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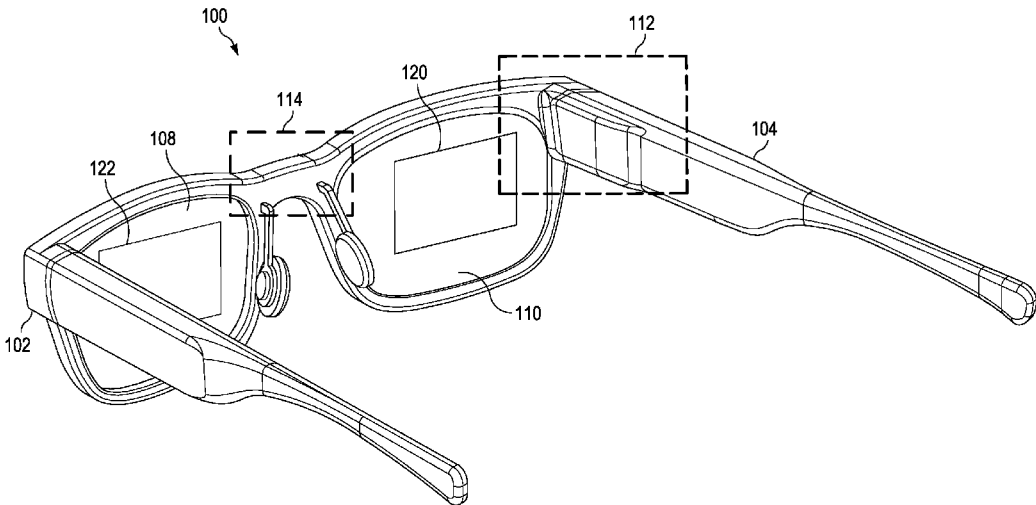


FIG. 1

(57) **Abstract:** A bi-ocular eyewear display includes a dual waveguide configuration. The dual waveguide configuration includes a first waveguide integrated into one lens of the eyewear display and a second waveguide integrated into the other lens of the eyewear display. The incoupler of the first waveguide and the incoupler of the second waveguide are serially arranged in the nose bridge region of the eyewear display in line with an image source such that the incoupler of the first waveguide incouples a first portion of the display light into the first waveguide while allowing a second portion of the display light to pass through. The second incoupler receives the second portion of the display light and incouples at least a portion of it into the second waveguide. The first waveguide and the second waveguide also include respective outcouplers to outcouple the light to each eye of the user of the eyewear display.

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WAVEGUIDE CONFIGURATIONS IN A BI-OCULAR EYEWEAR DISPLAY

BACKGROUND

[0001] In an augment reality (AR) or mixed reality (MR) eyewear display, display light from an image source is coupled into a light guide substrate, generally referred to as a waveguide, by an input optical coupling (referred to as an “incoupler”) which can be formed on a surface of the waveguide or disposed within the waveguide. Once the display light beams have been coupled into the waveguide, the display light beams are “guided” through the waveguide, typically by multiple instances of total internal reflection (TIR), to then be directed out of the waveguide by an output optical coupling (referred to as an “outcoupler”). The display light beams projected from the waveguide by the outcoupler overlap at an eye relief distance from the waveguide forming an exit pupil within which a virtual image generated by the image source can be viewed by the user of the eyewear display. In AR/MR configurations, the eyewear display also allows the user to observe their surrounding environment. In this manner, the eyewear display provides a visual experience that enhances the real world with generated virtual images.

[0002] Some eyewear displays are implemented as bi-ocular eyewear displays where display light from a common image source is routed to each lens, and thus to each eye of the user, of the eyewear display. While providing the added benefit of allowing the user to view the same virtual image at each lens of the eyewear display, bi-ocular display systems experience additional challenges including achieving uniformity in the display light output to each eye and designing the waveguide so that it conforms to the shape of the eyewear display which typically, at least to some degree, wraps around the user’s face.

SUMMARY

[0003] Various embodiments are directed to techniques for increasing the uniformity in the display light output to each eye of a user of a bi-ocular eyewear display.

[0004] A first embodiment includes a device including a first waveguide and a second waveguide. The first waveguide includes a first incoupler to incouple a first portion of display light into the first waveguide toward a first direction, and a second portion of the display light passes through the first incoupler and the first waveguide. The first waveguide also includes a first outcoupler to outcouple the first portion of display light from the first waveguide. The second waveguide includes a second incoupler to incouple a fraction of the second portion of display light into the second waveguide toward a second direction different from the first direction. The second waveguide also includes a second outcoupler to outcouple the fraction of the second portion of display light from the second waveguide.

[0005] In some aspects of the first embodiment, the first incoupler includes a first diffractive grating and the second incoupler includes a second diffractive grating. In some cases, the first diffractive grating and the second diffractive grating are different diffractive grating types. For example, in some embodiments, the first diffractive grating is a reflective grating, and the second diffractive grating is a transmissive grating. In other embodiments, the first diffractive grating is a transmissive grating, and the second diffractive grating is a reflective grating. In some aspects of the first embodiment, the first diffractive grating has a first diffraction efficiency, and the second diffractive grating has a second diffraction efficiency different from the first diffraction efficiency. In some aspects of the first embodiment, the first outcoupler includes a third diffractive grating and the second outcoupler includes a fourth diffractive grating. In some embodiments, the third diffractive grating has a third diffraction efficiency, and the fourth diffractive grating has a fourth diffraction efficiency different from the third diffraction efficiency.

[0006] In some aspects of the first embodiment, at least one of the first or second incouplers or the first or second outcouplers includes one or more reflective mirror facets.

[0007] In some aspects of the first embodiment, the first waveguide and the second waveguide overlap at sections including the first incoupler and the second incoupler, and the first waveguide and the second waveguide do not overlap at sections including the first outcoupler and the second outcoupler.

[0008] In some aspects of the first embodiment, the device includes a partial mirror between the first waveguide and the second waveguide. In some aspects, the device also includes a mirror adjacent to the second waveguide on an opposite side of the second waveguide from the partial mirror.

[0009] In some aspects of the first embodiment, the device includes a waveplate between the first waveguide and the second waveguide. The waveplate converts light from a second polarization state to a first polarization state. In some aspects, the display light includes light with the first polarization state and light with the second polarization state, where the first portion of light incoupled by the first incoupler corresponds to light having the first polarization state, and where the second portion of light that passes through the first incoupler and the first waveguide has the second polarization state. In some aspects, the fraction of the second portion of display light incoupled into the second waveguide has the first polarization state.

[0010] In some aspects of the first embodiment, the display light is received from a single optical engine.

[0011] In some aspects of the first embodiment, the first direction corresponds to a first field of view (FOV) area, and the second direction corresponds to a second FOV area different from the first FOV area. For example, the first FOV area is associated with a first optical combiner in a first lens element in an eyewear display and the second FOV area is associated with a second optical combiner in a second lens element in the eyewear display.

[0012] A second embodiment includes an eyewear display including an optical engine, a first lens, and a second lens. The optical engine is configured to emit display light. The first lens includes a first waveguide. The first waveguide includes a first incoupler to incouple a first portion of the display light into the first waveguide toward a first direction, where a second portion of the display light passes through the first incoupler and the first waveguide. The first waveguide also includes a first outcoupler to outcouple the first portion of display light from the first waveguide. The second lens includes a second waveguide. The second waveguide includes a second incoupler to incouple a fraction of the second portion of display light into the second

waveguide toward a second direction different from the first direction. The second waveguide also includes a second outcoupler to outcouple the fraction of the second portion of display light from the second waveguide.

[0013] In some aspects of the second embodiment, the optical engine, the first incoupler, and the second incoupler are positioned in a nose bridge region of the eyewear display, and the first waveguide extends from the nose bridge region into the first lens, and the second waveguide extends from the nose bridge region into the second lens.

[0014] In some aspects of the second embodiment, the eyewear display includes a partial beamsplitter between the first waveguide and the second waveguide, and the eyewear display also includes a mirror adjacent to the second waveguide on an opposite side of the second waveguide from the partial beamsplitter.

[0015] In some aspects of the second embodiment, the eyewear display includes a waveplate between the first waveguide and the second waveguide. The waveplate converts light from a second polarization state to a first polarization state.

[0016] In a third embodiment, a method includes incoupling a first portion of display light into a first waveguide, the first waveguide incorporated into a first lens of an eyewear display, wherein a second portion of the display light passes through the first waveguide, and incoupling a fraction of the second portion of the display light into a second waveguide, the second waveguide incorporated into a second lens of the eyewear display.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] The present disclosure may be better understood, and its numerous features and advantages made apparent to those skilled in the art by referencing the accompanying drawings. The use of the same reference symbols in different drawings indicates similar or identical items.

[0018] FIG. 1 is an example of a bi-ocular eyewear display, in accordance with some embodiments.

[0019] FIG. 2 is an example of one portion (i.e., corresponding to one eye) of a projection system of a bi-ocular eyewear display, such as the bi-ocular eyewear display of FIG. 1, in accordance with some embodiments.

[0020] FIG. 3 is an example of one portion (i.e., corresponding to one eye) of a bi-ocular eyewear display, such as the bi-ocular eyewear display of FIG. 1, in accordance with some embodiments.

[0021] FIG. 4 is an example of the propagation of light within a waveguide, such as the waveguide of FIGs. 2 and 3, along with an example of grating features of a diffractive grating, in accordance with some embodiments.

[0022] FIGs. 5-7 show examples of dual waveguide configurations in a bi-ocular eyewear display, such as the bi-ocular eyewear display of FIG. 1, in accordance with some embodiments.

[0023] FIG. 8 shows a dual waveguide configuration with a partial transmitter and a mirror in a bi-ocular eyewear display, such as the bi-ocular eyewear display of FIG. 1, in accordance with some embodiments.

[0024] FIG. 9 shows a dual waveguide configuration with a waveplate in a bi-ocular eyewear display, such as the bi-ocular eyewear display of FIG. 1, in accordance with some embodiments.

DETAILED DESCRIPTION

[0025] A bi-ocular eyewear display allows a user to observe virtual images at each one of its lenses from a common image source. A challenge with conventional bi-ocular eyewear displays is to provide balanced display light at both eyes. Furthermore, in some cases, conventional bi-ocular display systems utilize a single waveguide that routes the display light to both eyes. Due to the shape of eyewear displays (which typically wrap around the face of the user to some degree) and/or the flexibility of the frame of the eyewear display, having a single waveguide that routes light to both eyes can present design challenges and durability concerns as the waveguide may be prone to fractures or other defects that reduce its optical performance, thus diminishing the user experience. FIGs. 1-9 present a bi-ocular

eyewear display with a dual-waveguide configuration that provides a relatively uniform display light output via each of the lenses of the eyewear display while allowing the waveguides to be better fitted to the eyewear display's form factor.

