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HIGH CONTRAST LIQUID CRYSTAL POLARIZATION HOLOGRAMS

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TECHNOLOGICAL FIELD

[0001] The present disclosure generally relates to methods of manufacturing for augmented reality display devices, and more specifically to holographic optical components used in augmented reality devices.

BACKGROUND

[0002] Augmented reality (AR) is a form of reality that has been adjusted in some manner before presentation to a user, which may include, for example, a mixed reality, a hybrid reality, or some combination or derivatives thereof. In this regard, augmented reality, mixed reality, and hybrid reality devices often provide content through visual mechanisms, such as through a headset, e.g., glasses.

[0003] Liquid crystal polarization holograms (LCPHs), a geometric phase optical element, such as Pancharatnam Berry Phase (PBP) or Polarization Volume Hologram (PVH)) and or holographic optical elements (HOEs) may be used as an integral part of an optical system in an augmented reality (AR) display.

BRIEF SUMMARY

[0004] Exemplary embodiments are described for an optical system which may be associated with manufacturing and use of augmented reality (AR) devices or applications. The optical system used in the manufacturing process may include a narrow band angular reflector or filter and liquid crystal polarization hologram (LCPH) optical element(s). LCPH optical elements may include lenses, grating, and reflector made by Pancharatnam-Berry-phase (PBP) or Polarization Volume Hologram (PVH).

[0005] In an example embodiment, an optical system may include a PBP or PVH grating photo mask having a front and rear surface. The PBP or PVH grating photo mask may be associated with the polarization of light and may be arranged to guide light into the system to further filter or reflect undesirable polarizations of light (e.g., diffractive light orders). The light may be guided toward or through a narrow band angular reflector or filter that may filter or reflect 0^{th} order light and may be projected on a target PBP or PVH component or a target PBP or PVH lens component. Where the target PBP or PVH component may be used in final AR applications for presentation of an adjusted form of reality to a user.

[0006] Additional advantages will be set forth in part in the description which follows or may be learned by practice. The advantages will be realized and attainted by means of the elements and combinations particularly pointed out in the appended claims. It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory only and are not restrictive, as claimed.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] FIG. 1 is a plan view of a head-mounted display (HMD) associated with augmented reality content in accordance with an exemplary embodiment.

[0008] FIG. 2 is a detailed view of a light projector mounted to a frame of the head-mounted display, taken at dashed circle A of FIG. 1 in accordance with an exemplary embodiment.

[0009] FIG. 3 illustrates optical alignment of a projected pattern as viewed by a camera in accordance with an exemplary embodiment.

[0010] FIG. 4 is a cross-sectional view of a head-mounted display with alignment cameras in accordance with an exemplary embodiment.

[0011] FIG. 5A illustrates an example of light source with a PBP lens made with multiple duplication processes.

[0012] FIG. 5B illustrates an example resultant image displayed from the PBP lens shown in FIG. 5A.

[0013] FIG. 6A is a graph illustrating the efficiency of PBP at different thicknesses.

[0014] FIG. 6B is a graph illustrating diffraction efficiency of PBP as grating pitch ss increased.

[0015] FIG. 7A is a diagram illustrating manufacturing duplication process to make small pitch PBP grating photo mask.

[0016] FIG. 7B is a diagram illustrating the projection method to make PBP grating photo mask.

[0017] FIG. 8A illustrates a diagram illustrating an optical system comprising optical elements in accordance with an exemplary embodiment.

[0018] FIG. 8B illustrates an alternate embodiment of the optical system of FIG. 8A in accordance with an exemplary embodiment.

[0019] FIG. 9 illustrates transmittance in incident angle of the optical system of FIG.8A in accordance with an exemplary embodiment.

[0020] FIG. 10 illustrates a graph indicating diffraction efficiency at different diffractive orders of light of FIG. 8 and conventional systems using methods and processes of FIG. 7 in accordance with an exemplary embodiment.

[0021] FIG. 11 illustrates a cleaning circular polarizer with a LCPHs Lens in accordance with an exemplary embodiment.

[0022] FIG. 12 illustrates an angular reflector with a LCPHs lens in accordance with an exemplary embodiment

[0023] FIG. 13 illustrates an augmented reality system comprising a headset in accordance with an exemplary embodiment.

[0024] The figures depict various embodiments for purposes of illustration only. One skilled in the art will readily recognize from the following discussion that alternative embodiments of the structures and methods illustrated herein may be employed without departing from the principles described herein.

DETAILED DESCRIPTION

[0025] Some embodiments of the present disclosure will now be described more fully hereinafter with reference to the accompanying drawings, in which some, but not all embodiments of the disclosure are shown. Indeed, various embodiments of the disclosure may be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Like reference numerals refer to like elements throughout. As used herein, the terms “data,” “content,” “information” and similar terms may be used interchangeably to refer to data capable of being transmitted, received or stored in accordance with embodiments of the disclosure. Moreover, the term “exemplary”, as used herein, is not provided to convey any qualitative assessment, but instead merely to convey an illustration of an example. Thus, use of any such terms should not be taken to limit the spirit and scope of embodiments of the disclosure.

[0026] As defined herein a "computer-readable storage medium," which refers to a non-transitory, physical or tangible storage medium (e.g., volatile or non-volatile memory device), may be differentiated from a "computer-readable transmission medium," which refers to an electromagnetic signal.

[0027] As defined herein, a "sample or target" may refer to any final product of an optical system, for example, a display of an AR system, a flat sheet during manufacturing, or etc.

[0028] As referred to herein, a light projector may be any light source that projects light used in augmented reality systems including, but not limiting to, a light point source or a laser scanning projector.

[0029] As referred to herein, diffraction may refer to an instance in which a beam of light or other system of waves is spread out as a result of passing through a narrow aperture or across an edge.

[0030] As referred to herein, light leakage may indicate an instance where a stray light is able to "leak" into a system passing through a system unaffected.

[0031] As referred to herein, +/-1st order diffraction may indicate a relationship between diffraction of a light and a series of beams to either side of the diffracted light at angles where light waves from adjacent slits reinforce each other, where the first bright image on either side occurs when the difference in the pathlength of the light form the adjacent slits of the aperture is the same wavelength.

[0032] As referred to herein, 0th order diffraction may refer to an instance in which a ray of light behaves according to the laws of reflection (like a mirror) and refraction (like a lens) respectively, where there is no diffraction of light (e.g., non-diffracted light) as a ray of light passes through an aperture.

[0033] As referred to herein, satellite diffraction orders may refer to any undesirable diffraction order of light in a system.

[0034] It is to be understood that the methods and systems described herein are not limited to specific methods, specific components, or to particular implementations. It is also to be understood that the terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting.

[0035] Head mounted displays (HMDs) including one or more near-eye displays may often be used to present visual content to a user for use in augmented reality (AR) applications. One type of near-eye display may include an enclosure that houses components of the display or is configured to rest on the face of a user, such as for example a frame. The near-eye display may include optical elements that polarize light from a projector to a location in front of the user's eye. Because of human visual sensitivity, slight deviations in optical quality may be apparent to the user of a near-eye display. Since these devices may be wearable, it may be important for the device to be lighter and energy efficient to optimize user experience.

[0036] Conventionally, the duplication method and the projection method may be used for manufacturing LCPH components. LCPHs may be used as photo masks to make target LCPH components (i.e., final components used in AR applications). Due to manufacturing control or intrinsic properties of LCPHs in short pitch, LCPH photo mask may experience 0^{th} order light leakage. When LCPH photo masks are used in manufacturing of target LCPH components, the target LCPH components may have satellite diffraction orders due to 0^{th} order light leakage from LCPH photo mask. The satellite diffraction orders may impact performance for many applications, including displays. Additionally, in conventional systems filters may not be applied to or on LCPH photo mask to filter out 0^{th} order light leakage because lights from LCPH photo mask have both $+1^{st}$ and -1^{st} diffraction order with orthogonal polarization state.

[0037] Conventionally, due to manufacturing control or intrinsic properties of LCPHs in short pitch, the LCPH components used in near-eye display systems (e.g., AR systems) may have 0^{th} order light leakage. One conventional method to absorb 0^{th} order light leakage may be to add a cleaning circular polarizer to the optical system to enhance the contrast ratio between the target diffraction order to 0^{th} order light leakage. In this conventional embodiment the conversion of light by LCPHs with both left-handed and right-handed polarization states may include absorption of the light with one or more cleaning circular polarizers. The addition of circular polarizers may transmit light with one polarization state while absorbing the 0^{th} order light leakage. In such embodiments, the cleaning circular polarizer may also absorb the target diffraction order light, reduce transmission of light, and reduce intensity of the light.

[0038] In view of the foregoing drawbacks, disclosed herein is a method that may address optical element structures to reflect or filter 0^{th} order light leakage, optical quality, light transmission, and light intensity for a high-powered lens. Proper reflection or filtering of 0^{th} order light within a display may allow for increased optical quality or image quality within an HMD system.

[0039] The present disclosure is generally directed to systems and methods for improved optical quality and battery consumption within augmented reality systems. As disclosed herein, an optical system may include a first optical element, a second optical element, and a reflective or filtering optical element. Where the second optical element (e.g., target PBP or PVH component) may be used in a display of a HMD configured to display images from a light projector to a user's eye(s).

[0040] FIG. 1 illustrates an example head-mounted display 100 associated with augmented reality content. The head mounted display (HMD) 100 may include enclosure 102 and a display assembly 104 coupled to the enclosure 102. The display assembly 104 may include a light projector 106 (shown in dashed lines in FIG. 1) and a waveguide 108 configured to direct images from the light projector 106 to a user's eye. In some examples, waveguide 108 may include a number of linear crystal polarization holograms (LCPHs) optical elements configured to separate diffracted light polarizations to enter the waveguide and a reflective optical element or a filtering optical element to isolate (filter or reflect) 0^{th} order diffracted light. In some examples, the light projector 106 may include three sub-projectors 106A, 106B, and 106C that are configured to project light of different wavelengths (e.g., colors such as red, green, or blue). The waveguide 108 may include input grating assembly 110 positioned adjacent to the light projector 106. The input grating assembly 110 may be configured to enable light from the light projector 106 to enter into the waveguide 108, to be directed to the center of the waveguide 108 for presentation to the user's eye. For example, as shown in FIG. 1, the input grating 110 may include three optical apertures respectively aligned with the three sub-projectors 106A, 106B, and 106C of the light projector 106.

[0041] In some examples, head-mounted display 100 may be implemented in the form of augmented-reality glasses. Accordingly, the waveguide 108 may be at least partially transparent to visible light to allow the user to view a real-world environment through the waveguide 108.

