method of claim 1, wherein the planar glass substrate is optically transparent.

3. The method of claim 1 or 2, wherein the first optical layer assembly comprises one or more optical layers selected from the group consisting of a linear polarizer, a circular polarizer, a reflective polarizer, a transmissive polarizer, a quarter waveplate, and a half waveplate;

preferably wherein the second optical layer assembly comprises one or more optical layers selected from the group consisting of a linear polarizer, a circular polarizer, a reflective polarizer, a transmissive polarizer, a quarter waveplate, and a half waveplate.

4. The method of claim 3, wherein the first optical layer assembly comprises a linear polarizer and a quarter waveplate, and the second optical layer assembly comprises a reflective polarizer.

5. The method of any preceding claim, wherein forming the first optical layer assembly comprises laminating one or more first optical layers over the first surface of the planar glass substrate, and forming the second optical layer assembly comprises laminating one or more second optical layers over the second surface of the planar glass substrate.

6. The method of any preceding claim, further comprising forming a first protective thin film over the first optical layer assembly prior to laser cutting the first optical layer assembly, and forming a second protective thin film over the second optical layer assembly prior to laser cutting the second optical layer assembly.

7. The method of any preceding claim, wherein laser cutting the first optical layer assembly comprises first laser parameters, laser cutting the second optical layer assembly

comprises second laser parameters, and laser cutting the planar glass substrate comprises laser parameters different than the first and second laser parameters;
preferably wherein a laser power for laser cutting the planar glass substrate is greater than a laser power for laser cutting either the first optical layer assembly or the second optical layer assembly.

8. The method of any preceding claim, wherein:

forming the first optical layer assembly over the first surface of the planar glass substrate and forming the second optical layer assembly over the second surface of the planar glass substrate create a laminate sheet; and

a plurality of optical elements having the optical element pattern are cut from the laminate sheet.

9. The method of any of any preceding claim, further comprising forming the optical element over a planar surface of a lens, the optical element comprising, from top to bottom, a reflective polarizer, the planar glass substrate, a linear polarizer, and a quarter waveplate, wherein the quarter waveplate is located adjacent to the planar surface of the lens;
preferably wherein the lens has the optical element pattern.

10. A method comprising:

forming an optical element pattern in a first optical layer assembly disposed over a first surface of a planar glass substrate by laser cutting entirely through the first optical layer assembly from a first side of the planar glass substrate;

forming the optical element pattern in the planar glass substrate by laser cutting entirely through the planar glass substrate from the first side of the planar glass substrate; and

forming an optical element having the optical element pattern by laser cutting entirely through a second optical layer assembly from a second side of the planar glass substrate, the second optical layer assembly disposed over a second surface of the planar glass substrate.

11. The method of claim 10, wherein the planar glass substrate is optically transparent;
preferably wherein a laser power for laser cutting the planar glass substrate is different than a laser power for laser cutting either the first optical layer assembly or the second optical layer assembly

12. The method of claim 10 or 11, wherein the first optical layer assembly comprises

one or more optical layers selected from the group consisting of a linear polarizer, a circular polarizer, a reflective polarizer, a transmissive polarizer, a quarter waveplate, and a half waveplate;

preferably wherein the second optical layer assembly comprises one or more optical layers selected from the group consisting of a linear polarizer, a circular polarizer, a reflective polarizer, a transmissive polarizer, a quarter waveplate, and a half waveplate.

13. The method of claim 12, wherein the first optical layer assembly comprises a linear polarizer and a quarter waveplate, and the second optical layer assembly comprises a reflective polarizer.

14. A method comprising:

laminating a first optical layer assembly over a first surface of a transparent planar glass substrate;

laminating a second optical layer assembly over a second surface of the transparent planar glass substrate;

laser cutting through the first optical layer assembly from a first side of the transparent planar glass substrate to form an optical element pattern in the first optical layer assembly;

laser cutting through the transparent planar glass substrate from the first side of the transparent planar glass substrate to form the optical element pattern in the transparent planar glass substrate; and

laser cutting through the second optical layer assembly from a second side of the transparent planar glass substrate to form an optical element having the optical element pattern.