[0026] To illustrate, an eyewear display includes an image source (also referred to as an optical engine) such as a micro light-emitting diode (micro-LED) in a nose bridge region between two lenses of the eyewear display. The optical engine emits display light to generate the virtual images of the eyewear display. The eyewear display also includes two waveguides. The first one of the two waveguides is incorporated into one of the two lenses of the eyewear display, and the second one of the two waveguides is incorporated into the other one of the two lenses. The first waveguide includes a first incoupler and a first outcoupler, and the second waveguide includes a second incoupler and a second outcoupler. The first incoupler and the second incoupler are arranged in series in the nose bridge region to receive light from the image source. That is, the first incoupler receives the display light from the image source and incouples a first portion of the display light into the first waveguide in the first lens of the eyewear display, and a second portion of the display light passes through the first incoupler and first waveguide. The second incoupler then incouples a fraction of the second portion of the display light into the second waveguide in the second lens of the eyewear display. The first waveguide, including the first incoupler and the first outcoupler, and the second waveguide, including the second incoupler and the second outcoupler, are designed such that the amount of light output by the first and second waveguides is substantially the same. For example, the first incoupler includes a diffractive grating with a first diffraction efficiency and the second incoupler includes a diffractive grating with a second diffraction efficiency that is higher than the first diffraction efficiency so that the amount of light incoupled into the second waveguide is similar to or the same as the amount of light incoupled into the first waveguide even though a lower portion of the display light emitted from the image source reaches the second waveguide. Thus, the user perceives an equal light intensity in the virtual image at each eye, which improves the user experience.

[0027] FIGs. 1-9 illustrate techniques to balance the light output at each lens of a bi-ocular eyewear display such that the user observes an equal light intensity at each eye. Moreover, the techniques described herein facilitate the implementation of a bi-ocular configuration in an eyewear display form factor. However, it will be appreciated that the apparatuses and techniques of the present disclosure are not limited to implementation in this particular display system or method, but instead may be implemented in any of a variety of display systems using the guidelines provided herein.

[0028] FIG. 1 illustrates an example eyewear display 100 in accordance with various embodiments. The eyewear display 100 (also referred to as a wearable heads up display (WHUD), head-mounted display (HMD), near-eye display, or the like) has a support structure 102 that includes an arm 104 including a temple region 112 at an interface with a lens rim of the eyewear display 100 and a nose bridge region 114 joining the two lens rims of the eyewear display 102. In some embodiments, the nose bridge region 114 houses a micro-display projection system configured to project images toward the eye of a user, such that the user perceives the projected images as being displayed in a field of view (FOV) area 120, 122 of a display at one or both of lens elements 108, 110. In the depicted embodiment, the support structure 102 of the eyewear display 100 is configured to be worn on the head of a user and has a general shape and appearance (i.e., "form factor") of an eyeglasses frame. The support structure 102 contains or otherwise includes various components to facilitate the projection of such images toward the eye of the user, such as an image source and a waveguide (shown in FIG. 2, for example). In some embodiments, the support structure 102 further includes various sensors, such as one or more front-facing cameras, rear-facing cameras, other light sensors, motion sensors, accelerometers, and the like. The support structure 102 further can include one or more radio frequency (RF) interfaces or other wireless interfaces, such as a Bluetooth™ interface, a WiFi interface, and the like. Further, in some embodiments, the support structure 102 includes one or more batteries or other portable power sources for supplying power to the electrical components of the eyewear display 100. In some embodiments, some or all of these components of the eyewear display 100 are fully or partially contained within an inner volume of support structure 102, such

as within the arm 104 in region 112 of the support structure 102. It should be noted that while an example form factor is depicted, it will be appreciated that in other embodiments the eyewear display 100 may have a different shape and appearance from the eyeglasses frame depicted in FIG. 1.

[0029] One or both of the lens elements 108, 110 (also referred to as lenses, for short) are used by the eyewear display 100 to provide an augmented reality (AR) or mixed reality (MR) display in which rendered graphical content can be superimposed over or otherwise provided in conjunction with a real-world view as perceived by the user through the lens elements 108, 110. In some embodiments, one or both of lens elements 108, 110 serve as optical combiners that combine environmental light (also referred to as ambient light) from outside of the eyewear display 100 and light emitted from the image source in the eyewear display 100. For example, light used to form a perceptible image or series of images may be projected by the image source of the eyewear display 100 onto the eye of the user via a series of optical elements, such as a waveguide formed at least partially in the corresponding lens element, one or more scan mirrors, one or more optical relays (also referred to as projection optics), and/or one or more prisms. In some embodiments, the image source is configured to emit light having different wavelength ranges (e.g., different colors) and/or different polarization states (e.g., s-polarized light, p-polarized light, or a combination thereof). One or both of the lens elements 108, 110 thus includes at least a portion of a waveguide that routes display light received by the incoupler of the waveguide to an outcoupler of the waveguide, which outputs the display light toward an eye of a user of the eyewear display 100. The display light is modulated and projected onto the eye of the user such that the user perceives the display light as an image in FOV area 120, 122. In addition, each of the lens elements 108, 110 is sufficiently transparent to allow a user to see through the lens elements to provide a field of view of the user's real-world environment such that the image appears superimposed over at least a portion of the real-world environment.

[0030] In some embodiments, the image source is a digital light processing-based projector, a scanning laser projector, a liquid crystal on silicon (LCoS) light engine, or any combination of a modulative light source such as a laser or one or more light-

emitting diodes (LEDs), such as a micro-LED, or organic light-emitting diodes (OLEDs) located in nose bridge region 114. In some embodiments, the image source is configured to emit light of a first polarization state (e.g., s-polarized or p-polarized light). In some embodiments, the image source includes multiple laser diodes (e.g., a red laser diode, a green laser diode, and/or a blue laser diode) and at least one scan mirror (e.g., two one-dimensional scan mirrors, which may be micro-electromechanical system (MEMS)-based or piezo-based). The image source is communicatively coupled to the controller (not shown) and a non-transitory processor-readable storage medium or memory storing processor-executable instructions and other data that, when executed by the controller, cause the controller to control the operation of the light engine. In some embodiments, the controller controls a scan area size and scan area location for the light engine and is communicatively coupled to a light engine (not shown) that generates content to be displayed at the eyewear display 100. The light engine scans light over a variable area, designated the FOV area 120, 122 of the eyewear display 100. The scan area size corresponds to the size of the FOV area 120, 122, and the scan area location corresponds to a region of one of the lens elements 108, 110 at which the FOV area 120, 122 is visible to the user. Generally, it is desirable for a display to have a wide FOV area 120, 122 to accommodate the outcoupling of light across a wide range of angles.

[0031] As previously mentioned, in the case of bi-ocular displays, a waveguide is integrated into both lens elements 108, 110. In some embodiments, each waveguide includes a single waveguide substrate and in other embodiments, each waveguide includes multiple waveguide substrates stacked on top of one another (referred to as a waveguide stack). Each of the waveguides integrated into lens elements 108, 110 includes an incoupler in the nose bridge region 114. The incouplers are positioned in series in the nose bridge region 114 such that an incoupler of the first waveguide integrated into one of lens element 108, 110 receives light from the image source before the incoupler of the second waveguide integrated into the other one of the lens elements 108, 110. In some embodiments, each of the waveguides integrated into lens elements 108, 110 are tuned such that the output of light at each FOV area 120, 122 is the same. That is, although a lower portion of the display light emitted

from the image source is incident on one of the waveguides integrated into one of the lens elements 108, 110, the waveguides are designed (e.g., by varying the diffractive grating parameters of the respective incouplers and/or outcouplers) such that each of the lens elements 108, 110 displays a virtual image with a similar light intensity to the user.

[0032] FIG. 2 illustrates an example of a projection system 200 that projects images onto an eye 216 of a user in accordance with various embodiments. The projection system 200, which may be implemented in the eyewear display 100 in FIG. 1, includes one or more of an image source 202, projection optics 204, and a waveguide 210. In this example, the projection optics 204 includes a first scan mirror 206, a second scan mirror 207, and an optical relay 208. The waveguide 210 includes an incoupler 212 and an outcoupler 214, with the outcoupler 214 being optically aligned with an eye 216 of a user. For example, the outcoupler 214 substantially overlaps or corresponds with one of the FOV areas 120, 122 shown in FIG. 1. For purposes of clarity, FIG. 2 illustrates the projection system 200 with respect to propagating display light from the image source 202 to one eye 216 of the user. In some embodiments, the projection system 200 includes a similar configuration to propagate display light from the same image source 202 to a second eye of the user (not shown in FIG. 2). That is, another waveguide (not shown in FIG. 2) is included to direct light from the image source 202 to the user's second eye.

[0033] In some embodiments, the image source 202 (such as a micro-LED display) includes one or more light sources configured to generate and project display light 218 (e.g., visible light such as red, blue, and green light and, in some embodiments, non-visible light such as infrared light). In some embodiments, the image source 202 is coupled to a driver or other controller (not shown), which controls the timing of emission of display light from the light sources of the image source 202 in accordance with instructions received by the controller or driver from a computer processor coupled thereto to modulate the display light 218 to be perceived as images when output to the retina of an eye 216 of a user. For example, during operation of the projection system 200, one or more beams of display light 218 are output by the light source(s) of the image source 202 and then directed into the

waveguide 210 before being directed to the eye 216 of the user. The image source 202 modulates the respective intensities of the light beams so that the combined light reflects a series of pixels of an image, with the particular intensity of each light beam at any given point in time contributing to the amount of corresponding color content and brightness in the pixel being represented by the combined light at that time.

[0034] In some embodiments, the image source 202 projects the display light 218 to projection optics 204. One or both of the scan mirrors 206 and 207 of the projection optics 204 are MEMS mirrors in some embodiments. For example, the scan mirror 206 and the scan mirror 207 are MEMS mirrors that are driven by respective actuation voltages to oscillate during active operation of the projection system 200, causing the scan mirrors 206 and 207 to scan the display light 218.

[0035] In some embodiments, the optical relay 208 is a line-scan optical relay that receives the light 218 scanned in a first dimension by the first scan mirror 206, routes the light 218 to the second scan mirror 207, and introduces a convergence to the light 218 in the first dimension to an exit pupil beyond the second scan mirror 207. Herein, an “exit pupil” in an optical system refers to the location along the optical path where beams of light intersect. For example, the possible optical paths of the light 218, following reflection by the first scan mirror 206, are initially spread along a first scanning axis, but later these paths intersect at an exit pupil beyond the second scan mirror 207 due to convergence introduced by the optical relay 208. For example, the width (i.e., smallest dimension) of a given exit pupil approximately corresponds to the diameter of the light corresponding to that exit pupil. Accordingly, the exit pupil can be considered a “virtual aperture.” According to various embodiments, the optical relay 208 includes one or more collimation lenses that shape and focus the light 218 on the second scan mirror 207 or includes a molded reflective relay that includes two or more spherical, aspheric, parabolic, and/or freeform lenses that shape and direct the light 218 onto the second scan mirror 207. The second scan mirror 207 receives the display light 218 and scans the display light 218 in a second dimension, the second dimension corresponding to the long dimension of the incoupler 212 of the waveguide 210. In some embodiments, the second scan mirror 207 causes the exit pupil of the display light 218 to be swept along a line along the second dimension.