[0042] FIG. 2 illustrates the light projector 106 of the head-mounted display 100 shown in the dashed circle A of FIG. 1. The waveguide 108 is not shown in FIG. 2, to more clearly show underlying features of the head-mounted display 100. As shown in FIG. 2, the light projector 106 may be mounted on the enclosure 102 of the head-mounted display 100, such as in an upper corner of the enclosure 102. The first sub-projector 106A may include a blue light source, the second sub-projector 106B may include a red light source, and the third sub-projector 106C may include a green light source. Other colors and arrangements of the sub-projectors 106A, 106B, and 106C may also be possible.

[0043] To assemble the head-mounted display 100, the three sub-projectors 106A, 106B, and 106C may be initially assembled with each other (e.g., three light sources mounted to a common substrate, three collimating lenses aligned on the three light sources) to form the light projector 106 as a unit. The light projector 106 may include one or more projector fiducial marks 116, which may be used in optically aligning (e.g., positioning, orienting, or securing) the light projector 106 with the enclosure 102. In some examples, the enclosure 102 may likewise include one or more frame fiducial marks 118 to assist in the optical alignment of the light projector 106 with the enclosure 102.

[0044] Optical alignment of the light projector 106 relative to the enclosure 102 may involve viewing the light projector 106 or enclosure 102 during placement of the light projector 106 in or on the enclosure 102 with one or more cameras, which may be used to identify the location and orientation of the projector fiducial mark(s) 116 relative to the location and orientation of the frame fiducial mark(s) 118. The projector fiducial mark(s) 116 on both sides of the enclosure 102 may be used to balance the frame into a computer aided design (CAD)-nominal position. The projector fiducial mark(s) 116 and the enclosure fiducial mark(s) 118 are each shown in FIG. 2 in the shape of a plus sign. However, other shapes, physical features (e.g., of the light projector 106 or of the enclosure 102), reflective surfaces, or other optical identifiers may be used to optically align the light projector 106 relative to the enclosure 102.

[0045] FIG. 3 illustrates optical alignment of a projected pattern 302 as viewed by a camera. In some embodiments, the light projector 106 may be aligned relative to the frame 102 using an image projected by the light projector 106. The projected pattern 302 may be a cross or another pattern. The projected pattern 302 may be aligned with a camera target 304. The camera target 304 may be an area identified using computer vision (CV) to identify a center of the projected pattern 302 (e.g., the intersection of two lines if the projected pattern 302 is a cross). The camera may be calibrated to a global-equipment coordinate system such that the mechanical and optical position of the camera target 304 is optimized. The light projector 106 may be physically manipulated to align to the detected center of the projected pattern 302 (e.g., the camera target 304). The projected pattern 302 may be produced by a light projector, such as the light projector 106 described above. One or more cameras may view the projected pattern 302 and compare the location and orientation of the projected pattern 302 to the camera target 304. The light projector or a frame to which the light projector is to be mounted may be moved (e.g., laterally shifted, angled, rotated, etc.) to align the projected pattern 302 with the camera target 304 to an acceptable resolve (e.g., within an acceptable tolerance) before the light projector is fixed in position relative to the frame. An acceptable tolerance may be, for example, within 2 arcminutes (arcmin) between the projected pattern 302 and the camera target. Other acceptable tolerances (e.g., 3 arcmin, etc.) between the projected pattern 302 and the camera target may be possible.

[0046] FIG. 4 is a cross-sectional view of a head-mounted display 400 with alignment cameras 424. Alignment cameras 424 may also be artificial eyes or eyes of a user. In at least some respects, the head-mounted display 400 may be similar to the head-mounted display 100 described above. For example, the head-mounted display 400 may include a frame 402, and a display assembly 404 including a light projector 406 and a waveguide 408 mounted to the frame 402.

[0047] The alignment cameras 424 may be used during assembly of the head-mounted display 400 to optically align the light projector 406 with the frame 402 or to optically align the waveguide 408 with the light projector 406. For example, the alignment cameras 424 may be used to detect the location or orientation of a fiducial mark (e.g., the projector fiducial marks 116, the frame fiducial marks 118, etc.), a physical component or feature, a reflective material, etc. In additional examples, the alignment cameras 424 may be used to detect a location or orientation of a projected pattern (e.g., the projected pattern 302). This detected information may be used to adjust a position or orientation of the light projector 406 relative to the frame 402 or of the waveguide 408 relative to the light projector 406 or frame 402.

[0048] As shown in FIG. 4, a gap 426 may be between the waveguide 408 and the light projector 406. Thus, in some embodiments, the waveguide 408 and the light projector 406 may not be directly coupled to each other. Rather, the light projector 406 and the waveguide 408 may each be separately mounted to the frame 402. This may allow for adjustments in relative position or orientation between the light projector 406 and the waveguide 408.

[0049] The frame 402 and the light projector 406 may be used substantially aligned. For example, the frame 402 and the light projector 406 may be aligned such that, when viewed by a camera, a projected pattern produced by a light projector 406 and a camera target (e.g., projected pattern 302 and camera target 304 in FIG. 3) are within an acceptable tolerance (e.g., 2 arcmin, 3 arcmin, etc.).

[0050] FIG. 5A is a block diagram illustrating an example of a resultant image produced from a light source 206 being projected through a PBP lens 204. Light source(s) 206 (e.g., a red-green-blue (RGB) laser beam) when passing through PBP lens 204 may cause diffraction orders. These diffraction orders may be seen in the resultant image 200, as “ghost” images may be created. PBP lens 204 may be using a multiple duplication process used in manufacturing of target PBP or PVH components used in HMD displays. In an exemplary embodiment, the system may have a range of diffractive light orders or particular orders of diffraction (e.g., 1st diffraction order) to display the proper image, whereas diffraction light orders outside of the particular range of wanted diffraction light orders may disrupt or alter the image. These “ghost” images may be due to unwanted diffractive light orders resulting from light, via light source(s) 206, being diffracted through PBP lens 204. “Ghost” images may appear to be blurry regions on the resultant image 200, creating an image with reduced quality. In the resultant image 200, these “ghost” regions may be classified as alternate or multiple images of the desired image having different focal lengths from the target diffraction order range.

[0051] FIG. 5B illustrates an example of diffraction orders created as light diffracts through PBP lens 204 of FIG. 5A. Light source(s) 206 as shown in FIG. 5A when projecting or diffracting through PBP lens 204, that may have undergone the multiple duplication process, may cause target 1st diffraction orders 208. The light source(s) 206 passing or diffracting through PBP lens 204 may also cause satellite diffraction orders 210 because there may be 0th order light leakage resulting from the 1st PBP mask used in the multiple duplication process. More diffraction orders may be created from the 0th order light as the ray of light passes through another PBP mask used in the multiple duplication process.

[0052] FIG. 6A is a graph 600 illustrating the efficiency of PBP components at different thicknesses. Graph 600 shows how the thickness control of PBP and a submicron difference in thickness may affect the diffraction orders output from PBP masks, where 0th order diffracted light (e.g., line 601) and +/- 1st order light (e.g., line 602). Now referring to FIG. 6B, a graph 605 illustrating diffraction efficiency of PBP as grating pitch is increased. It is shown that conventionally, as grating pitch is increased, there may be increased diffraction efficiency of the targeted +/-1st diffraction order light (e.g., line 603) whereas as grating pitch is increased there may be less diffraction efficiency 0^{th} diffraction order light (e.g., line 604). Conventionally, in systems where the pitch is large the light may be of 1^{st} order diffraction (e.g., line 603). Although a system with large pitch may output more of the targeted diffraction order (1^{st} order), such systems may lack lens power. Conventionally, methods such as duplication are used to create a smaller pitch thus allowing for a high-powered lens, but greatly increased 0^{th} order diffraction. It may be beneficial to absorb the 0^{th} light order diffractions for optimal image quality.

[0053] FIG. 7A is a diagram illustrating manufacturing duplication process to make small pitch PBP grating photo mask. The light source (e.g., light projector 106) may generate light 706 (e.g., an RGB laser beam). As can be seen in FIG. 7A, due to the specific design of the PBP grating photo masks of the exemplary embodiment, having specific pitches, distinct polarization states are created as the ray of light passes through each PBP mask. PBP masks may diffract light 706 by half wave shifts causing diffraction orders such as +/- 0.5th Order for every PBP mask in the duplication process. For optimal image quality light 706 may be diffracted to obtain +/- 1^{st} order diffraction, where light 706 may be diffracted using the duplication process and other methods such as the projection method.

[0054] PBP optical components may be configured to receive unpolarized light, where light may comprise two oppositely polarized components with equal or substantially equal intensities, e.g., a right-handed circular polarization component (RHC) or left-handed circular polarization (e.g., LHC) component. PBP grating photo mask may be any optical component such as a lens, grating, or any combination thereof. PBP grating photo mask (PBP mask) may be configured to split light 706 in a first direction into two separate lights, a first polarization (e.g., RHC), where the first polarization light is transmitted by the PBP mask in a second direction, and a second polarization (e.g., LHC) in a third direction, opposite of the second polarization where the second polarization is transmitted by the PBP mask in a third direction different from the second direction, as shown in FIG. 7A. In FIG 7A, light 706 may be projected through a PBP mask having the first polarization (e.g., RHC), light having the second polarization (e.g., LHC). In some embodiments, PBP mask may function to reverse the polarizations of both the RHC component of light 706 and LHC component of light 706 and redirect these components into the second direction and the third direction, respectively. In some embodiments, the second direction of RHC corresponds to $+1^{st}$ order diffraction 707 of light 706 and the third direction of light of LHC corresponds to -1^{st} order diffraction 708 of light 706. In some embodiments, the PBP optical element may be a polarization volume holographic (PVH) optical element. With every PBP optical component used in duplication method, the grating pitch may be adjusted by half wave phase shifts, so if duplicated multiple times the final gradient pitch may be small, thus creating a large deflection angle to create a high-power lens. Conversely, as the number of duplications increase there may be more satellite diffraction orders created.

[0055] FIG. 7B is a diagram illustrating the projection method to make a target PBP phot grating mask or target PBP component. The light source (e.g., light projector 106) may generate light 706 (e.g., an RGB laser beam). As can be seen in FIG. 7B, due to the specific design of the PBP mother mask 710 of the projection method, of an exemplary embodiment, having specific pitches at a controlled magnified rate of pitch, specific polarization states are created as the ray of light passes through a projection lens system 712.