15. The method of claim 14, further comprising forming a first protective thin film over the first optical layer assembly prior to laser cutting the first optical layer assembly, and forming a second protective thin film over the second optical layer assembly prior to laser cutting the second optical layer assembly.

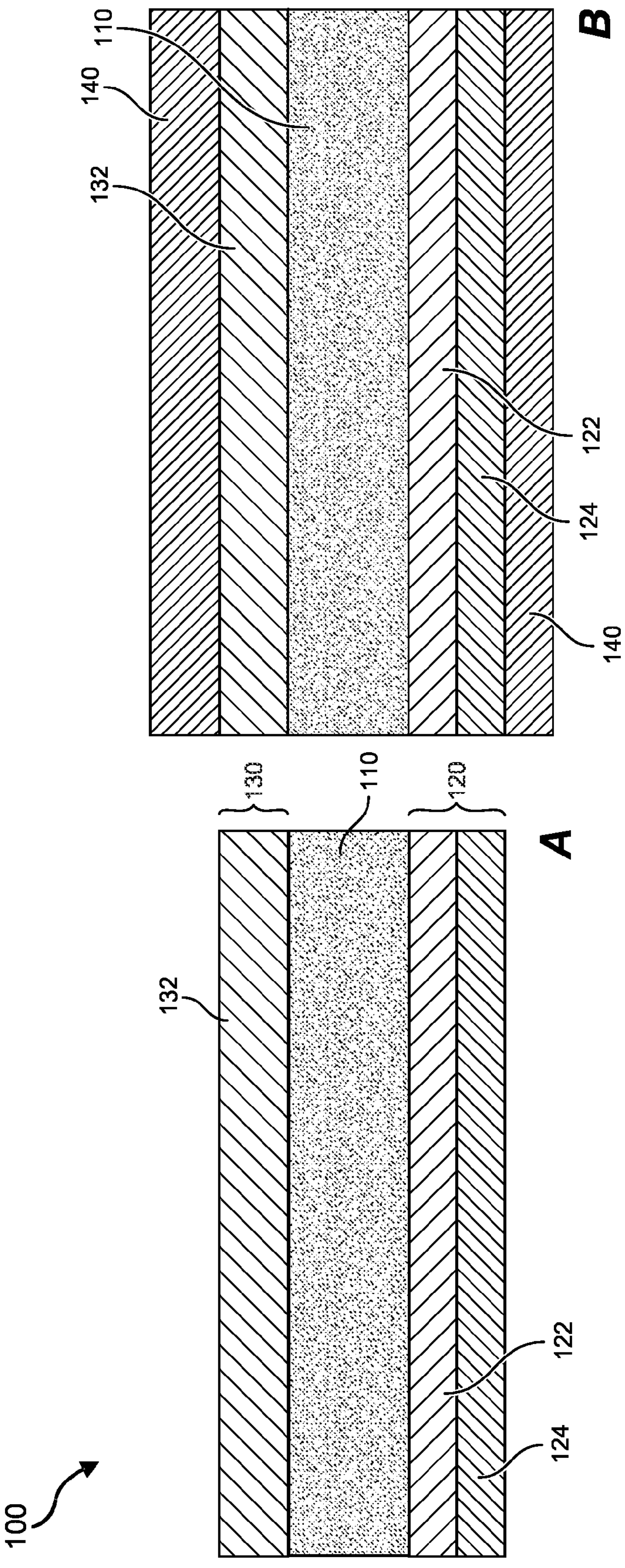

FIG. 1

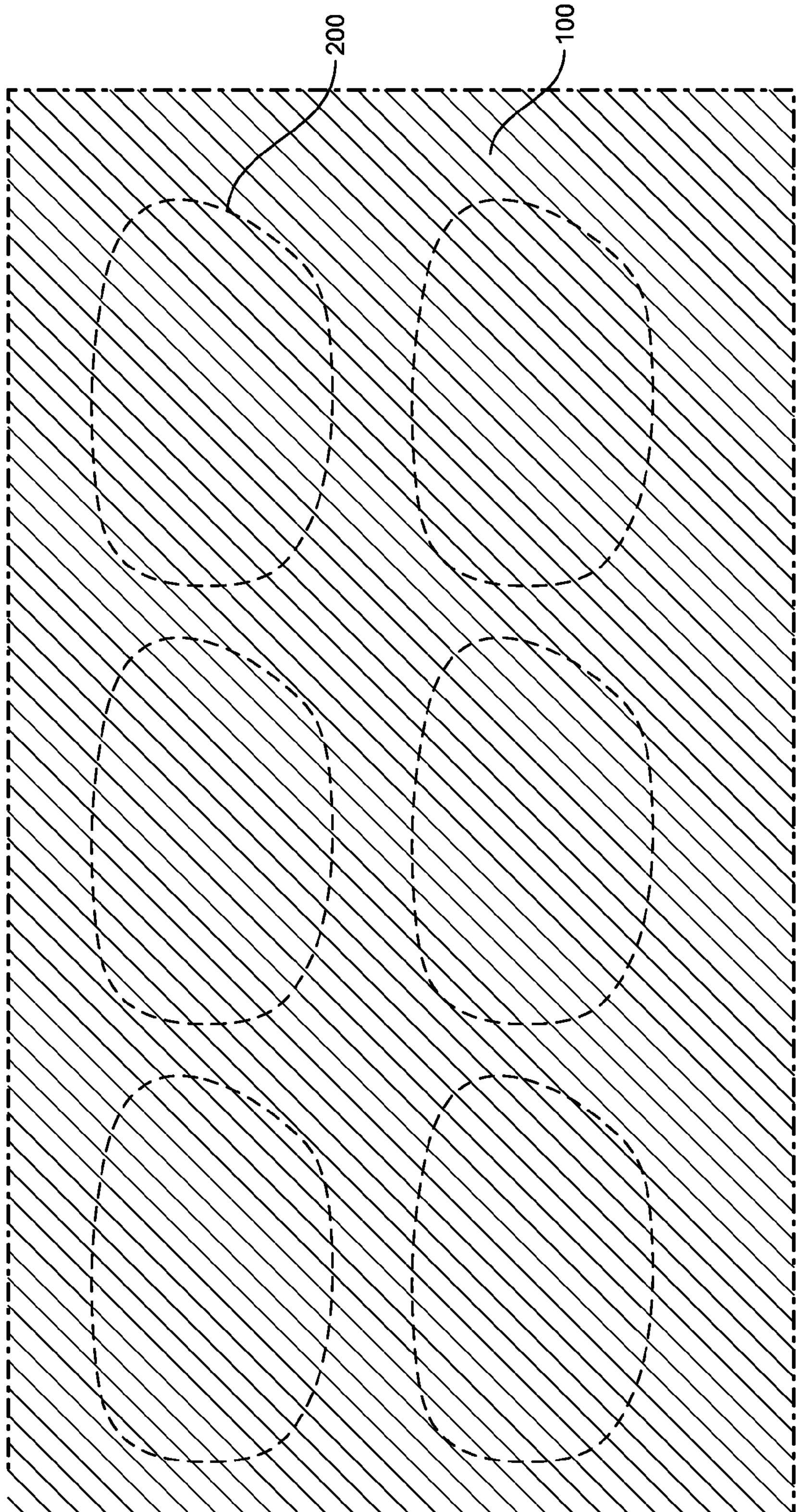

FIG. 2

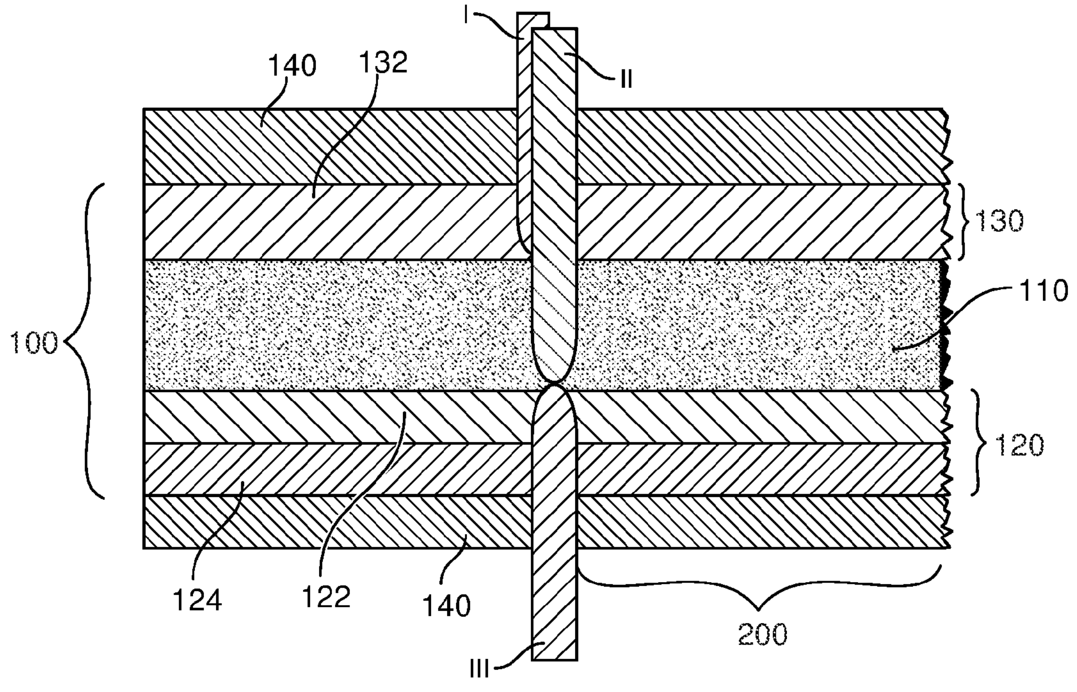

FIG. 3