[0036] In some embodiments, the image source 202 projects the display light 218 directly to the incoupler 212. That is, in some embodiments, the optical scanner 204 is absent from projection system 200. In other embodiments, the optical scanner 204 is included with fewer or more optical components than those depicted in FIG. 2. For example, in some embodiments, the scan mirrors 206, 207 are absent from the projection optics 204. Accordingly, in some embodiments, the image source 202 is positioned such that the optical path of the display light 218 emitted from the image source 202 is in line with the incoupler 212.

[0037] As illustrated in FIG. 2, the waveguide 210 of the projection system 200 includes the incoupler 212 and the outcoupler 214. The term “waveguide,” as used herein, will be understood to mean a combiner using one or more of total internal reflection (TIR), specialized filters, or reflective surfaces, to transfer light from an incoupler (such as incoupler 212) to an outcoupler (such as the outcoupler 214). In some display applications, the light is a collimated image, and the waveguide 210 transfers and replicates the collimated image to the eye. In general, the terms “incoupler” and “outcoupler” will be understood to refer to any type of optical grating structure, including, but not limited to, diffraction gratings, holograms, holographic optical elements (e.g., optical elements using one or more holograms), volume diffraction gratings, volume holograms, surface relief diffraction gratings, and/or surface relief holograms. In some embodiments, a given incoupler or outcoupler is configured as a transmissive grating (e.g., a transmissive diffraction grating or a transmissive holographic grating) that causes the incoupler or outcoupler to transmit light and to apply designed optical function(s) to the light during the transmission. In some embodiments, a given incoupler or outcoupler is a reflective grating (e.g., a reflective diffraction grating or a reflective holographic grating) that causes the incoupler or outcoupler to reflect light and to apply designed optical function(s) to the light during the reflection. In other embodiments, a given incoupler or outcoupler includes one or more reflective mirror facets. For example, the incoupler or the outcoupler includes a set of partially reflective mirror facets with the same or with different reflection to transmission ratios.

[0038] The incoupler 212 is configured to receive the display light 218 and direct the display light 218 into the waveguide 210. In some embodiments, the incoupler 212 is defined by a smaller dimension (i.e., width) and a larger orthogonal dimension (i.e., length) with a first edge that is in the optical path toward the outcoupler 214 and a second edge that is on the opposite side of the optical path toward the outcoupler 214. In some embodiments, the “incoupler region” is defined as the region of the waveguide 210 between the first edge and the second edge. Similarly, the “outcoupler region” is defined as the region of the waveguide occupied by the outcoupler 214. In the present example, the light 218 received at the incoupler 212 is relayed to the outcoupler 214 via the waveguide 210 using TIR. A portion of the light 218 is then output to the eye 216 of a user via the outcoupler 214. Also, in some embodiments, an exit pupil expander (not shown in FIG. 2), such as a fold grating, is arranged in an intermediate stage between incoupler 212 and outcoupler 214 to receive light that is coupled into waveguide 210 by the incoupler 212, expand the light in one dimension, and redirect the light towards the outcoupler 214, where the outcoupler 214 then couples the light out of waveguide 210. In some embodiments, the exit pupil expander and the outcoupler 214 are integrated into a common component. As described above, in some embodiments the waveguide 210 is implemented in an optical combiner as part of a lens, such as one of the lens elements 108, 110 of FIG. 1.

[0039] The waveguide 210 further includes two major surfaces 220 and 222, with major surface 220 being world-side (i.e., the surface farthest from the user) and major surface 222 being eye-side (i.e., the surface closest to the user). In some embodiments, the waveguide 210 is between a world-side lens and an eye-side lens, which form lens elements 108, 110 shown in FIG. 1, for example. In some embodiments, the incoupler 212 and the outcoupler 214 are located, at least partially, at major surface 220. In another embodiment, the incoupler 212 and the outcoupler 214 are located, at least partially, at major surface 222. In further embodiments, the incoupler 212 is located at one of the major surfaces, while the outcoupler 214 is located at the other of the major surfaces.

[0040] FIG. 3 illustrates an example of a portion of an eyewear display 300 in accordance with various embodiments. In some embodiments, the eyewear display 300 corresponds to the eyewear display 100 of FIG. 1 and includes the projection system 200 of FIG. 2 or components thereof.

[0041] As shown in FIG. 3, the eyewear display 300 includes an image source 302 (such as one corresponding with image source 202 of FIG. 2) in a nose bridge region 314 (e.g., corresponding with nose bridge region 114 of FIG. 1) of the eyewear display 300. The image source 302 emits display light 318 toward the incoupler 312 of a waveguide 310 that is integrated into lens 302 (e.g., corresponding to one of lens elements 108, 110 of FIG. 1). An arm 330 of the portion of the eyewear display 300 is also illustrated for clarity purposes.

[0042] The eyewear display 300 includes a lens 302 that serves as an optical combiner. In some embodiments, the lens 302 corresponds to one of lens elements 108, 110 of FIG. 1. In some embodiments, the lens 302 is held in one of the two lens rims of the eyewear display 300. The lens 302 includes a lens stack including a first lens layer 304, a second lens layer 306, and a waveguide 310 disposed between the first lens layer 304 and the second lens layer 306. As illustrated, the first lens layer 304 is a world-side lens layer and the second lens 306 is an eye-side lens layer. In some embodiments, the waveguide 310 includes an incoupler 312 to incouple display light 318 into the waveguide 310 such that the display light is propagated within the waveguide 310 via various instances of TIR. The waveguide 310 also includes an outcoupler 314 to outcouple the display light 324 toward an eye 216 of the user. Thus, the eyewear display 300 includes a lens 302 serving as an optical combiner that is held in place by a corresponding lens rim of the eyewear display 300. Light exiting through the outcoupler 214 travels through the second lens 306. In use, the light exiting second lens 306 enters the pupil of an eye 216 of a user wearing the eyewear display 300, causing the user to perceive a displayed image carried by the light output by the image source 302. For example, the user perceives the displayed image over an FOV area such as one of FOV areas 120, 122 of FIG. 1. The different layers of the lens 302 are substantially transparent, such that light from real-world scenes corresponding to the environment around the eyewear display 300 passes

through the first lens layer 304, the second lens layer 306, and the waveguide 310 to the eye 216 of the user. In this way, images or other graphical content output by the image projection system 300 are combined (e.g., overlaid) with real-world images of the user's environment when projected onto the eye 216 of the user to provide an AR experience to the user. Although not shown in the depicted example, in some embodiments additional optical elements are included in any of the optical paths between the image source 302 and the incoupler 312, in between the incoupler 312 and the outcoupler 314, and/or in between the outcoupler 314 and the eye 216 of the user (e.g., in order to shape the display light for viewing by the eye 216 of the user).

[0043] In some embodiments, a similar configuration is implemented at the other one of the lenses (not shown) of the eyewear display 300 sharing the image source 302. For example, a second waveguide with a corresponding incoupler positioned in the nose bridge region 314 receives a portion of the display light 318 after it passes through the waveguide 310 and incoupler 312 shown in FIG. 3.

[0044] FIG. 4 illustrates an example of light propagation within a waveguide 210 of the projection system 200 of FIG. 2. As shown, display light is received via the incoupler 212, scanned along the axis 402, directed into an exit pupil expander (EPE) 416, and then routed to the outcoupler 214 to be output from the waveguide 210 (e.g., toward the eye of the user). In some embodiments, EPE 416 expands one or more dimensions of the eyebox of an eyewear display that includes the projection system 200 (e.g., with respect to what the dimensions of the eyebox of the eyewear display would be without the EPE 416). In some embodiments, the incoupler 212 and the EPE 416 each include respective one-dimensional diffraction gratings (i.e., diffraction gratings that extend along one dimension). It should be understood that FIG. 4 shows a case in which the incoupler 212 directs light straight down (with respect to the presently illustrated view) in a first direction that is perpendicular to the scanning axis 402, and the EPE 416 directs light to the right (with respect to the presently illustrated view) in a second direction that is perpendicular to the first direction. While not shown in the present example, it should be understood that, in some embodiments, the first direction in which the incoupler 212 directs light is

slightly or substantially diagonal, rather than exactly perpendicular, with respect to the scanning axis 402.

[0045] Also shown in FIG. 4 is a cross-section 420 of the incoupler 212 illustrating grating features that can be configured to tune the diffraction efficiency of the incoupler 212. In some embodiments, the outcoupler 214 also includes grating features that can be configured and tuned in a similar manner to the grating features discussed with respect to the incoupler 212. For example, in a configuration where both the incoupler 212 and the outcoupler 214 include a diffractive grating, the diffractive grating features (e.g., the period, height, fill factor, transmittance, reflectance, etc.) can be designed such that each of the incoupler 212 and/or the outcoupler 214 have a diffraction efficiency as discussed herein. The period p of the grating is shown having two regions, with transmittances t_1 and t_2 and widths d_1 and d_2 , respectively. The grating period is constant $p=d_1+d_2$, but the relative widths d_1 , d_2 of the two regions may vary. In some embodiments, the relationship between the relative widths and the period is indicated by a fill factor such that $d_1=xp$ and $d_2=(1-x)p$. In addition, while the profile shape of the grating features in cross-section 420 is generally shown as being square or rectangular with a height h , the shape can be modified based on the wavelength of light that the incoupler 212 is intended to receive. For example, in some embodiments, the shape of the grating features is triangular, rather than square, to create a more “saw-toothed” profile. In some embodiments, the incoupler 212 is configured as a grating with a constant period but different fill factors, heights, and slant angles (θ) based on the desired efficiency of the respective incoupler 212 or the desired efficiency of a region of the respective incoupler 212. Although shown as being at or near 90° in FIG. 3, in some embodiments, the slant angles (θ) can be acute or obtuse angles. For example, slanted or blazed gratings include slant angles (θ) other than 90° .

[0046] FIG. 5 illustrates an example of a bi-ocular dual-waveguide configuration 500 in accordance with various embodiments. As illustrated in FIG. 5, the bi-ocular dual-waveguide configuration 500 includes an image source 502 (such as an image source as illustrated in the previous figures) and two waveguides 510-1, 510-2. In some embodiments, the bi-ocular dual-waveguide configuration 500 also includes

projection optics 504 (such as those corresponding to one or more of the components described for the projection optics 204 of FIG. 2).

[0047] The first waveguide 510-1 and the second waveguide 510-2 each include respective incouplers 512-1, 512-2 that are positioned in the nose bridge region 114 of the eyewear display (e.g., in nose bridge region 114 of eyewear display 100 of FIG. 1) along with the image source 502. The image source 502 emits display light (shown by the dashed line initiating from the center of image source 502) through the projection optics 504 (if included) to the first waveguide 510-1. The first incoupler 512-1 of the first waveguide 510-1 incouples a first portion of the display light into waveguide 510-1 in a first direction 562, where the incoupled portion of display light is propagated through the first waveguide 510-1 via various TIR instances until it reaches the first outcoupler 514-1 of the first waveguide 510-1. The first outcoupler 514-1 outcouples the light from first waveguide 510-1 as light 552 to be observed by a first eye of the user (not shown). A second portion of the display light (i.e., the remaining portion that passes through the first waveguide 510-1) is incident on the second incoupler 512-2 of the second waveguide 510-2 and is incoupled in a second direction 564, where it is propagated through the second waveguide 510-2 via various TIR instances until it reaches the second outcoupler 514-2 of the second waveguide 510-2. The second outcoupler 514-2 outcouples the light from second waveguide 510-2 as light 554 to be observed by a second eye of the user (not shown). FIG. 5 also illustrates the exit pupil location 550 of the image source 502.