[0056] FIG. 8A illustrates an optical system comprising optical elements in accordance with an exemplary embodiment. The optical system 800 may include optical elements such as a narrow band angular reflector 802, PBP grating photo mask 801, and target PBP component 803. The light source (e.g., light projector 106) may generate light 806 (e.g., an RGB laser beam). As can be seen in FIG. 8A, PBP grating photo mask 801 of an exemplary embodiment, may have separated light 806 into +1st order diffraction order 804, - 1st order diffraction 805, and 0th order diffraction 807. Light 806 projected to narrow band angular reflector 802 may not allow (or a negligible portion) of 0th order light (e.g., non-diffracted light) to pass through to target PBP component 803. 0th order light (e.g., 0th order diffraction 807) may be referred to as light leakage, therefore narrow band angular reflector 802 may not allow for 0th order light leakage to be present in the optical system 800 or HMD 100. Narrow band angular reflector 802 may be a wavelength specific optical element designed to reflect diffractive light orders e.g., 0th order diffraction 807. In this regard, after 0th order light interacts with narrow band angular reflector 802, 0th order light leakage may reflect to PBP grating photo mask 801 such that 0th order light leakage does not occur within the optical system 800, thus stopping creation of diffraction orders caused by 0th order light.

[0057] As such, the light 806, entering the optical system 800, passing through optical elements e.g., PBP grating photo mask 801, narrow band angular reflector 802, and target PBP component 803 may not exhibit any energy loss or only exhibit negligible energy loss. For example, the rays of light 806 entering through the narrow band angular reflector 802 to target

PBP component 803 may not exhibit 0^{th} order diffraction 807. Narrow band angular reflector 802 may be a narrow band angular filter, cholesteric liquid crystal (CLC) reflector, holographic optical element (HOE) reflector, any reflective optical element, or any other suitable optical element that may reflect or filter 0^{th} order diffraction.

[0058] FIG. 8B illustrates an alternate embodiment of the optical system 800 of FIG. 8A in accordance with an exemplary embodiment. In FIG. 8B the alternate optical system 820 illustrates an embodiment in which the narrow band angular reflector is a narrow band angular filter 810. In the example embodiment, a lens 822 is contemplated, as such the orientation of the lens 822 may be zoned due to properties of lens 822 properties when light 806 is focused on the center of the lens 822, the light polarization direction does not change. Narrow band angular filter 810 may be a wavelength specific optical element filter designed to filter diffractive light orders e.g., 0^{th} order diffraction 815. Lens 822 may be configured so that as light 806 is projected through the center of the PBP lens mask 808 to lens 822 0^{th} order diffraction and the +/-1^{st} order diffraction are the same, meaning the properties of light (e.g., light 806) will not change in the center region of lens 822. Thus, a narrow band angular filter 810 may not work at the center of lens 822 in respect to the center of PBP lens mask 808. As such, lens 822 may be zoned, relative to the center of the PBP lens mask 808 where lens 822 may not have a light altering optical element allowing for light to pass through the center of lens 822, referred to as a center zone 816. Center zone 816 (or no filter zone) of lens 822 may be any isotropic material, translucent material, or any material that allows light 806 to pass through the lens 822 without altering the lights properties. Positioned on opposite sides of the center zone 816 of lens 822 relative to opposite sides of PBP lens mask 808 center, closer to the edge of the PBP lens mask 808, there may be zones for narrow band angular filter 810 to filter 0^{th} order light 815 from light 806. Optical quality may not be affected by the no filter zone or center zone 816. In zones comprising of angular filters 810, +1^{st} order light diffraction 813 and -1^{st} order light diffraction 814 may be transmitted to target PBP lens component 812. Target PBP lens component 812 may receive light 806 through the center zone 816 and +/- 1^{st} order light diffractions 813, 814. Narrow band angular filter 810 may be any optical element filter that filter diffraction orders.

[0059] FIG. 9 illustrates transmittance in incident angle of the optical system of FIG. 8A in accordance with an exemplary embodiment. The graph 900 illustrates transmission of light for a narrow band angular reflector 802 (e.g., line 901) and a conventional system (e.g., line 902).

Narrow band angular reflector 802 may be configured to allow +/- 1st order diffraction 804, 805 to transmit to the target PBP component 803 and reflect 0th order diffraction 807. Transmission of 0th order diffraction 807 in the optical system 800 is almost zero for 0th order diffracted light (e.g., 807), meaning there is almost no light 806 of 0th order diffraction 807 coming out of the narrow band angular reflector 802. Instead in such systems, +/- 1st order diffracted light 804, 805 may come out of the narrow band angular reflector 802. Transmittance of light for narrow band angular filter 802 may also allow for increased transmission (e.g., line 901) of light 806 when compared to conventional systems (e.g., line 902). Conventional systems (e.g., line 902), as shown in graph 900, may allow for its highest transmission rates of light 806 for 0th order diffractions, where transmission rates may be at it the lowest point of line 902 for +/-1st order diffractions. Thus, in conventional systems there may be substantial light leakage from 0th order light and satellite diffractions.

[0060] FIG. 10 illustrates a graph 1000 indicating diffraction efficiency at different diffractive orders of light of the optical system of FIG. 8 with conventional systems using methods and processes of FIG. 7 in accordance with an exemplary embodiment. For graph 1000 two systems were used: one system using a CLC reflector, and a conventional system without a CLC reflector. Looking at the diffraction efficiency of CLC reflector (e.g., bars 1001), the CLC reflector reflects 0th order diffraction to a point where the diffraction efficiency is zero, whereas, +/- 1st order diffraction passes through the reflector with the same diffraction efficiency as conventional system without the CLC reflector (e.g., bars 1002). The diffraction efficiency at +/- 1st order diffractions for both systems may be similar to because there is no extra absorption in our CLC reflector. Whereas the system with the CLC reflector (e.g., bars 1001) blocks (or reflects) the 0th order diffractions (or 0th order light leakage) that occurs in nature. Conventional systems (e.g., bars 1002) may allow for some light leakage from 0th order light being able to diffract through conventional systems. In accordance with the graph 1000, Table 1 illustrates Stokes parameters S1, S2, and S3 that may be found. Stokes parameters may be used to describe the polarization states of light. For Table 1, stokes parameter values are shown for left-handed circular polarized light. Table 1 illustrates the polarization of output light at S3 is where the system is closed to -1st order diffracted light, and S1 and S2 is where the system was closed to 0th order light. Based off the values determined with and without the CLC reflector the output does not change (or has negligible difference) by the addition of a CLC reflector to the system.

Table 1:

	No CLC Reflector	With CLC Reflector
S1	0	0.003
S2	0	-0.007
S3	-1	-0.999

[0061] FIG. 11 is a diagram of an example of a cleaning circular polarizer with a LCPHs lens 1108. In FIG.11, the circular polarizer 1110 may include retarders 1111 and linear polarizer 1112. Conventionally, circular polarizer(s) 1110 may be added to optical systems after the use of methods and processes described above and shown in FIG. 7. Light 1106 (e.g., RGB laser beam and light source 706) may be introduced to the optical system 1100 and transmitted through a LCPHs lens 1108, where light 1106 may be diffracted into 0th order diffracted light 1107 and +1 order diffracted light 1109. Although only +1st order diffracted light 1109 is illustrated it can be contemplated that -1st order diffracted light is also in the optical system 1100. When the diffracted lights transmit through circular polarizer 1110 there may be light leakage from 0th order diffracted light1107 (e.g., 0th order diffraction 807) and absorption of some of the target +1st order diffracted light 1109. Due to the properties of linear polarizer 1112, linear polarizer 1112 may absorb some of the 1st order diffracted light 1109, thus reducing light transmission of 1st order diffracted light.

[0062] FIG. 12 is a diagram of an exemplary embodiment of an angular reflector 1210 with a LCPHs lens 1208. As shown in FIG 12, narrow band angular reflector 1210 may reflect 0th order light diffraction 1207 (e.g., 0th order diffraction 807) from 2D light source(s) 1206 (e.g., light source 106) as light, via light source 1206, diffracts through LCPHs lens 1208. Narrow band angular reflector 1210 may be configured to reduce 0th order light leakage (e.g., 0th order diffraction 1207) from LCPH lens to improve quality of light (e.g., 806) transmission of wanted range of diffraction orders through the target LCPH components. Narrow band angular filters or reflectors may reduce 0^{th} order diffraction light and not reduce 1^{st} order diffraction light of LCPHs components.

[0063] Narrow band angular reflectors or narrow band angular filters may provide improved system performance and increased image quality due to reducing 0^{th} order diffracted light from target LCPH components. In turn, the reduction in 0^{th} order light leakage may improve system performance due to less processing power needed to lower heat in the system, that may be conventionally caused by light leakage. The system may have increased image quality associated with a sharper image (or clarity) due a higher contrast ratio between signal light and noise light (e.g., 0^{th} order light).

[0064] FIG. 13 illustrates an example augmented reality system 1300. The augmented reality system 1300 may include a head-mounted display (HMD) 1310 (e.g., smart glasses) comprising a frame 1312, one or more displays 1314, and a computing device 1308 (also referred to herein as computer 1308). The displays 1314 may be transparent or translucent allowing a user wearing the HMD 1310 to look through the displays 1314 to see the real world (e.g., real world environment) and displaying visual augmented reality content to the user at the same time. The HMD 1310 may include an audio device 1306 (e.g., speakers/microphones) that may provide audio augmented reality content to users. The HMD 1310 may include one or more cameras 1316, 1318 which may capture images or videos of environments. In one exemplary embodiment, the HMD 1310 may include a camera(s) 1318 which may be a rear-facing camera tracking movement or gaze of a user's eyes.

[0065] One of the cameras 1316 may be a forward-facing camera capturing images or videos of the environment that a user wearing the HMD 1310 may view. The HMD 1310 may include an eye tracking system to track the vergence movement of the user wearing the HMD 1310. In one exemplary embodiment, the camera(s) 1318 may be the eye tracking system. In some exemplary embodiments, the camera(s) 1318 may be one camera configured to view at least one eye of a user. In some other exemplary embodiments, the camera(s) 1318 may include multiple cameras viewing each of the eyes of a user to enhance the capture of an image(s). The HMD 1310 may include a microphone of the audio device 1306 to capture voice input from the user. The augmented reality system 1300 may further include a controller 1304 comprising a trackpad and one or more buttons. The controller 1304 may receive inputs from users and relay the inputs to the computing device 1308. The controller 1304 may also provide haptic feedback to one or more users. The computing device 1308 may be connected to the HMD 1310 and the controller 1304 through cables or wireless connections. The computing device 1308 may control the HMD 1310 and the controller 1304 to provide the augmented reality content to and receive inputs from one or more users. In some example embodiments, the controller 1304 may be a standalone controller 1304 or integrated within the HMD 1310. The computing device 1308 may be a standalone host computer device, an on-board computer device integrated with the HMD 1310, a mobile device, or any other hardware platform capable of providing augmented reality content to and receiving inputs from users. In some exemplary embodiments, HMD 1310 may include an artificial reality system/virtual reality system.

[0066] The foregoing description of the embodiments has been presented for the purpose of illustration; it is not intended to be exhaustive or to limit the patent rights to the precise forms disclosed. Persons skilled in the relevant art may appreciate that many modifications and variations are possible in light of the above disclosure.