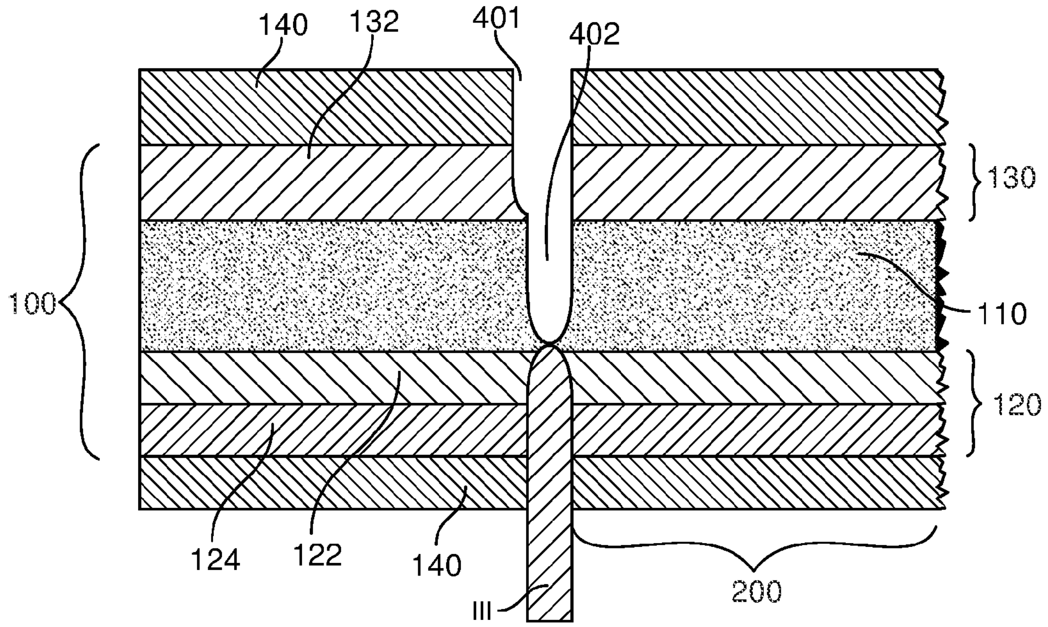

FIG. 4

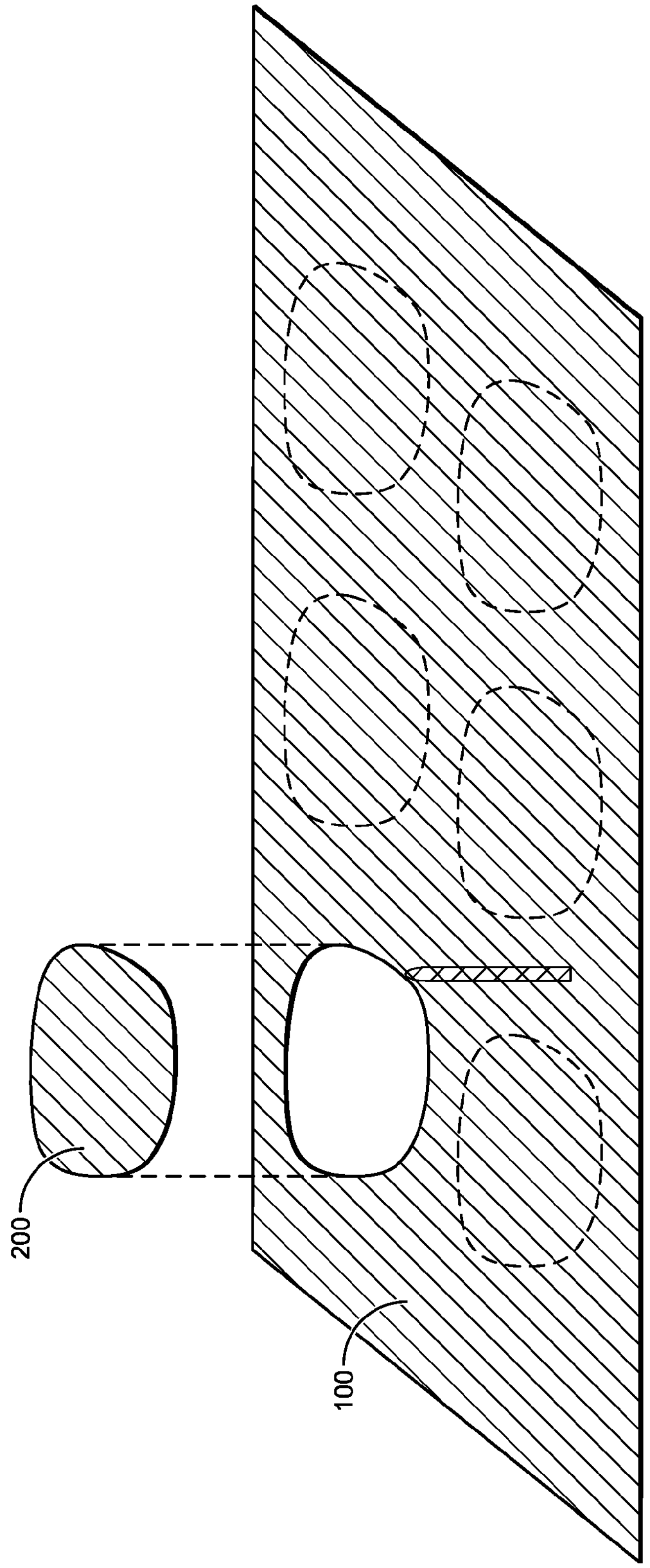

FIG. 5

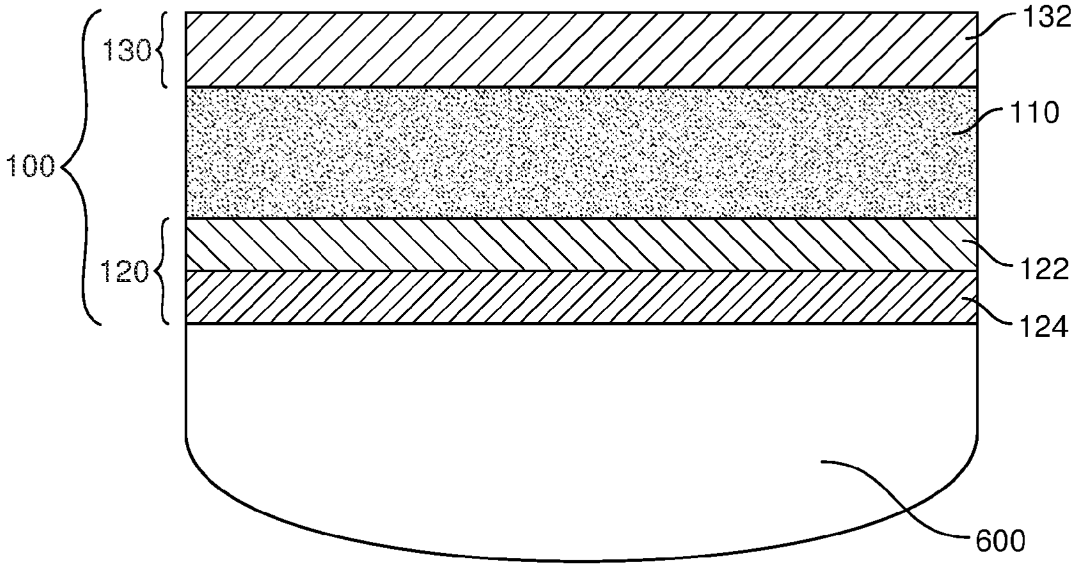

FIG. 6