[0048] In the embodiment shown in FIG. 5, both incouplers 512-1, 512-2 are depicted as reflective diffractive gratings. That is, the incouplers 512-1, 512-2 incouple the display light into their respective waveguide 510-1, 510-2 by reflecting a portion of the light incident thereon at a first angle into the waveguide. For example, referring to incoupler 512-1, the incoupler 512-1 receives the display light emitted from the image source and reflects a first portion of this display light into the waveguide 510-1 such that it is propagated in the first direction via various TIR bounces off of the outer major surfaces of the waveguide 510-1. Similarly, incoupler 512-2 incouples light into waveguide 510-2 by reflecting the light into the waveguide

510-2 toward direction 564. In other embodiments, the incouplers 510-1, 510-2 are provided as transmissive diffractive gratings.

[0049] In the embodiment shown in FIG. 5, both outcouplers 514-1, 514-2 are depicted as transmissive diffractive gratings. That is, the outcouplers 514-1, 514-2 outcouple the light incident thereon by transmitting it out of their respective waveguide 510-1, 510-2. For example, referring to outcoupler 514-1, the light propagating in the waveguide 510-1 that is incident on the outcoupler 514-1 is directed out of the waveguide 510-1 as light 552 in the same general downward direction (with respect to the orientation of the FIG. 6). That is, the outcoupler 514-1 does not outcouple the light incident thereon upwards. Similarly, outcoupler 514-2 outcouples the light incident thereon as light 554. In other embodiments, the outcouplers 514-1, 514-2 are provided as reflective diffractive gratings.

[0050] While shown as being substantially horizontal and parallel to one another in FIG. 5, in some embodiments, the waveguide 510-1, 512-2 are positioned at angles with respect to one another (e.g., as illustrated in FIGs. 7 and 8). Thus, by implementing a waveguide 510-1, 510-2 into each lens (e.g., lens 108, 110 of FIG. 1) of an eyewear display, the waveguides can be better positioned to fit the form factor of the eyewear display while minimizing potential fractures or other defects that may occur if a single waveguide is used.

[0051] In addition, in some embodiments, by implementing the dual-waveguide bi-ocular configuration shown in FIG. 5, each of the waveguides 510-1, 510-2 are configurable to output the same light intensity to each eye (i.e., the intensity of the outcoupled light 552 is equal to intensity of outcoupled light 554). For example, in some embodiments, the grating features of the incouplers 512-1, 512-2 are designed (e.g., by varying the fill factor, grating height, or other parameters discussed with respect to FIG. 4) such that the intensity of the light outcoupled by each waveguide 510-1, 510-2 is substantially the same. In another example, in some embodiments, the grating features of the outcouplers 514-1, 514-2 are designed (e.g., by varying the fill factor, grating height, or other parameters discussed with respect to FIG. 4) such that the intensity of the light outcoupled by each waveguide 510-1, 510-2 is the same. In yet another embodiment, the substrate materials or dimensions (e.g.,

thickness) of the waveguides 510-1, 510-2 are selected such that the intensity of the light outcoupled by each waveguide 510-1, 510-2 is the same. In some embodiments, a combination of one or more of the above embodiments (incoupler grating feature design, outcoupler grating feature design, or waveguide substrate design) is used to selectively tune the amount of light outcoupled by each waveguide 510-1, 510-2. Examples of different grating feature configurations are shown in FIGs. 7 and 8.

[0052] Thus, by selectively designing each of the separate waveguides 510-1, 510-2, the light output at each of outcoupled light 552, 554 can be balanced to be substantially the same even though the light initially incident at each of the waveguides 510-1, 510-2 is different. For example, the display light from the image source 502 incident on incoupler 512-2 will inherently be less intense than the display light from the image source 502 incident on incoupler 512-1 since at least some of the display light is incoupled into waveguide 510-1.

[0053] FIG. 6 illustrates another example of a bi-ocular dual-waveguide configuration 600 in accordance with various embodiments. As illustrated in FIG. 6, the bi-ocular dual-waveguide configuration 600 includes an image source 602 (such as an image source as illustrated in the previous figures) and two waveguides 610-1, 610-2. In some embodiments, the bi-ocular dual-waveguide configuration 600 also includes projection optics 604 (such as those corresponding to one or more of the components described for the projection optics 204 of FIG. 2).

[0054] The first waveguide 610-1 and the second waveguide 610-2 each include respective incouplers 612-1, 612-2 that are positioned in the nose bridge region 114 of the eyewear display (e.g., in nose bridge region 114 of eyewear display 100 of FIG. 1) along with the image source 602. The image source 602 emits display light (shown by the dashed line initiating from the center of image source 602) through the projection optics 604 (if included) to the first waveguide 610-1. The first incoupler 612-1 of the first waveguide 610-1 incouples a first portion of the display light into waveguide 610-1 in a first direction 662, where the incoupled portion of display light is propagated through the first waveguide 610-1 via various TIR instances until it reaches the first outcoupler 614-1 of the first waveguide 610-1. The first outcoupler

614-1 outcouples the light from first waveguide 610-1 as light 652 to be observed by a first eye of the user (not shown). A second portion of the display light (i.e., the remaining portion that passes through the first waveguide 610-1) is incident on the second incoupler 612-2 of the second waveguide 610-2 and is incoupled in a second direction 664, where it is propagated through the second waveguide 610-2 via various TIR instances until it reaches the second outcoupler 614-2 of the second waveguide 610-2. The second outcoupler 614-2 outcouples the light from second waveguide 610-2 as light 654 to be observed by a second eye of the user (not shown).

[0055] In the embodiment shown in FIG. 6, the first incoupler 612-1 is implemented as a reflective diffractive grating and the second incoupler 612-2 is implemented as a transmissive diffractive grating. That is, the grating features of the second incoupler 612-2 are designed to incouple the light incident thereon into the waveguide 610-2 along the same direction (e.g., downward direction as illustrated in FIG. 6) as the light incident thereon. By implementing the first incoupler 612-1 as a diffractive grating of a reflective type and the second incoupler 612-2 as a diffractive grating of a transmissive type, the waveguides 610-1, 610-2 can be positioned closer together. By designing the image source 602 and/or the projection optics 604 accordingly, the exit pupil location 650 can be positioned to occur closely between the incouplers 612-1, 612-2. Thus, in some embodiments, the bi-ocular dual-waveguide configuration 600 occupies less space in the nose bridge region 114. In some aspects, this facilitates the implementation of a bi-ocular dual-waveguide configuration into eyewear displays with limited space/volume in the nose bridge region.

[0056] FIG. 7 illustrates an example of a bi-ocular dual-waveguide configuration 700 in accordance with various embodiments. As illustrated in FIG. 7, the bi-ocular dual-waveguide configuration 700 includes two waveguides 710-1, 710-2. Each of the waveguides 710-1, 710-2 has a respective incoupler 712-1, 712-2 to incouple light and a respective outcoupler 714-1, 714-2 to outcouple light to one of the eyes 216-1, 216-2 of the user. The first waveguide 710-1 is integrated into a first lens of an eyewear display and the second waveguide is integrated into a second lens of the eyewear display and both incouplers 712-1, 712-2 are positioned in the nose bridge

region of the eyewear display. For example, waveguide 710-1 is integrated into one of lens elements and waveguide 710-2 is integrated into the other one of the lens elements in eyewear display 100 of FIG. 1 with both incouplers 712-1, 712-2 positioned in the nose bridge region 114.

[0057] An image source (not shown in FIG. 7) emits display light 718. For example, the image source corresponds to one of the image sources described in the previous figures. In some embodiments, the image source is a micro-LED positioned in a nose bridge region of an eyewear display such as eyewear display 100 of FIG. 1. For purposes of clarity and facilitating this explanation, display light 718 includes 100% of the light output from the image source.

[0058] The display light 718 is incident on the first waveguide 710-1 at first incoupler 712-1. In this example, the first incoupler 712-1 is a binary diffractive grating with a diffraction efficiency of 15%. The incoupler 712-1 incouples a first portion of the display light 718 into the waveguide 710-1 as incoupled light 720 toward direction 762 (i.e., in a direction of the outcoupler 714-1 in the waveguide 710-1). Since incoupler 712-1 has a 15% diffraction efficiency, incoupled light 720 includes 15% of the light output from the image source (i.e., 15% of the display light 718). Additionally, due to the nature of binary diffractive gratings, a lost light portion 719 also includes 15% of the light output from the image source (i.e., 15% of the display light 718). In this example, the first outcoupler 714-1 also includes a diffraction efficiency of 15%. That is, the first outcoupler 714-1 receives incoupled light 720 (which has 15% of the light output from the image source) and outcouples 15% of this light as outcoupled light 722 toward the eye 216-1 of the user. Thus, outcoupled light 722 includes 2.25% of the light output from the image source ($15\% \times 15\% = 2.25\%$).

[0059] Referring back to the principal line of direction of the light emitted from the image source (corresponding to the vertical direction in line with beams 718, 724, 730 in FIG. 7), a second portion of light 724 passes through the first waveguide 710-1 and includes 70% of the total output from the image source in 718 ($100\% - 2 \times 15\% = 70\%$, where the 15% corresponds to the diffracted light in light 720 and light 719). This second portion of light 724 is incident on the second waveguide 710-2 at second incoupler 712-2. In this example, the second incoupler 712-2 is a binary diffractive

grating with a diffraction efficiency of 21.43%. The second incoupler 712-2 incouples the light incident thereon (i.e., second portion of light 724 with 70% of the total output from the image source in light 718) toward a second direction 764 within the waveguide 710-2 so that it is propagated toward the second outcoupler 714-2. With a diffraction efficiency of 21.43%, second incoupled portion 726 includes 15% of the total output from the image source at 718 (21.43% of the 70% at light 724, $21.43\% \times 70\% = 15\%$ (approximately)). Due to the nature of binary diffractive gratings a second lost portion of light 725 also includes 15% of the light output from the image source. In this example, the second outcoupler 714-2 also includes a diffraction efficiency of 15%. That is, the second outcoupler 714-2 receives the second incoupled light 726 (which has 15% of the light output from the image source) and outcouples 15% of this light as outcoupled light 728 toward the eye 216-2 of the user. Thus, outcoupled light 728 includes 2.25% of the light output from the image source ($15\% \times 15\% = 2.25\%$). Accordingly, each of the outcoupler lights 722 and 728 are the same. Thus, the user observes the same image with equal light intensity at each of their eyes 216-1, 216-2.

[0060] In the example described above with respect to FIG. 7, the grating features of the incouplers 712-1, 712-2 are designed to implement the discussed diffraction efficiencies such that the light output to each eye is the same. In some embodiments, the diffraction efficiencies of the outcouplers 714-1, 714-2 are tuned in a similar manner by varying their respective grating features such that the outcouplers are the components that ensure that the light output to each eye is the same. Furthermore, in other embodiments, the diffraction efficiencies of both the incouplers 712-1, 712-2 and both the outcouplers 714-1, 714-2 are varied (e.g., by modifying their respective grating features) to ensure that the light output to each eye is the same.