[0067] Embodiments also may relate to a product that is produced by a computing process described herein. Such a product may comprise information resulting from a computing process, where the information is stored on a non-transitory, tangible computer readable storage medium and may include any embodiment of a computer program product or other data combination described herein.

[0068] The language used in the specification has been principally selected for readability and instructional purposes, and it may not have been selected to delineate or circumscribe the inventive subject matter. It is therefore intended that the scope of the patent rights be limited not by this detailed description, but rather by any claims that issue on an application based hereon. Accordingly, the disclosure of the embodiments is intended to be illustrative, but not limiting, of the scope of the patent rights, which is set forth in the following claims.

[0069] Herein, “or” is inclusive and not exclusive, unless expressly indicated otherwise or indicated otherwise by context. Therefore, herein, “A or B” means “A, B, or both,” unless expressly indicated otherwise or indicated otherwise by context. Moreover, “and” is both joint and several, unless expressly indicated otherwise or indicated otherwise by context. Therefore, herein, “A and B” means “A and B, jointly or severally,” unless expressly indicated otherwise or indicated otherwise by context.

WHAT IS CLAIMED:

1. A device comprising:

at least one light source configured to generate a first light in a first direction;

a first optical element configured to receive the first light and diffract the first light into a second light;

a reflective optical element positioned relative to the first optical element so that the reflective optical element receives the second light transmitted through the first optical element, wherein:

the reflective optical element reflects at least a portion of the second light received, and

some of the second light is transmitted through the reflective optical element, creating a third light, and

a second optical element positioned relative to the reflective optical element so that the second optical element receives the third light transmitted through the reflective optical element, wherein:

the third light comprises a first diffracted light and a second diffracted light, and

the third light transmitted through the second optical element projects an image.

2. The device of claim 1, wherein:

the first optical element and the second optical element are liquid crystal polarization hologram optical elements, and

the first optical element is a Pancharatnam Berry phase (PBP) grating photo mask, and the second optical element is a target PBP component, and

the first optical element is a geometric phase optical element configured to perform half wave phase shifts for light.

3. The device of claim 1, wherein the second light comprises the first diffracted light, the second diffracted light, and a non-diffracted light.

4. The device of claim 3, wherein the first diffracted light has a first circular polarization in a second direction distinct from the first direction, the second diffracted light has a second

circular polarization in a third direction distinct from the first direction, and the non-diffracted light in the first direction with no circular polarization.

5. The device of claim 4, wherein the second direction corresponds to $+1^{st}$ order diffraction, the third direction corresponds to -1^{st} order diffraction, and the first direction corresponds to 0^{th} order diffraction.

6. The device of claim 1, wherein the reflective optical element is a wavelength specific optical element designed to reflect diffractive light orders.

7. The device of claim 1, wherein the reflective optical element is designed to isolate and transmit +/-1st order diffracted light while reflecting 0th order diffracted light.

8. The device of claim 1, wherein the reflective optical element reflects some of 0th order diffracted light to the first optical element.

9. The device of claim 1, wherein the first diffracted light and the second diffracted light are transmitted through the reflective optical element and transmitted to the second optical element.

10. A device comprising:

at least one light source configured to generate a first light in a first direction;

a first optical element configured to receive the first light and diffract the first light into a second light;

a lens positioned relative to the first optical element so that the lens receives the second light transmitted through the first optical element, the lens comprises a center and at least one optical element filter, wherein:

the optical element filter, filters at least a portion of the second light, and

the center allows the first light to transmit through the lens, and

some of the second light is transmitted through the optical element filter, creating a third light, and a second optical element positioned relative to the lens so that the second optical element receives the third light transmitted through the optical element filter and the first light transmitted through the center of the lens, wherein:

The third light comprises a first diffracted light and a second diffracted light, and

The third light and the first light transmitted through the lens to the second optical element projects an image.

11. The device of claim 10, wherein the center comprises any material allowing the first light to transmit through the lens without diffraction.

12. The device of claim 10, wherein:

the first optical element and the second optical element are liquid crystal polarization hologram optical elements, and

the first optical element is a Pancharatnam Berry phase (PBP) lens mask, and the second optical element is a target PBP lens component.

13. The device of claim 10, wherein the lens is zoned comprises a first zone, a second zone, and a third zone, wherein:

the second zone is positioned centrally at the center of the lens, and

the first zone and third zone are positioned on opposite sides of the second zone of the lens.

14. The device of claim 10, wherein the second light comprises the first diffracted light, the second diffracted light, and a non-diffracted light.

15. The device of claim 14, wherein the first diffracted light has a first circular polarization in a second direction distinct form the first direction, the second diffracted light has a second circular polarization in a third direction, and the non-diffracted light in the first direction with no circular polarization.

16. The device of claim 15, wherein the second direction corresponds to +1st order diffraction, the third direction corresponds to -1st order diffraction, and the first direction corresponds to 0th order diffraction.

17. The device of claim 10, wherein the optical element filter is a wavelength specific optical element designed to filter diffractive light orders.

18. The device of claim 13, wherein the optical element filter, positioned in the first zone and the third zone, is designed to isolate, and transmit +/- 1^{st} order diffracted light while filtering 0^{th} order light diffractions.

19. The device of claim 10, wherein the optical element filter filters some 0^{th} order diffracted light.

20. The device of claim 10, wherein second zone allows the first light to transmit to the second optical element unpolarized and without diffraction.

ABSTRACT OF THE DISCLOSURE

Methods and systems for using narrow band angular filters or reflectors to reflect or filter out satellite diffraction orders for manufacturing of target optical components to propagate target diffraction orders into a waveguide are provided. The system may include a light source for directing light into a liquid crystal polarization hologram (LCPH) optical element. The optical system may include at least one LCPH optical element that polarizes light and a narrow band angular filter or reflector. The LCPH may receive one or more rays of light associated with the light from a light source and may diffract the rays of light. The rays of light may be directed to a narrow band angular filter or reflector to filter or reflect satellite diffraction orders and allow target diffraction orders to be transmitted on a final sample or target component (e.g., display of a HMD, or any augmented reality device).