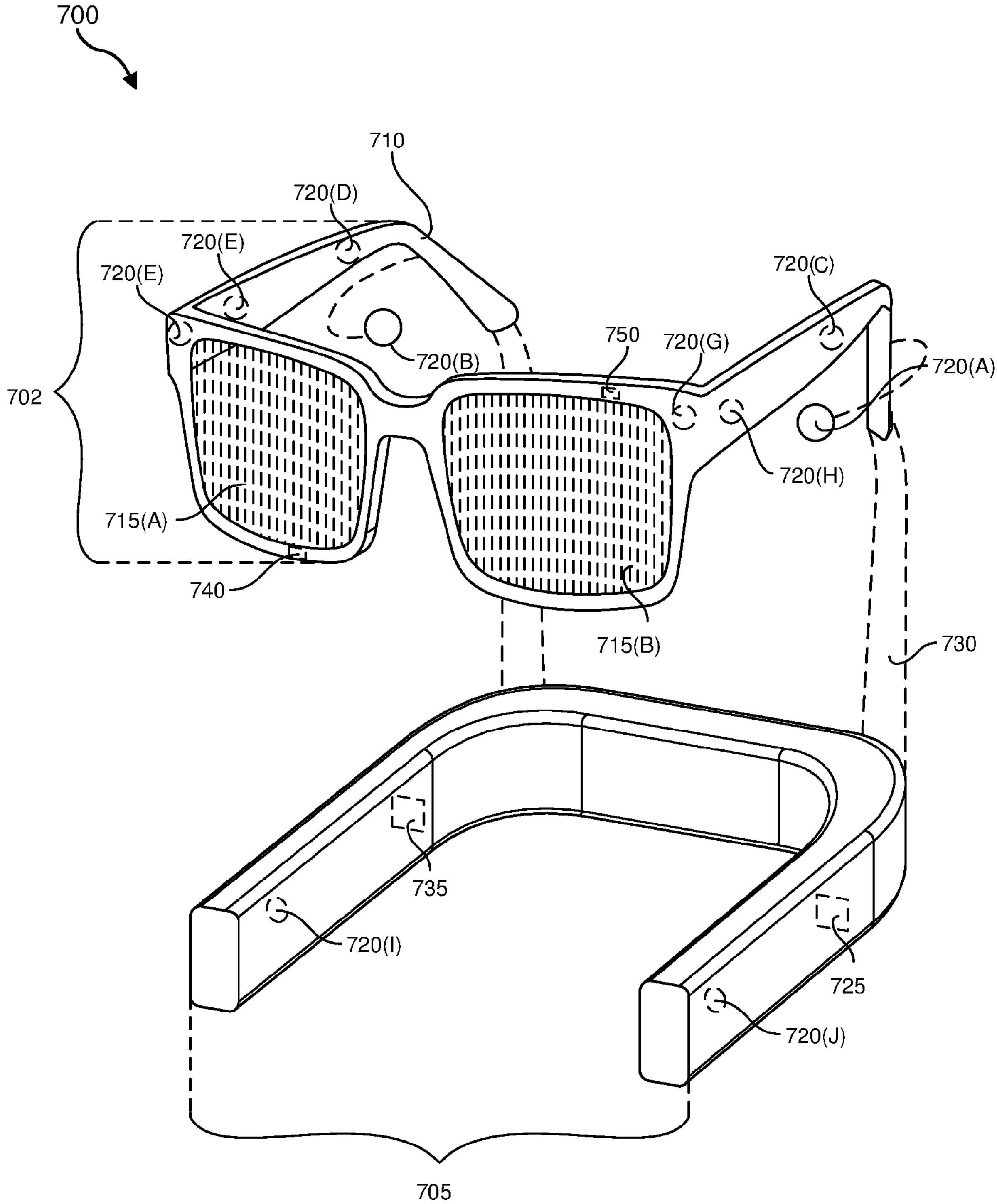
700
710
720(D)
720(E)
720(E)
720(C)
750
720(G)
720(A)
720(B)
702
720(H)
715(A)
740
715(B)
730
735
720(I)
725
720(J)
705