[0061] FIG. 8 illustrates another example of a bi-ocular dual-waveguide configuration 800 in accordance with various embodiments. As illustrated in FIG. 8, the bi-ocular dual-waveguide configuration 800 includes an image source 802 (such as an image source as illustrated in the previous figures) and two waveguides 810-1, 810-2. In some embodiments, the bi-ocular dual-waveguide configuration 800 also

includes projection optics 804 (such as those corresponding to one or more of the components described for the projection optics 204 of FIG. 2).

[0062] The bi-ocular dual-waveguide configuration 800 illustrated in FIG. 8 also includes a partial mirror 842 and a mirror 844 to boost the amount of light incoupled into each of the respective waveguides 810-1, 810-2. In some embodiments, the partial mirror 842 and the mirror 844 are parallel to the waveguides 810-1, 810-2. As illustrated in FIG. 8, the partial mirror 842 is positioned between the first waveguide 810-1 and the second waveguide 810-2 and the mirror is positioned on the opposite side of the second waveguide 810-2 as the partial mirror 842. That is, the order of the components of the bi-ocular dual-waveguide configuration (from the direction of the image source 802) is the first waveguide 810-1, the partial mirror 842, the second waveguide 810-2, and the mirror 844. The partial mirror 842 is as a partial reflector/transmitter to reflect a first portion of the light incident thereon back toward the first incoupler 812-1 while allowing the remaining portion to pass through to second incoupler 812-2. In some embodiments, the partial mirror 842 is designed to reflect or transmit light with a particular wavelength range or polarization state to balance the relative amounts of reflected and transmitted light. In this manner, the partial mirror 842 provides the first incoupler 812-1 with an extra opportunity to incouple additional light into the first waveguide 810-1. The mirror 844 reflects the light incident thereon back toward the second incoupler 812-2 so that at least a portion of it can be incoupled into the second waveguide 810-2. In this manner, the mirror 844 provides the second incoupler 812-2 with an extra opportunity to incouple additional light into the second waveguide 810-2.

[0063] The first waveguide 810-1 and the second waveguide 810-2 each include respective incouplers 812-1, 812-2 that are positioned in the nose bridge region 114 of the eyewear display (e.g., in nose bridge region 114 of eyewear display 100 of FIG. 1) along with the image source 802 and the partial mirror 842 and the mirror 844. The image source 802 emits display light (shown by the dashed line initiating from the center of image source 802) through the projection optics 804 (if included) to the first waveguide 810-1. The first incoupler 812-1 of the first waveguide 810-1 incouples a first portion of the display light into waveguide 810-1 in a first direction

862, where the incoupled portion of display light is propagated through the first waveguide 810-1 via various TIR instances until it reaches the first outcoupler 814-1 of the first waveguide 810-1. The first outcoupler 814-1 outcouples the light from first waveguide 810-1 as light 852 to be observed by a first eye of the user (not shown). Some of the light that passes through the first waveguide 810-1 is reflected back to the first incoupler 812-1 by the partial mirror 842 while the remaining light passes through the partial mirror 842. This portion of light that passes through the partial mirror 842 is incident on the second incoupler 812-2 of the second waveguide 810-2 and is incoupled in a second direction 864, where it is propagated through the second waveguide 810-2 via various TIR instances until it reaches the second outcoupler 814-2 of the second waveguide 810-2. The second outcoupler 814-2 outcouples the light from second waveguide 810-2 as light 854 to be observed by a second eye of the user (not shown). Another portion of light passes through the second waveguide 812-2 and is reflected by the mirror 844 back toward the second incoupler 812-2 so that at least a portion of this reflected back light is incoupled into the second waveguide 812-2.

[0064] In some embodiments, by adding a partial mirror 842 and mirror 844 to the bi-ocular dual-waveguide configuration 800, the bi-ocular dual-waveguide configuration 800 is able to increase or further tune the amount of light that is output to each eye of the user. In some cases, this facilitates the balancing of light output to each eye of the user and/or increases the amount of light outcoupled by each waveguide.

[0065] In the embodiment shown in FIG. 8, the first incoupler 812-1 and the second incoupler 812-2 are implemented as reflective diffractive gratings. In some embodiments, one or both of the first incoupler 812-1 and the second incoupler 812-2 are implemented as transmissive diffractive gratings. Similarly, in the embodiment shown in FIG. 8, the first outcoupler 814-1 and the second outcoupler 814-2 are implemented as transmissive diffractive gratings. In some embodiments, one or both of the first outcoupler 814-1 and the second outcoupler 814-2 are implemented as reflective diffractive gratings.

[0066] FIG. 9 illustrates another example of a bi-ocular dual-waveguide configuration 900 in accordance with various embodiments. As illustrated in FIG. 9, the bi-ocular dual-waveguide configuration 900 includes an image source 902 (such as an image source as illustrated in the previous figures) and two waveguides 910-1, 910-2. In some embodiments, the bi-ocular dual-waveguide configuration 900 also includes projection optics 904 (such as those corresponding to one or more of the components described for the projection optics 204 of FIG. 2).

[0067] The bi-ocular dual-waveguide configuration 900 illustrated in FIG. 9 also includes a waveplate 952 to balance the amount of light incoupled at the second waveguide 910-2 with the amount of light incoupled at the first waveguide 910-1. For example, in some embodiments the waveplate 952 is a $\frac{1}{2}$ -wavelength waveplate to convert p-polarized light to s-polarized light (or vice versa). In some cases, the light emitted from the image source 902 includes multiple polarization states. For example, the image source 902 emits display light having both s-polarized light and p-polarized light. Moreover, in some cases, the diffractive gratings used at the incouplers 912-1, 912-2 include grating features that are polarization sensitive. That is, one of or both the incouplers 912-1, 912-2 include types of diffractive gratings (e.g., slanted or blazed diffractive gratings) that diffract light of one polarization at a higher efficiency than light having other types of polarization. Thus, bi-ocular dual-waveguide configuration 900 balances the light output at each of the waveguides 910-1, 910-2 with polarization sensitive incouplers 912-1, 912-2 and a waveplate 952 positioned between the two waveguides 910-1, 910-2.

[0068] To illustrate by way of example, the image source emits light having s- and p- polarized light. The first incoupler 912-1 includes a slanted or blazed grating to diffract s-polarized light. Thus, the first incoupler 912-1 incouples s-polarized light into the first waveguide 910-1 in a direction 962 toward the first outcoupler 914-1 and allows p-polarized light to pass through the waveguide 910-1. The first outcoupler 914-1 receives the incoupled light from the first incoupler 910-1 and outcouples the light as outcoupled light 952. The p-polarized light that passes through the waveguide 910-1 then passes through waveplate 952, which converts the p-polarized light to s-polarized light. Thus, the light that is incident on the second incoupler 912-2 (which is

similar in nature to the first incoupler 912-1 in that it is tuned to diffract s-polarized light) is s-polarized light. The second incoupler 912-2 then incouples the light incident thereon into waveguide 910-2 in a direction 964 toward the second outcoupler 914-2. The second outcoupler 914-2 receives the incoupled light from the second incoupler 910-2 and outcouples the light as outcoupled light 954.

[0069] In some embodiments, by adding a waveplate 952 to the bi-ocular dual-waveguide configuration 900 and designing the incouplers 912-1, 912-2 to be polarization sensitive (e.g., by varying the slant angles of the diffract grating features), the bi-ocular dual-waveguide configuration 900 is able to increase or further tune the amount of light that is output to each eye of the user. In some cases, this facilitates the balancing of light output to each eye of the user and/or increases the amount of light outcoupled by each waveguide.

[0070] In the embodiment shown in FIG. 9, the first incoupler 912-1 and the second incoupler 912-2 are implemented as reflective diffractive gratings. In some embodiments, one or both of the first incoupler 912-1 and the second incoupler 912-2 are implemented as transmissive diffractive gratings. Similarly, in the embodiment shown in FIG. 9, the first outcoupler 914-1 and the second outcoupler 914-2 are implemented as transmissive diffractive gratings. In some embodiments, one or both of the first outcoupler 914-1 and the second outcoupler 914-2 are implemented as reflective diffractive gratings.

[0071] In the embodiments described above with respect to FIGs. 4-9, the incoupler and the outcoupler are discussed as being different types of diffractive gratings. In other embodiments, at least one of the incoupler or the outcoupler are implemented in the respective waveguides as one or more reflective mirror facets instead. For example, either one of or both of the incoupler and the outcoupler includes a series of reflective mirror facets configured to reflect or transmit different ratios of light (e.g., partially reflective mirror facets with 10R/90T, 20R/80T, 30R/70T, 40R/60T, 50R/50T, 60R/40T, 70R/30T, 80R/20T, 90R/10T, or the like) so that the display light propagated to each eye of the user is substantially similar or the same. Thus, in such embodiments, the incoupler or the outcoupler are implemented as a set of partially reflective mirror facets having one or more particular reflection to

transmission ratios (R/T ratios) to produce the incoupling and outcoupling behaviors described above.

[0072] Note that not all of the activities or elements described above in the general description are required, that a portion of a specific activity or device may not be required, and that one or more further activities may be performed, or elements included, in addition to those described. Still further, the order in which activities are listed is not necessarily the order in which they are performed. Also, the concepts have been described with reference to specific embodiments. However, one of ordinary skill in the art appreciates that various modifications and changes can be made without departing from the scope of the present disclosure as set forth in the claims below. Accordingly, the specification and figures are to be regarded in an illustrative rather than a restrictive sense, and all such modifications are intended to be included within the scope of the present disclosure.

[0073] Benefits, other advantages, and solutions to problems have been described above with regard to specific embodiments. However, the benefits, advantages, solutions to problems, and any feature(s) that may cause any benefit, advantage, or solution to occur or become more pronounced are not to be construed as a critical, required, or essential feature of any or all the claims. Moreover, the particular embodiments disclosed above are illustrative only, as the disclosed subject matter may be modified and practiced in different but equivalent manners apparent to those skilled in the art having the benefit of the teachings herein. No limitations are intended to the details of construction or design herein shown, other than as described in the claims below. It is therefore evident that the particular embodiments disclosed above may be altered or modified and all such variations are considered within the scope of the disclosed subject matter. Accordingly, the protection sought herein is as set forth in the claims below.

WHAT IS CLAIMED IS:

1. A device comprising:
 - a first waveguide comprising:
 - a first incoupler to incouple a first portion of display light into the first waveguide toward a first direction, wherein a second portion of the display light passes through the first incoupler and the first waveguide; and
 - a first outcoupler to outcouple the first portion of display light from the first waveguide; and
 - a second waveguide comprising:
 - a second incoupler to incouple a fraction of the second portion of display light into the second waveguide toward a second direction different from the first direction; and
 - a second outcoupler to outcouple the fraction of the second portion of display light from the second waveguide.
2. The device of claim 1, wherein the first incoupler comprises a first diffractive grating and the second incoupler comprises a second diffractive grating.
3. The device of claim 2, wherein the first diffractive grating and the second diffractive grating are different diffractive grating types.
4. The device of claim 3, wherein the first diffractive grating is a reflective grating, and the second diffractive grating is a transmissive grating.
5. The device of claim 3, wherein the first diffractive grating is a transmissive grating, and the second diffractive grating is a reflective grating.
6. The device of claim 2, wherein the first diffractive grating has a first diffraction efficiency, and the second diffractive grating has a second diffraction efficiency different from the first diffraction efficiency.