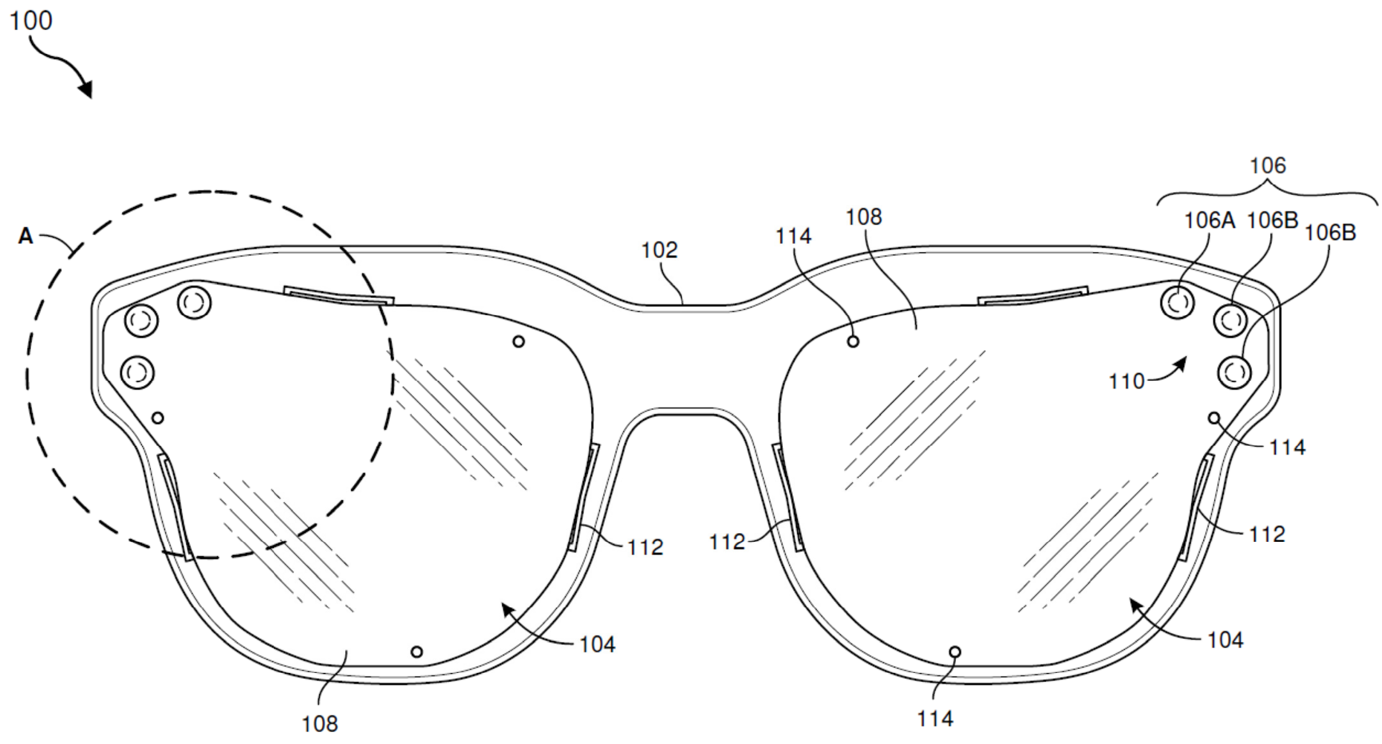

100
106
A
106A
106B
106B
108
102
114
110
114
112
112
112
104
104
108
114

FIG. 1

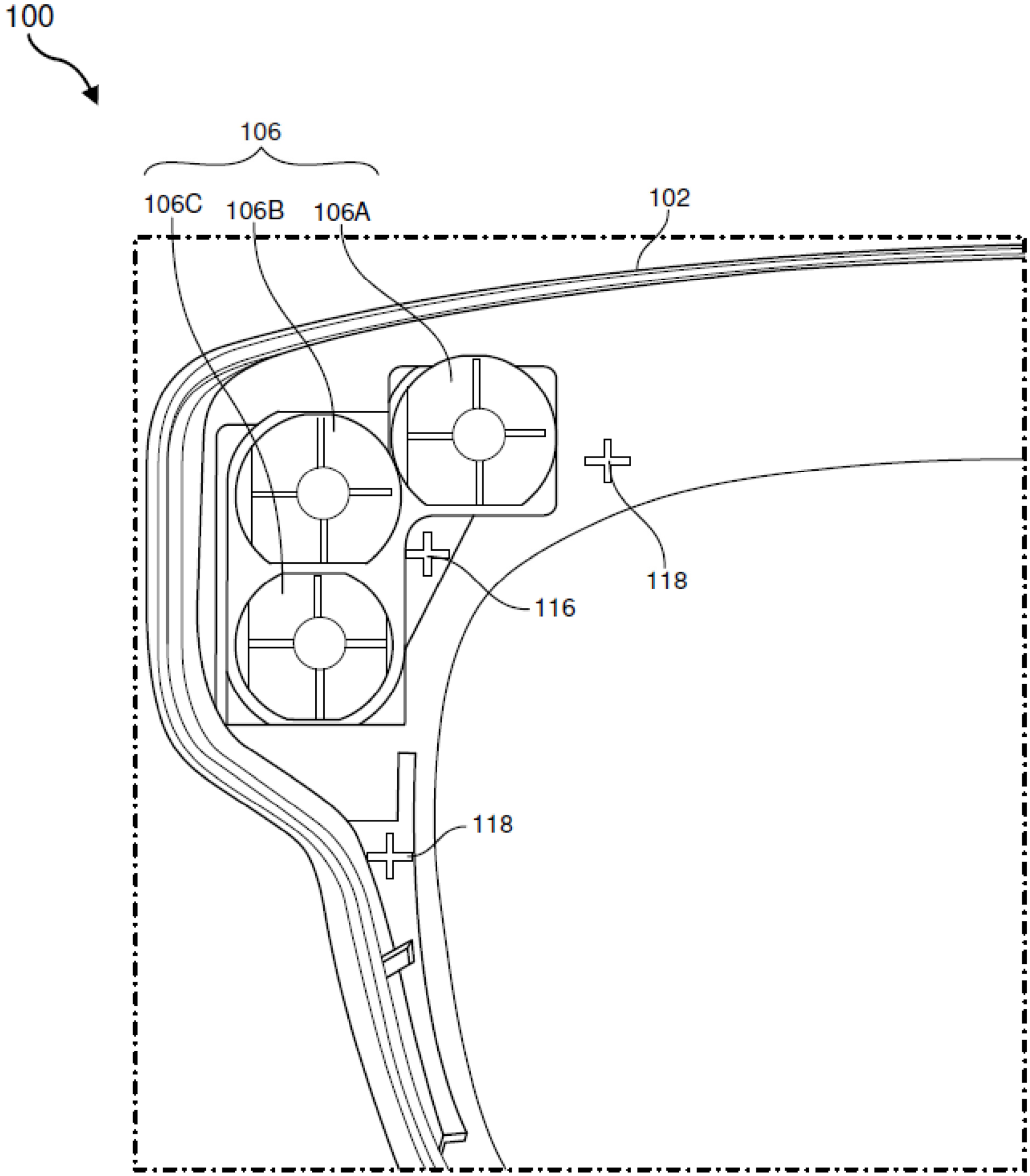


FIG. 2

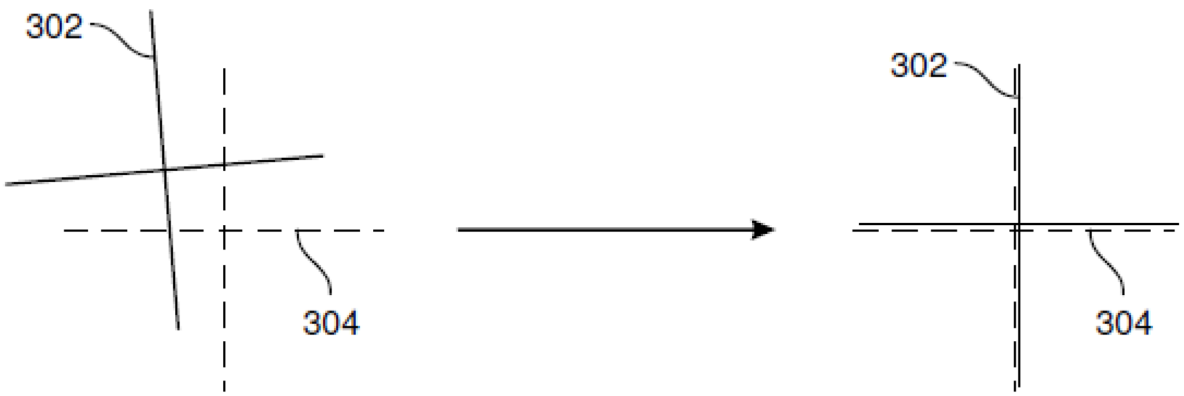


FIG. 3

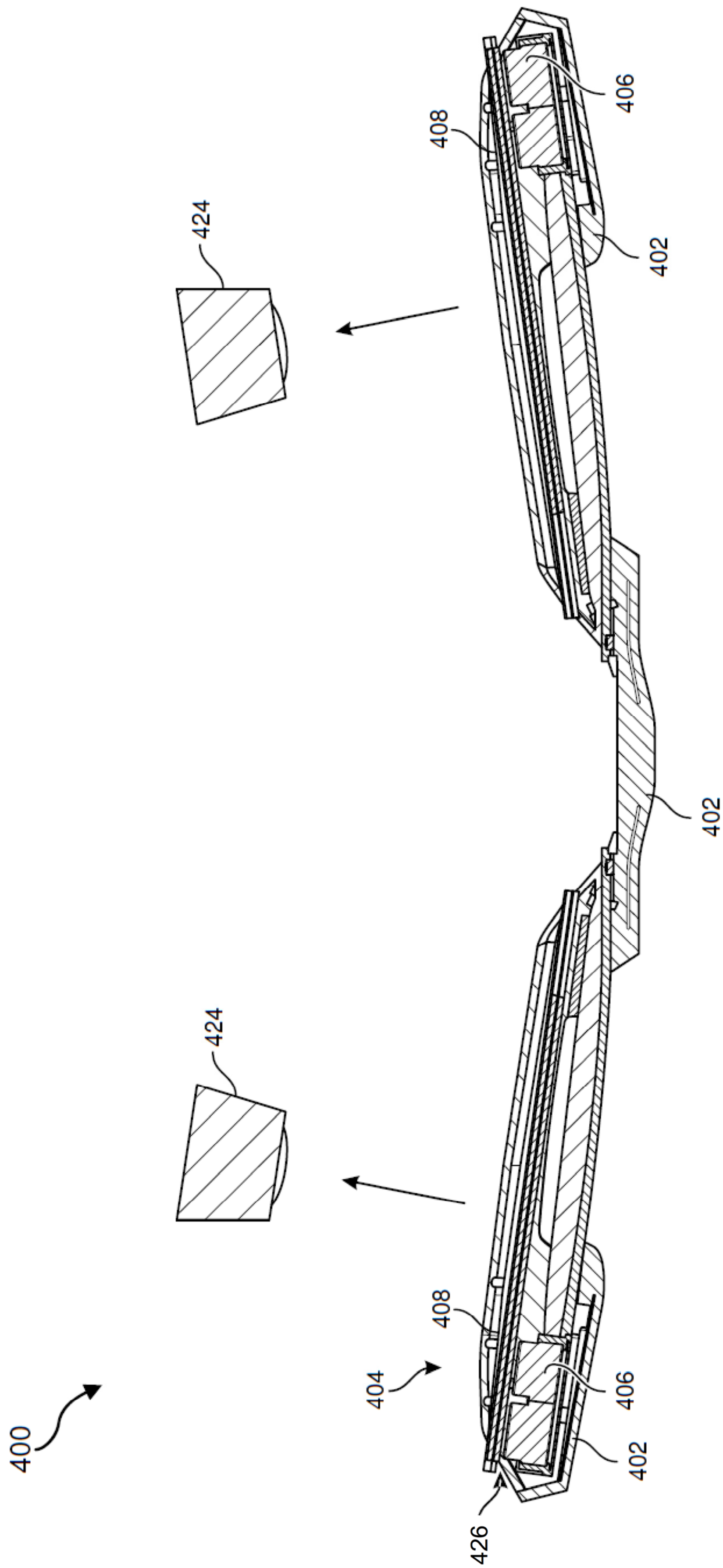


FIG. 4

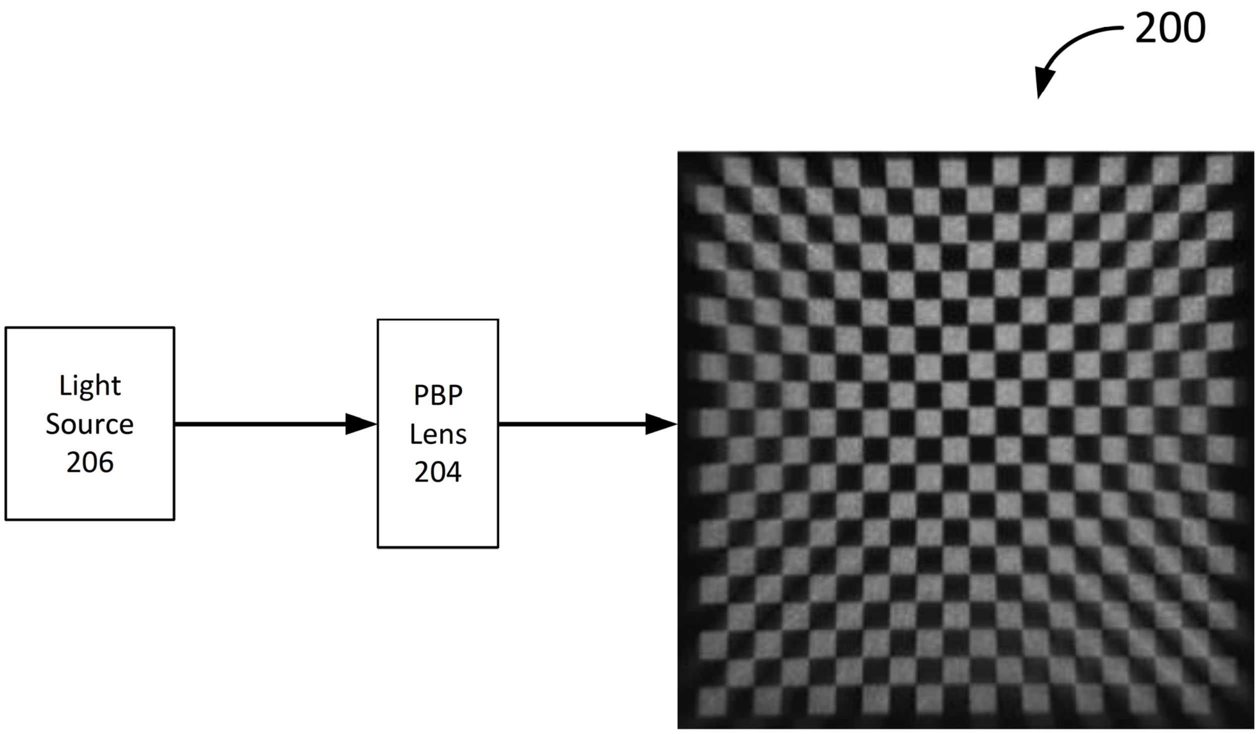


FIG. 5A

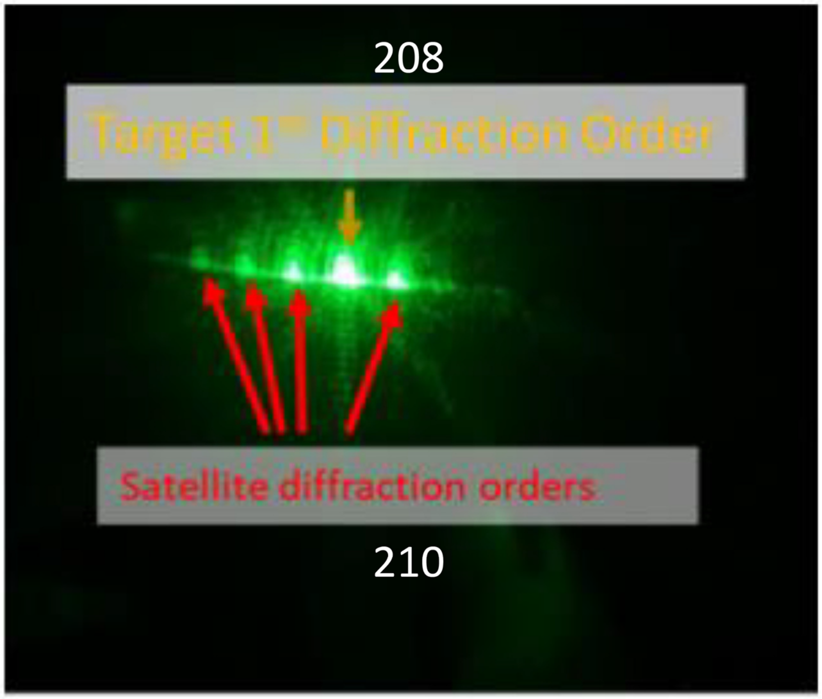

208
Target 1st Diffraction Order
Satellite diffraction orders
210

FIG. 5B

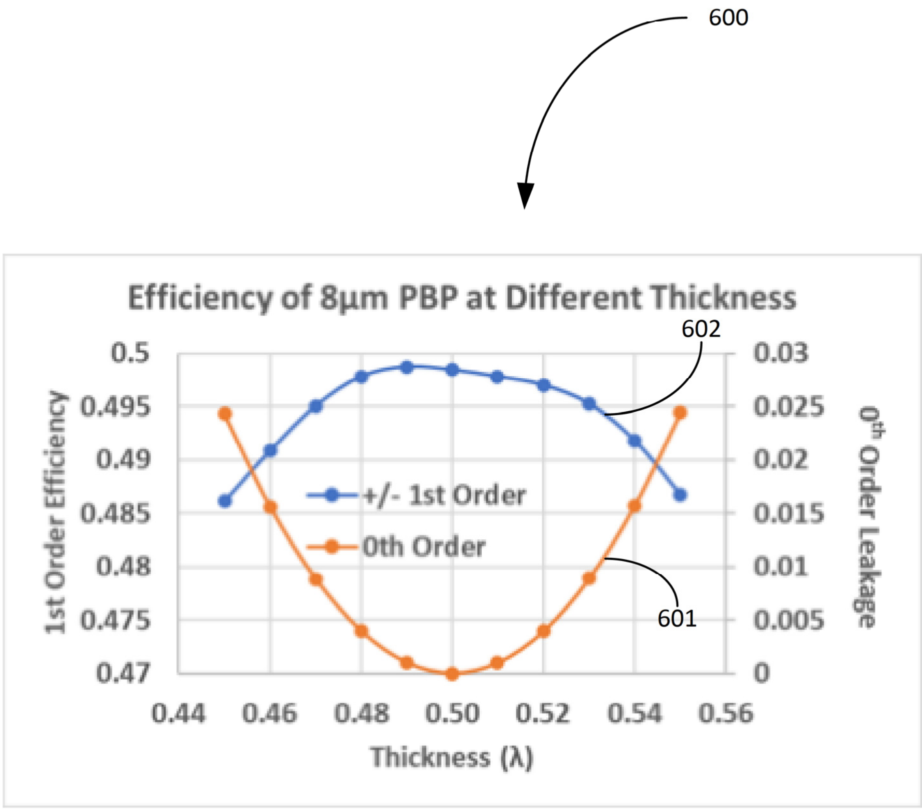

600
Efficiency of 8µm PBP at Different Thickness
602
601
1st Order Efficiency
0th Order Leakage
Thickness (λ)
+/- 1st Order
0th Order
0.5
0.495