FIG. 7

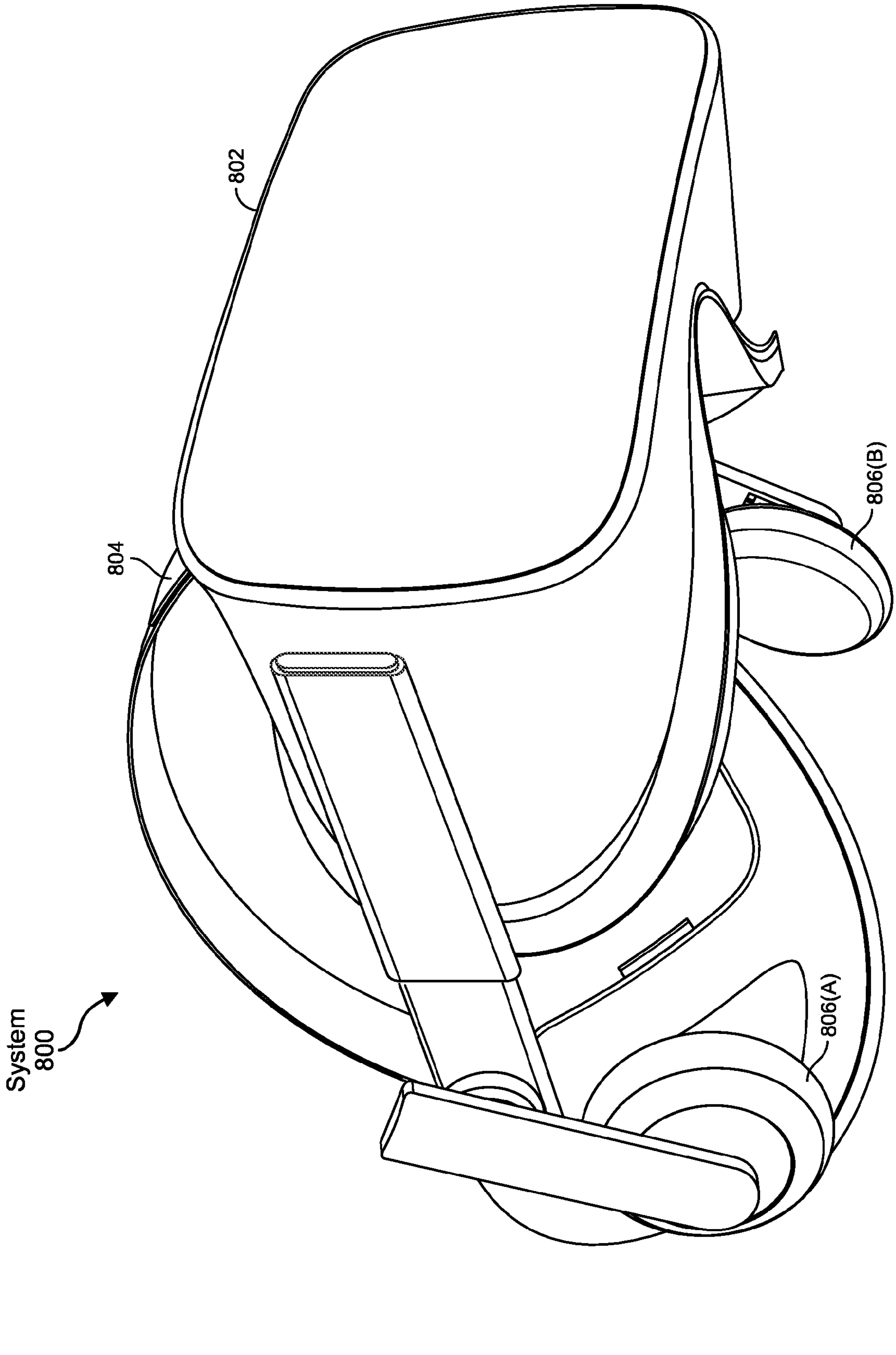

FIG. 8

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2023/019518

A. CLASSIFICATION OF SUBJECT MATTER

INV. B23K26/00 B23K26/06 B23K26/364 B23K26/38 B23K26/402
C03B33/02 C03B33/07 B32B17/06
ADD. G02B5/30 G02B27/01

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)

B23K C03B G02B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2021/181766 A1 (NITTO DENKO CORP [JP]) 16 September 2021 (2021-09-16) paragraphs [0035], [0042], [0047], [0048], [0055], [0061], [0084], [0085] figures 2a-2d, 4 -----	1-15
X	JP 2014 043363 A (HAMAMATSU PHOTONICS KK) 13 March 2014 (2014-03-13) paragraphs [0008], [0024], [0025] figures 4, 5 -----	1,10,14
A	US 2022/080529 A1 (SNAP INC [US]) 17 March 2022 (2022-03-17) paragraphs [0011], [0019] figures 1-5 -----	1,10,14
	-/--	

[X] Further documents are listed in the continuation of Box C.

[X] 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

"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	Date of mailing of the international search report
2 August 2023	14/08/2023

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Hillmayr, Heinrich

1

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2021/100201 A1 (MITSUBISHI HEAVY IND LTD [JP]) 27 May 2021 (2021-05-27) paragraphs [0069] - [0071] figure 12 -----	1,10,14

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2023/019518

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2021181766 A1	16-09-2021	CN 115485097 A	16-12-2022
		JP WO2021181766 A1	16-09-2021
		KR 20220148197 A	04-11-2022
		TW 202134702 A	16-09-2021
		WO 2021181766 A1	16-09-2021
JP 2014043363 A	13-03-2014	NONE	
US 2022080529 A1	17-03-2022	CN 116096681 A	09-05-2023
		EP 4211085 A1	19-07-2023
		KR 20230068419 A	17-05-2023
		US 2022080529 A1	17-03-2022
		WO 2022055724 A1	17-03-2022
WO 2021100201 A1	27-05-2021	EP 4046742 A1	24-08-2022
		US 2022410319 A1	29-12-2022
		WO 2021100201 A1	27-05-2021