7. The device of any one of claims 2-6, wherein the first outcoupler comprises a third diffractive grating and the second outcoupler comprises a fourth diffractive grating.
8. The device of claim 7, wherein the third diffractive grating has a third diffraction efficiency, and the fourth diffractive grating has a fourth diffraction efficiency different from the third diffraction efficiency.
9. The device of claim 1, wherein at least one of the first or second incouplers or the first or second outcouplers comprises one or more reflective mirror facets.
10. The device of claim 1, wherein the first waveguide and the second waveguide overlap at sections comprising the first incoupler and the second incoupler, wherein the first waveguide and the second waveguide do not overlap at sections comprising the first outcoupler and the second outcoupler.
11. The device of claim 1, further comprising a partial mirror between the first waveguide and the second waveguide.
12. The device of claim 11, further comprising a mirror adjacent to the second waveguide on an opposite side of the second waveguide from the partial mirror.
13. The device of claim 1, further comprising a waveplate between the first waveguide and the second waveguide, the waveplate to convert light from a second polarization state to a first polarization state.
14. The device of claim 13, wherein the display light comprises light with the first polarization state and light with the second polarization state, wherein the first portion of light incoupled by the first incoupler corresponds to light having the first polarization state, wherein the second portion of light that passes through the first incoupler and the first waveguide has the second polarization state.

15. The device of claim 14, wherein the fraction of the second portion of display light incoupled into the second waveguide has the first polarization state.
16. The device of claim 1, wherein the display light is received from a single optical engine.
17. The device of any one of claims 1-16, wherein the first direction corresponds to a first field of view (FOV) area, and the second direction corresponds to a second FOV area different from the first FOV area.
18. The device of claim 17, wherein the first FOV area is associated with a first optical combiner in a first lens element in an eyewear display and the second FOV area is associated with a second optical combiner in a second lens element in the eyewear display.
19. An eyewear display comprising:
an optical engine to emit display light;
a first lens comprising a first waveguide, the first waveguide comprising:
a first incoupler to incouple a first portion of the display light into the first waveguide toward a first direction, wherein a second portion of the display light passes through the first incoupler and the first waveguide; and
a first outcoupler to outcouple the first portion of display light from the first waveguide; and
a second lens comprising a second waveguide, the second waveguide comprising:
a second incoupler to incouple a fraction of the second portion of display light into the second waveguide toward a second direction different from the first direction; and
a second outcoupler to outcouple the fraction of the second portion of display light from the second waveguide.

20. The eyewear display of claim 19, wherein the optical engine, the first incoupler, and the second incoupler are positioned in a nose bridge region of the eyewear display, wherein the first waveguide extends from the nose bridge region into the first lens, and wherein the second waveguide extends from the nose bridge region into the second lens.
21. The eyewear display of claim 19, further comprising a partial beamsplitter between the first waveguide and the second waveguide, and a mirror adjacent to the second waveguide on an opposite side of the second waveguide from the partial beamsplitter.
22. The eyewear display of claim 19, further comprising a waveplate between the first waveguide and the second waveguide, the waveplate to convert light from a second polarization state to a first polarization state.
23. A method comprising:
- incoupling a first portion of display light into a first waveguide, the first waveguide incorporated into a first lens of an eyewear display, wherein a second portion of the display light passes through the first waveguide; and
 - incoupling a fraction of the second portion of the display light into a second waveguide, the second waveguide incorporated into a second lens of the eyewear display.

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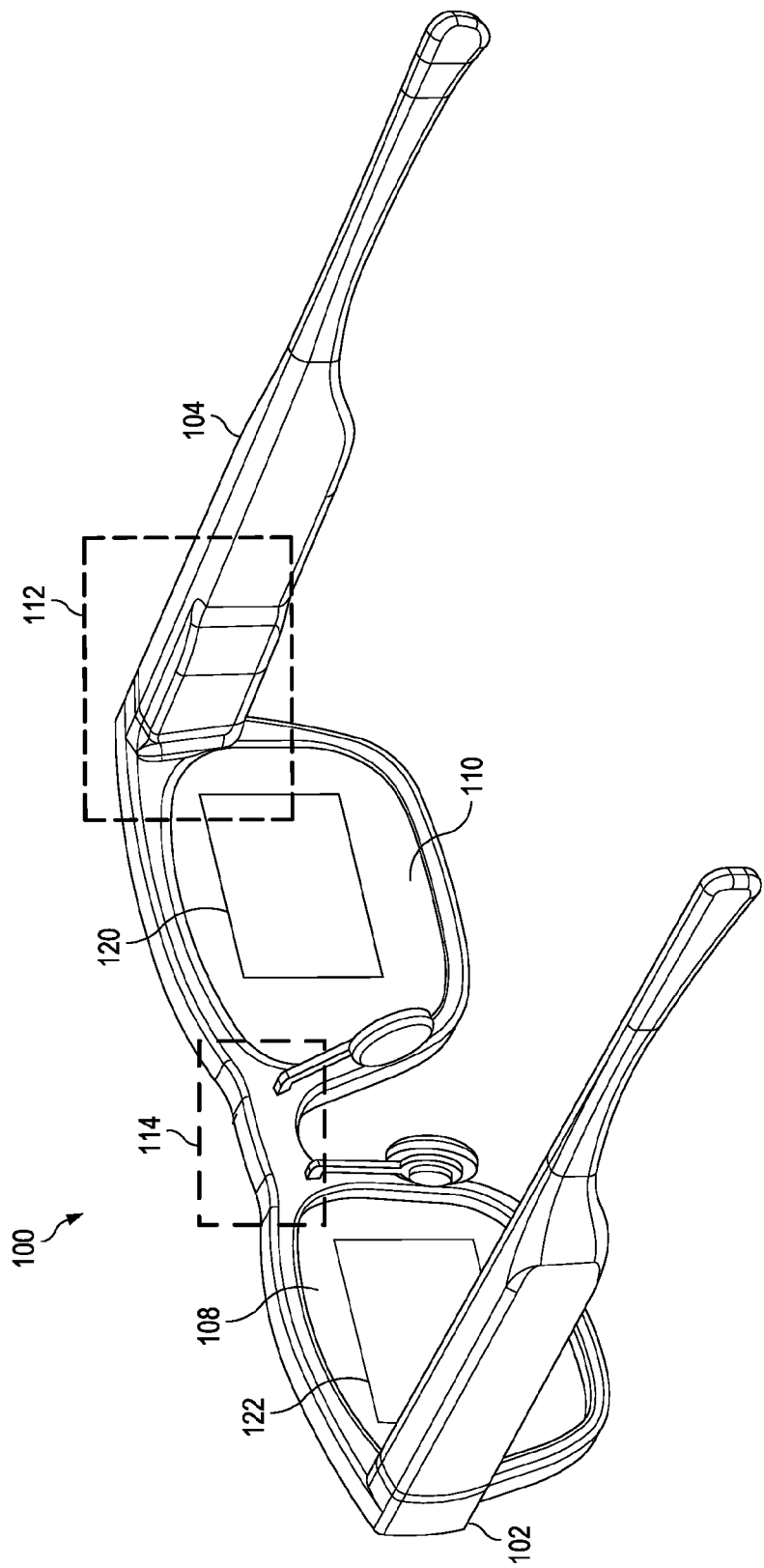