0.49
0.485
0.48
0.475
0.47
0.03
0.025
0.02
0.015
0.01
0.005
0
0.44
0.46
0.48
0.50
0.52
0.54
0.56

FIG. 6A

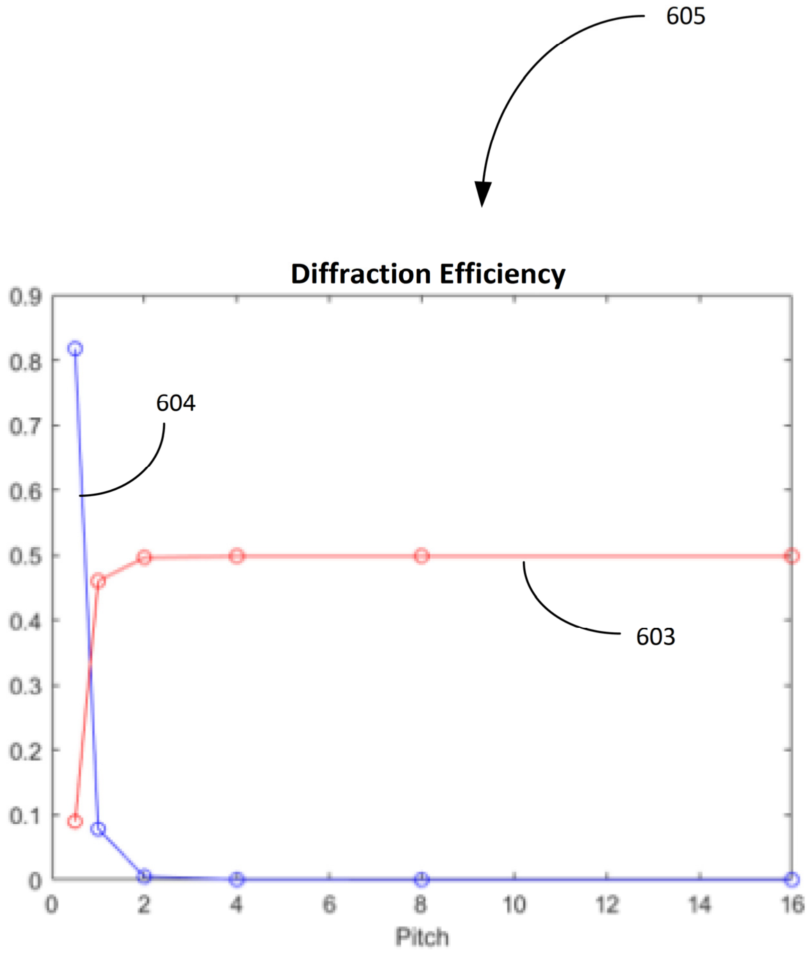

605
Diffraction Efficiency
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
604
603
0
2
4
6
8
10
12
14
16
Pitch

FIG. 6B

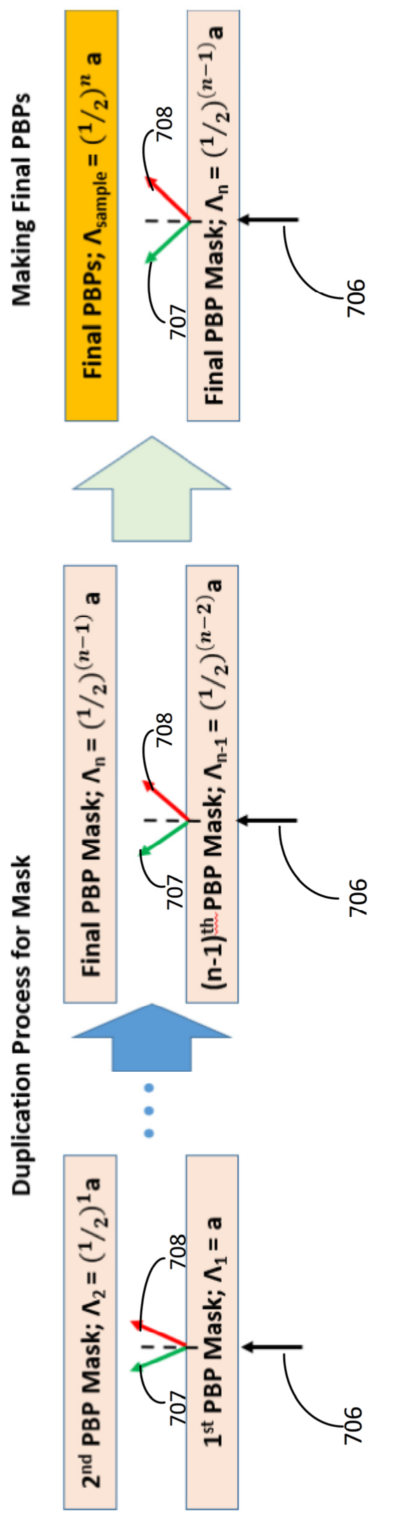

Duplication Process for Mask
Making Final PBPs
2nd PBP Mask; $\Lambda_2 = (^1/_2)^1$a
1st PBP Mask; Λ_1 = a
Final PBP Mask; $\Lambda_n = (^1/_2)^{(n-1)}$ a
(n-1)th PBP Mask; $\Lambda_{n-1} = (^1/_2)^{(n-2)}$ a
Final PBPs; $\Lambda_{sample} = (^1/_2)^n$ a
Final PBP Mask; $\Lambda_n = (^1/_2)^{(n-1)}$ a
706
707
708

FIG. 7A

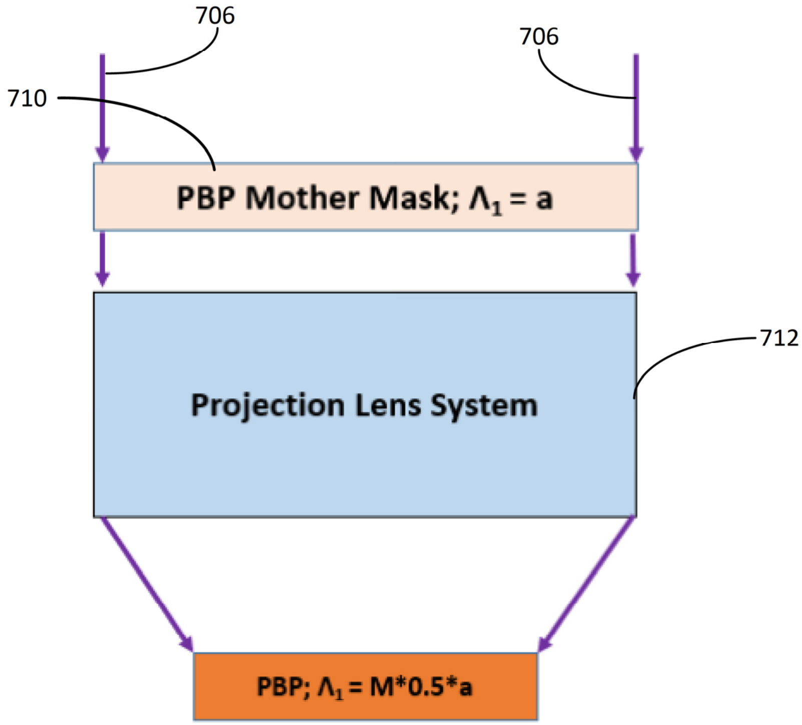

706
706
710
PBP Mother Mask; Λ1 = a
Projection Lens System
712
PBP; Λ1 = M*0.5*a

FIG. 7B

- 31 -

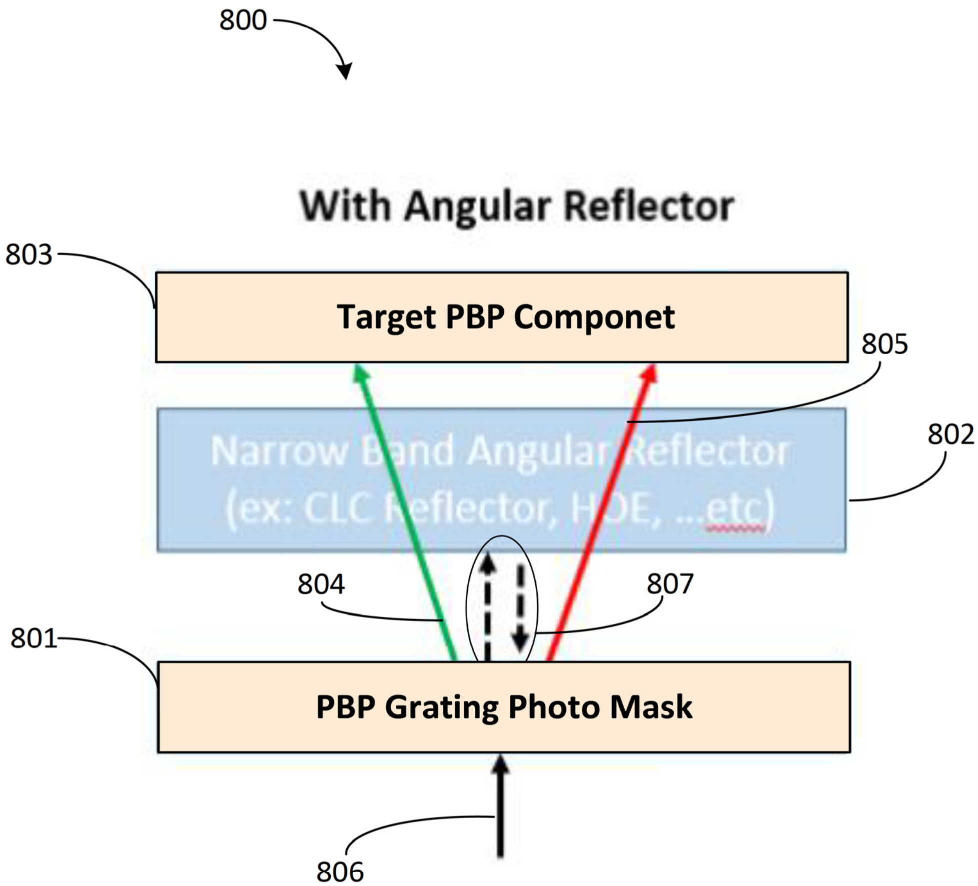
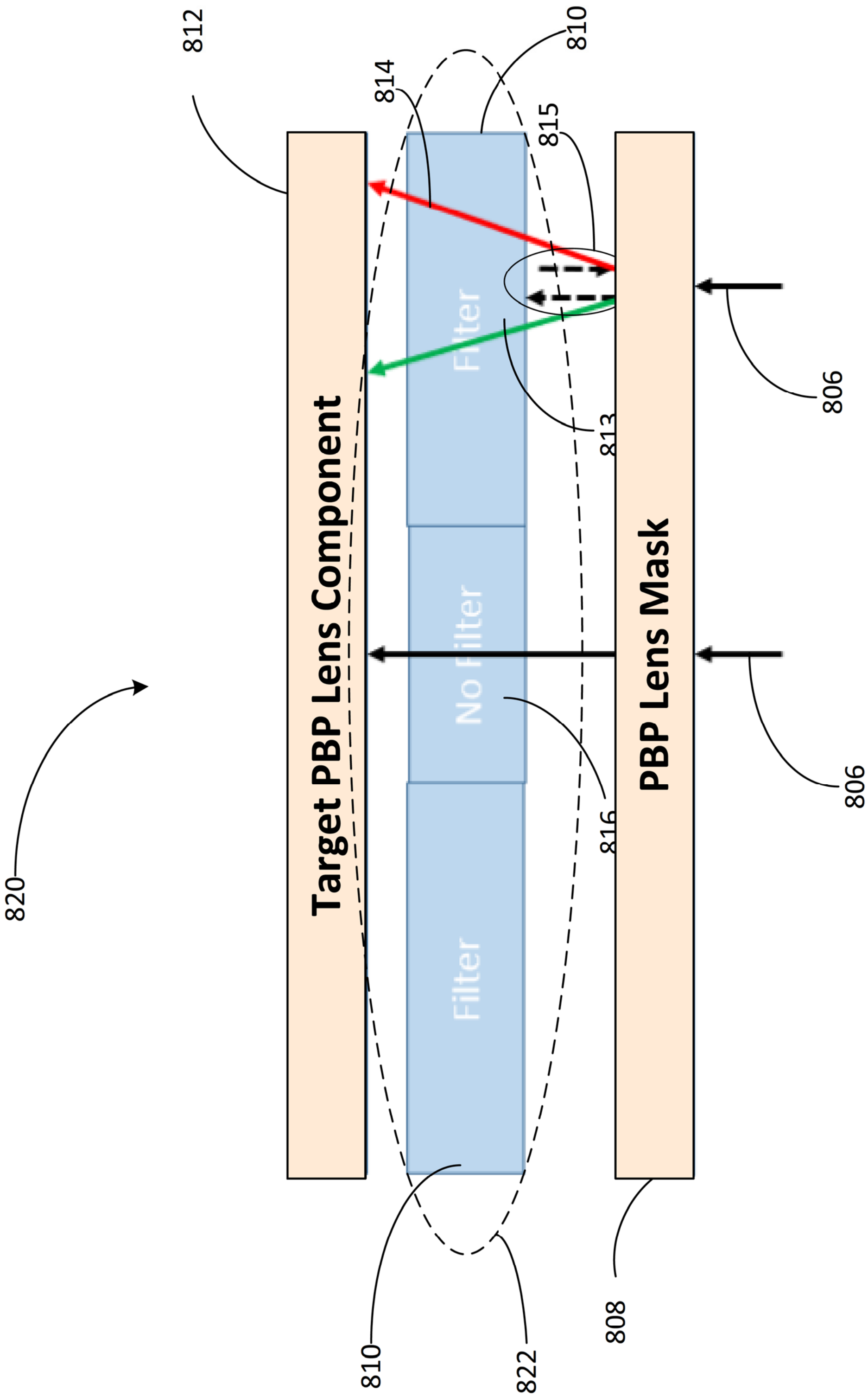

800
With Angular Reflector
803
Target PBP Componet
805
Narrow Band Angular Reflector
(ex: CLC Reflector, HOE, ...etc)
802
804
807
801
PBP Grating Photo Mask
806

FIG. 8A



812
814
810
815
Filter
No Filter
Filter
Target PBP Lens Component
PBP Lens Mask
813
816
806
806
820
810
822
808

FIG. 8B

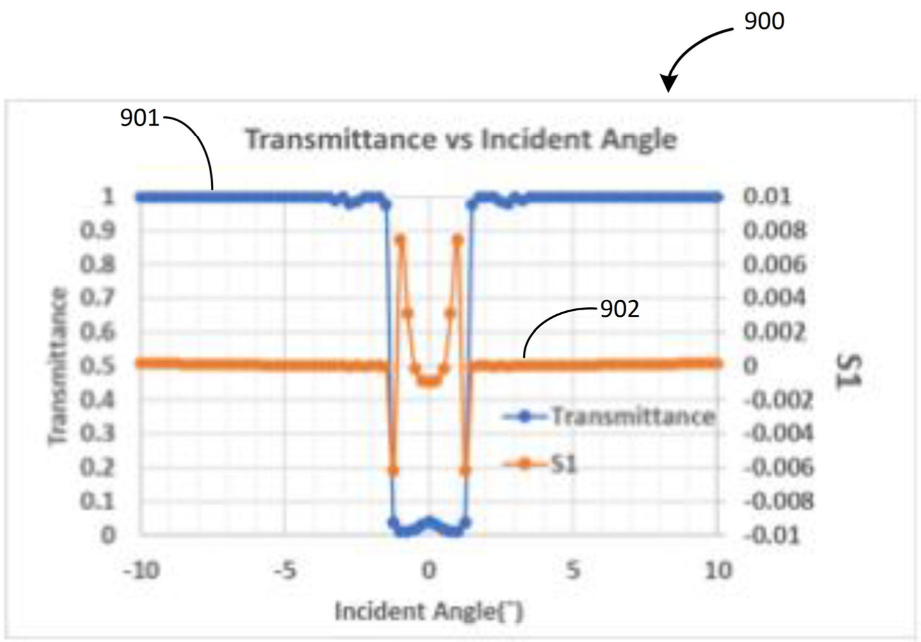

900
901
902
Transmittance vs Incident Angle
Transmittance
S1
Incident Angle(°)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.01
0.008
0.006
0.004
0.002
0
-0.002
-0.004
-0.006
-0.008
-0.01
-10
-5
0
5
10
Transmittance
S1