FIG. 1

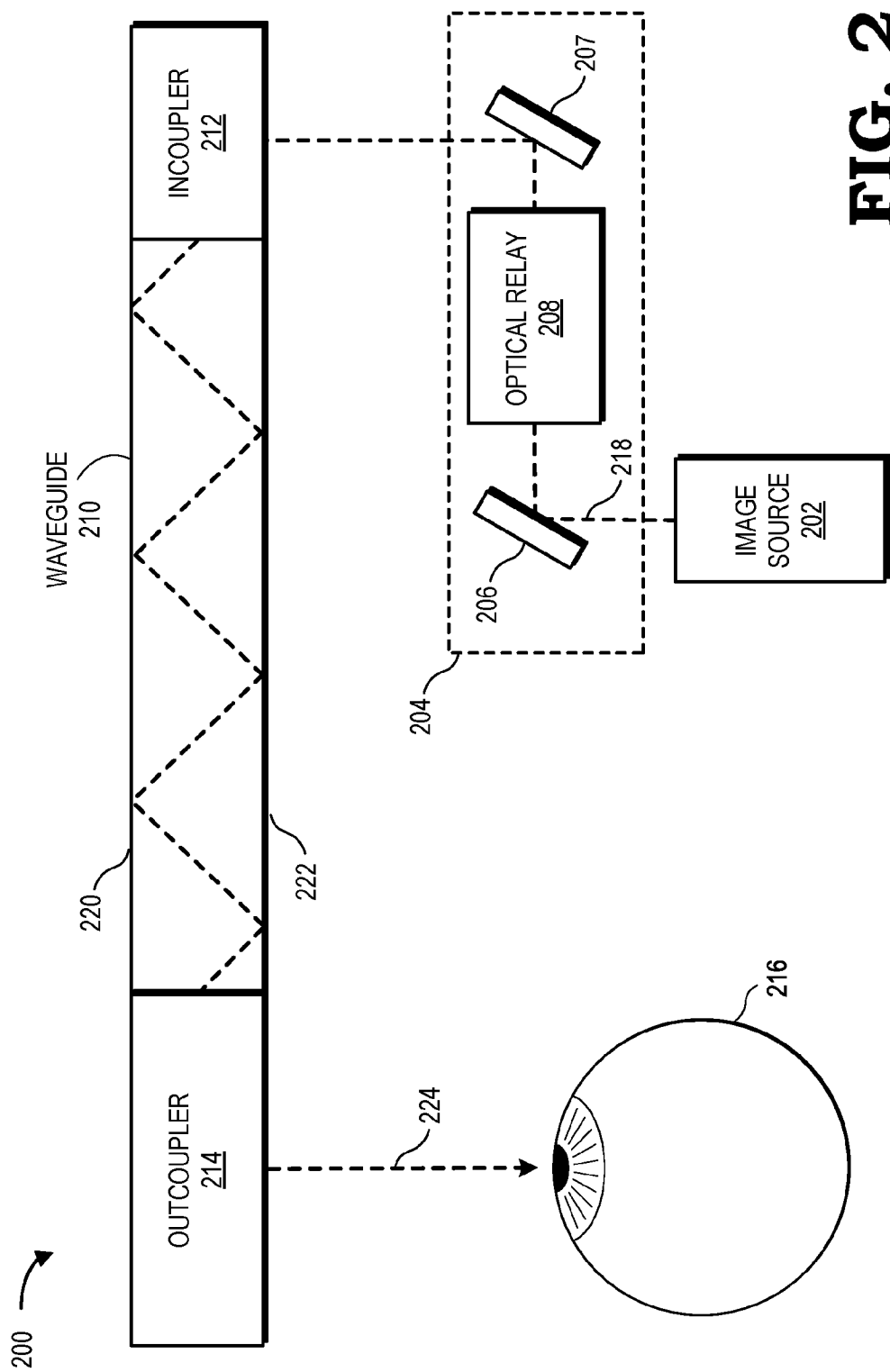


FIG. 2

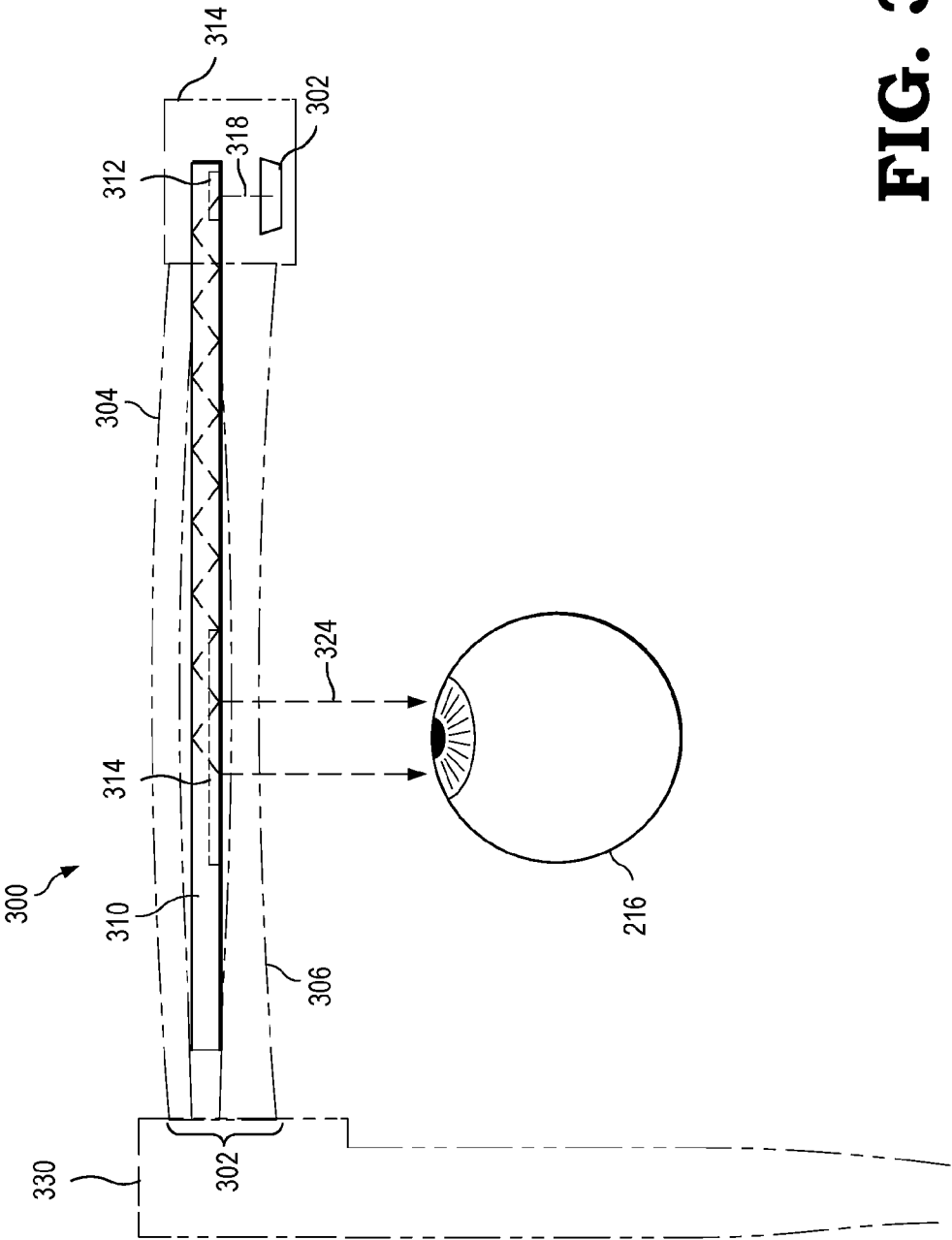


FIG. 3

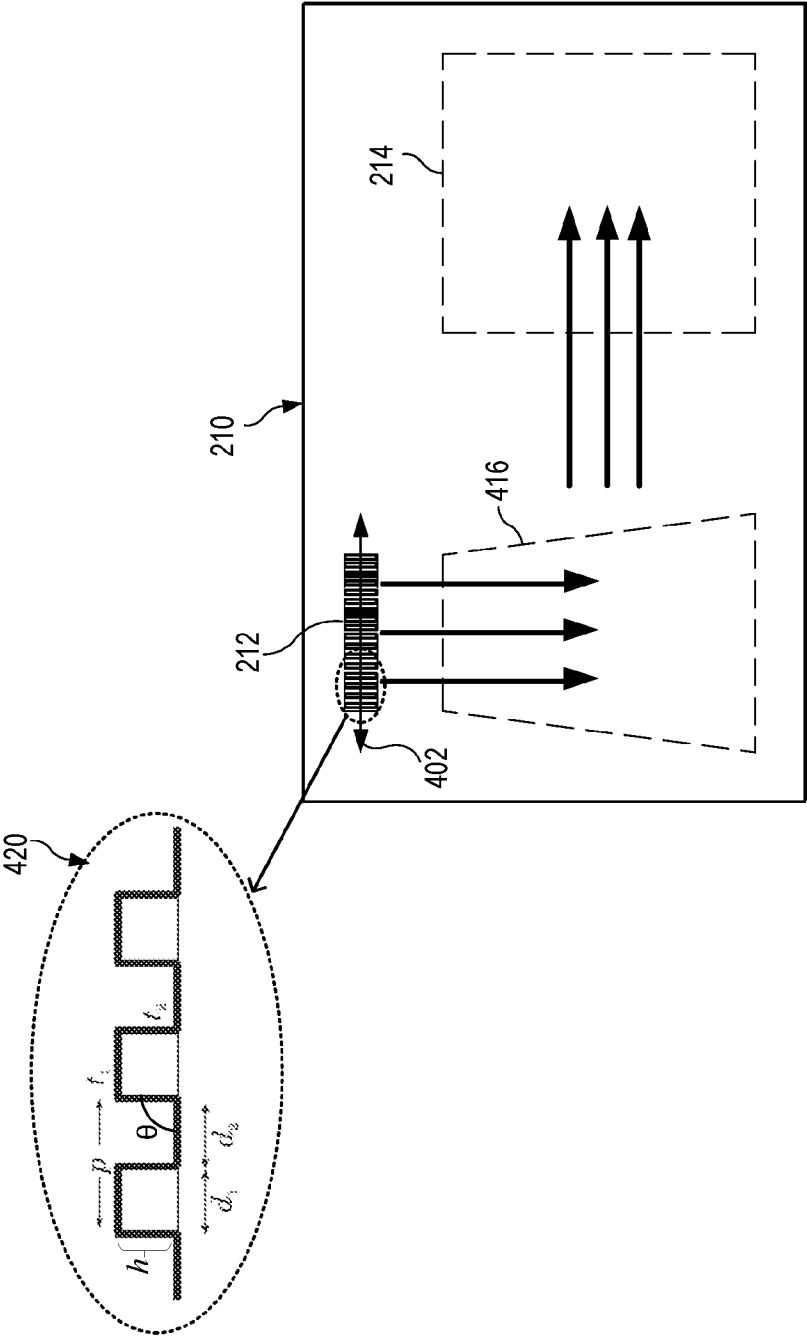
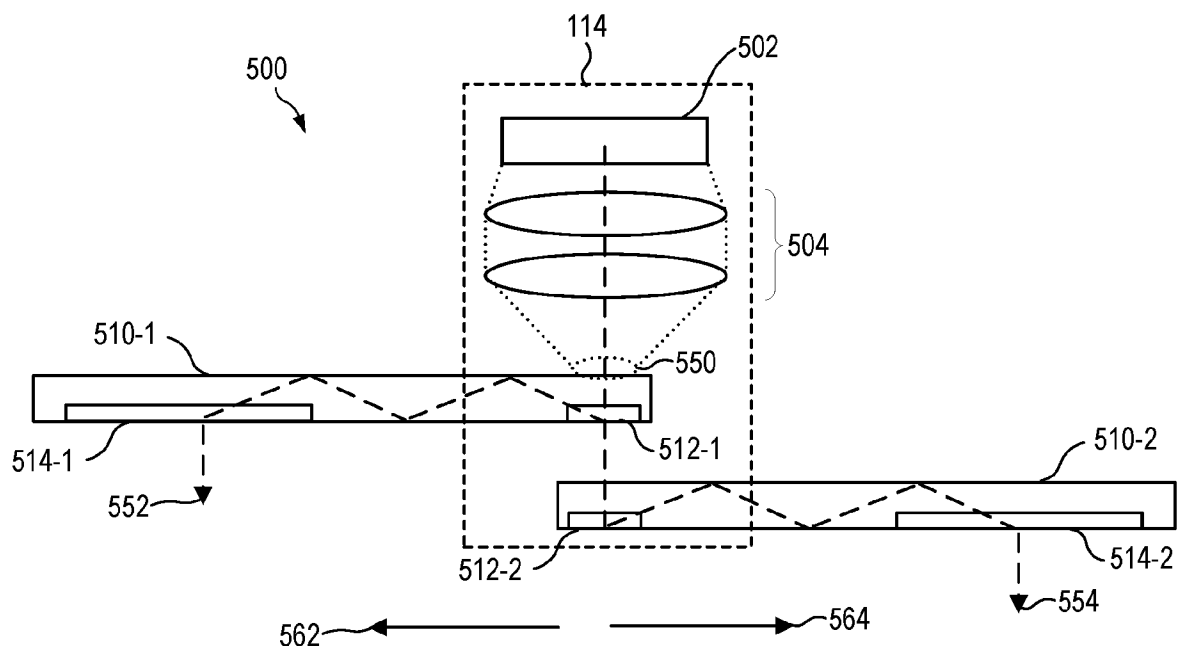
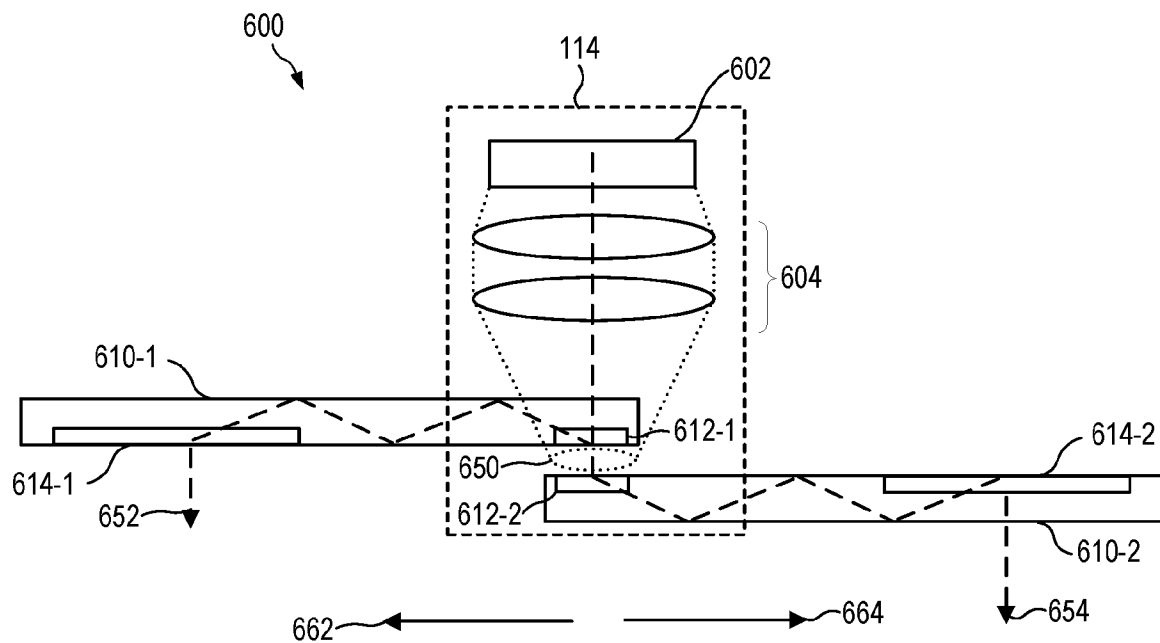