FIG. 9

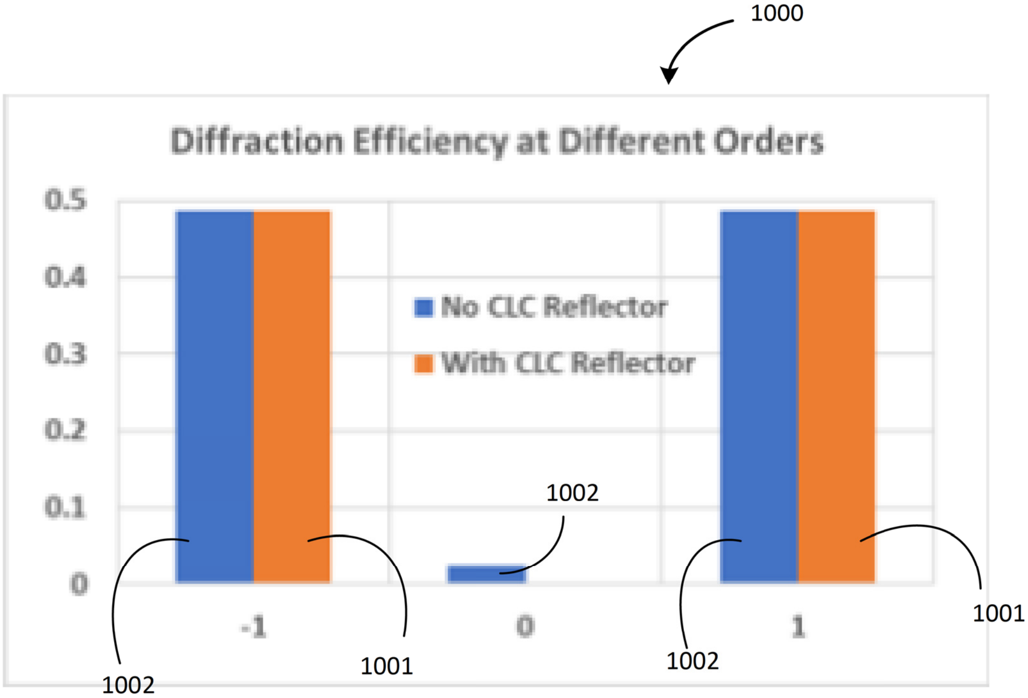

1000
Diffraction Efficiency at Different Orders
0.5
0.4
0.3
0.2
0.1
0
No CLC Reflector
With CLC Reflector
1002
-1
0
1
1002
1001
1002
1001

FIG. 10

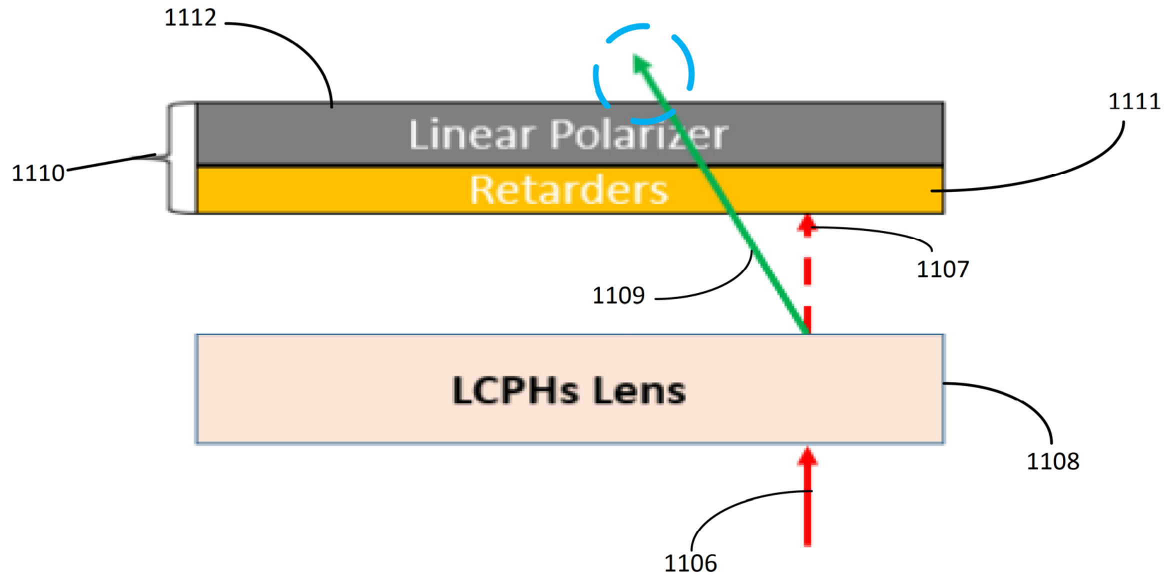

1112
1111
Linear Polarizer
1110
Retarders
1107
1109
LCPHs Lens
1108
1106

FIG. 11

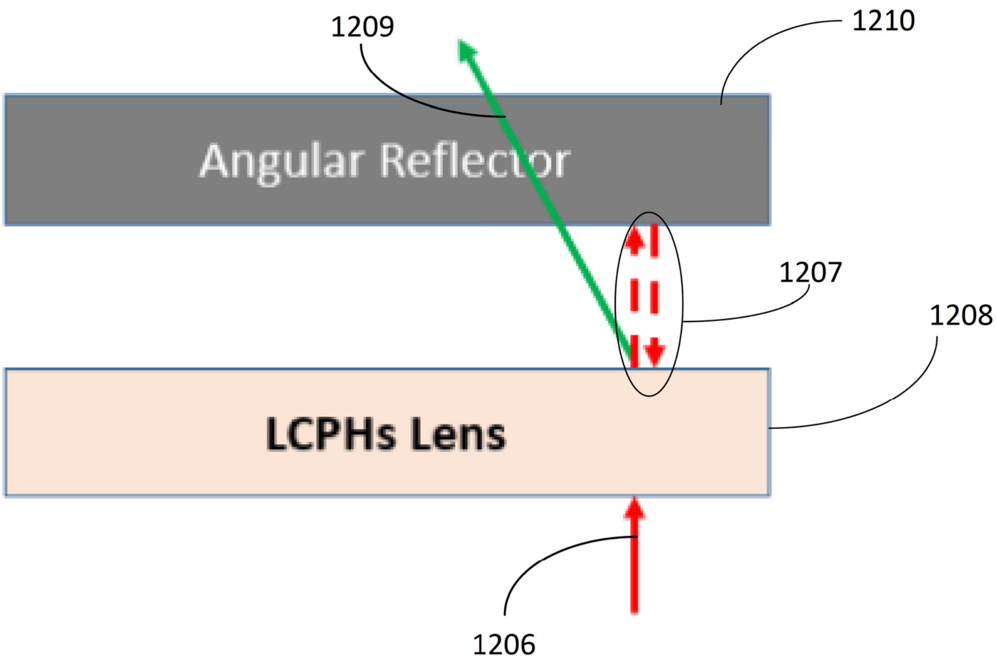


FIG. 12

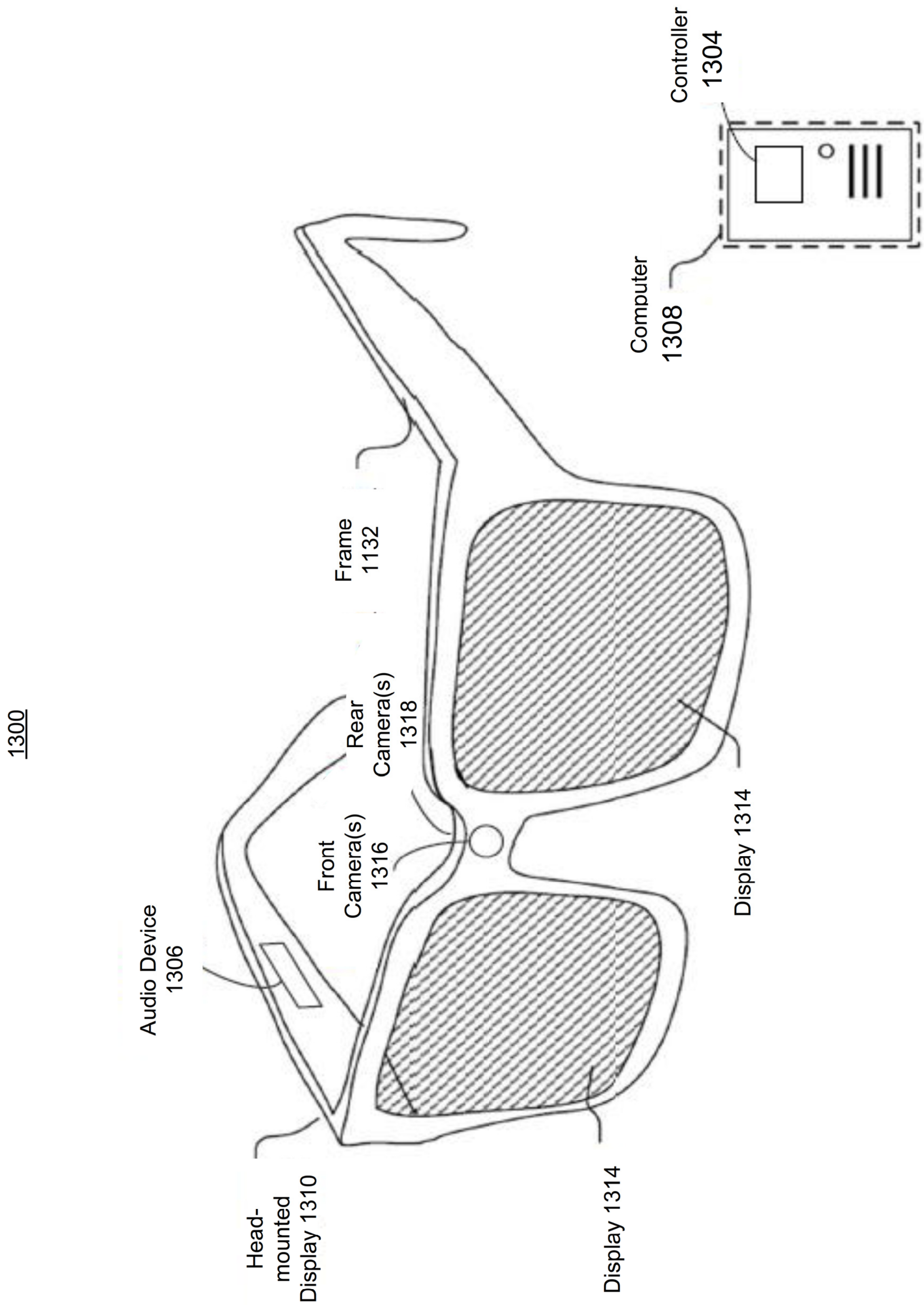

1300
Controller
1304
Computer
1308
Frame
1132
Rear
Camera(s)
1318
Front
Camera(s)
1316
Audio Device
1306
Head-
mounted
Display 1310
Display 1314
Display 1314

FIG. 13