FIG. 4

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**FIG. 5****FIG. 6**

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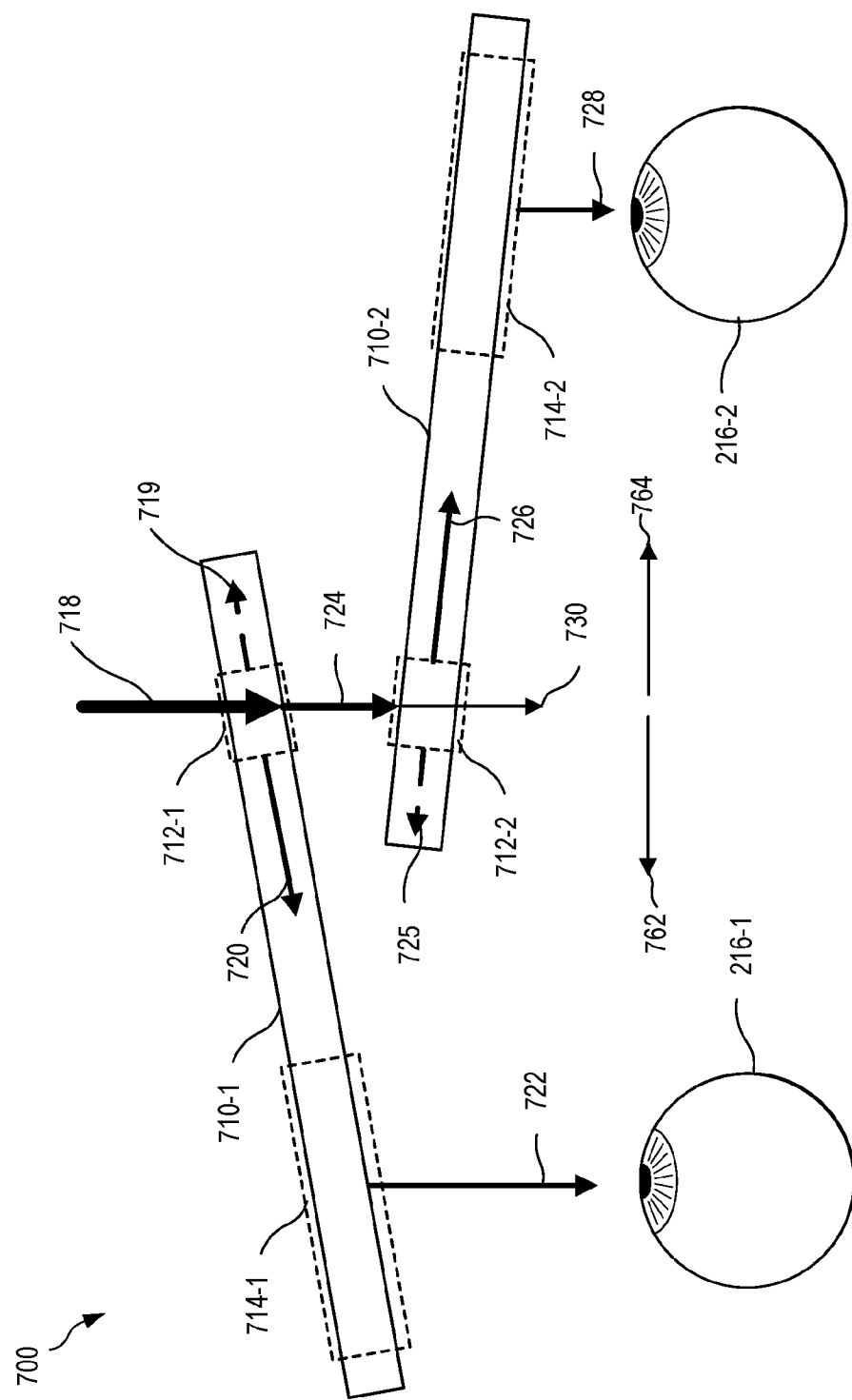
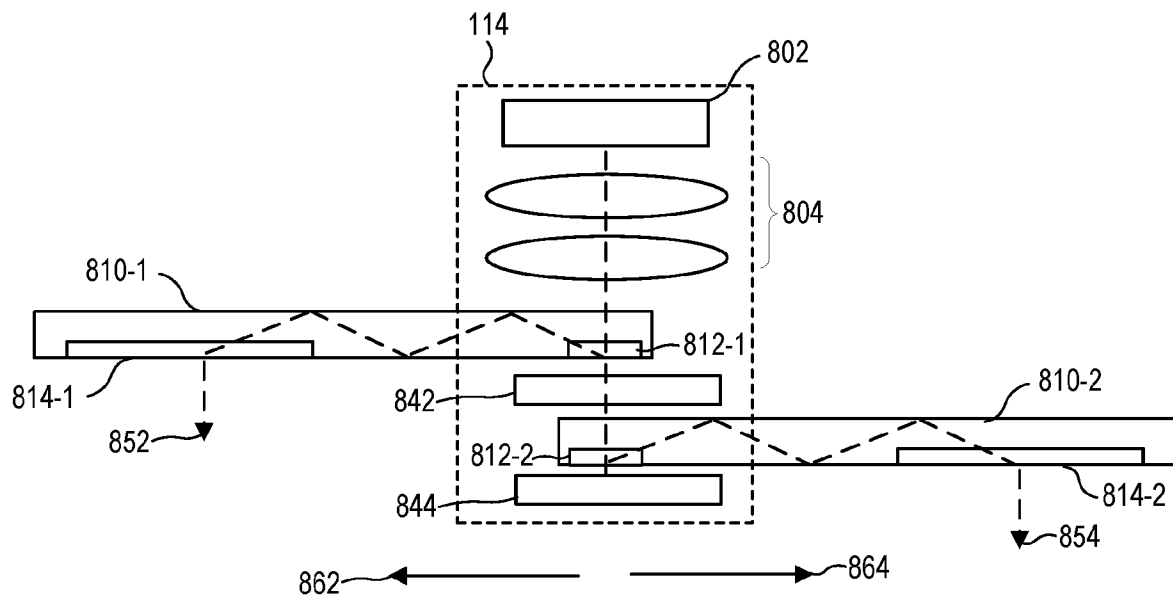
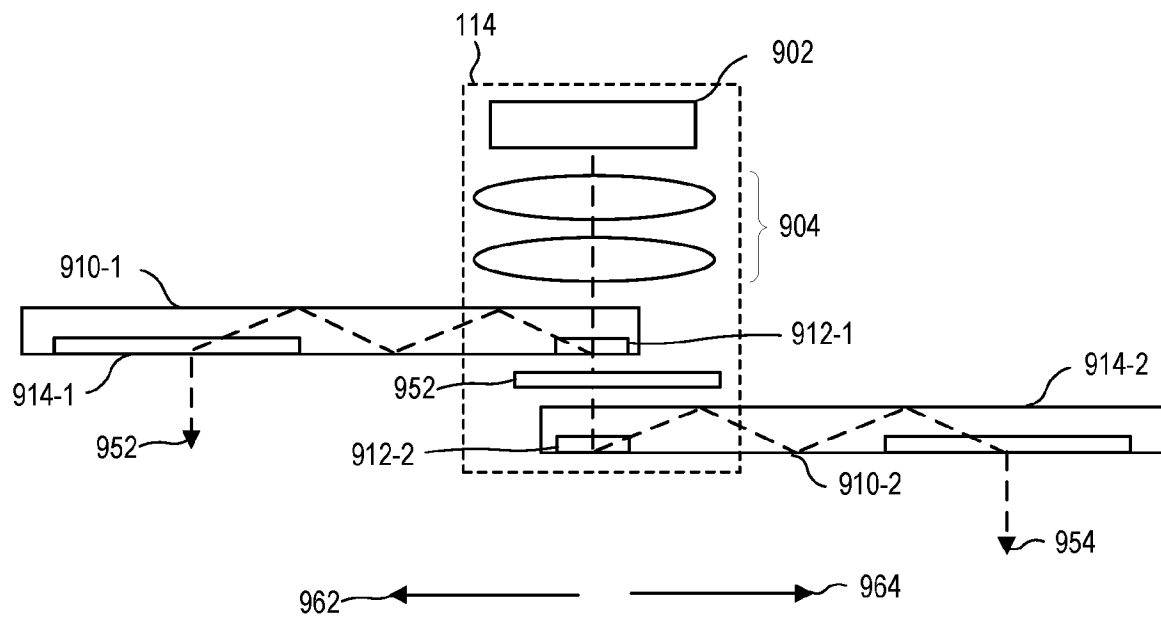


FIG. 7

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**FIG. 8****FIG. 9**

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2023/025521

A. CLASSIFICATION OF SUBJECT MATTER**INV. G02B27/01****ADD. F21V8/00**

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)

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	US 2022/390744 A1 (ALASAARELA TAPANI MATIAS [FI]) 8 December 2022 (2022-12-08)	1, 2, 6-13, 16-23
Y	paragraph [0030] - paragraph [0036]; figure 7	3-5
X	CN 115 933 187 A (UNIV CHONGQING POSTS & TELECOM) 7 April 2023 (2023-04-07) abstract; figure 2	1, 13-15, 19, 23
Y	WO 2021/191132 A1 (INTERDIGITAL CE PATENT HOLDINGS SAS [FR]) 30 September 2021 (2021-09-30) abstract; figure 27	3-5
A	CN 114 153 073 A (GOOLTON TECHNOLOGY CO LTD) 8 March 2022 (2022-03-08) abstract; figures 1-4	1, 19, 23



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

1 December 2023

Date of mailing of the international search report

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2023/025521

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