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(54) **Title:** VIRTUAL IMAGE DELIVERY SYSTEM FOR NEAR EYE DISPLAYS

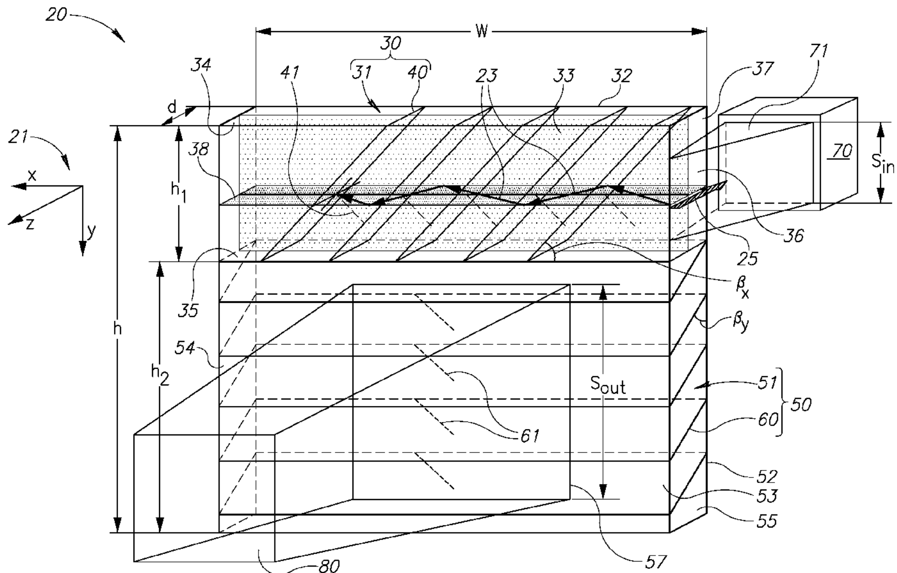

FIG.1

(57) **Abstract:** An image delivery system (IDS) comprising: a first waveguide comprising an input aperture for receiving an input virtual image provided by a display engine and a first plurality of first facets positioned to reflect light from the received input virtual image out from the first waveguide; a second waveguide configured to receive the light reflected out from the first waveguide and comprising a second plurality of second facets positioned to reflect the received light out from the second waveguide to project an output virtual image responsive to the input into an eye motion box (EMB); and a partially reflective coating formed on each facet selected from a number of different partially reflective coatings less than a total number of facets equal to a sum of the number of facets in the first and second pluralities; wherein the output virtual image exhibits a fidelity of 80% or better.

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VIRTUAL IMAGE DELIVERY SYSTEM FOR NEAR EYE DISPLAYS

RELATED APPLICATIONS

[0001] The present application claims the benefit under 35 U.S.C. 119(e) of U.S. Provisional Application 63/032,767 filed on June 01, 2020, the disclosure of which is incorporated herein by reference.

FIELD

[0002] Embodiments of the disclosure relate to providing near eye display (NED) images.

BACKGROUND

[0003] The proliferating headsets, head mounted displays (HMDs) and smart eyeware that are used to provide a user with any of the various new flavors of reality - virtual reality (VR), augmented reality (AR), mixed reality (MR) - deliver computer generated “virtual images”, to the eye of a user. For VR, the images are immersive and block out images of the user’s real environment. For AR and MR, the images are superposed on “real images” of scenes in the user’s real environment that the user sees in his or her field of view (FOV). The virtual images may by way of example provide the user with entertainment and/or informational material related to the real images, a task performed by the user, and/or an explicit or implicit user request.

[0004] A display system conventionally referred to as a near eye display (NED) provides the user with the virtual images. The NED comprises a computer controlled display engine such as a liquid crystal on silicon (LCOS), organic light emitting diode (OLED), or laser beam scanning (LBS) microdisplay, that generates the virtual images and an image delivery system that delivers the generated virtual images to the eye of the user for viewing. The image delivery system comprises at least one light guiding optical element (LOE) that receives the virtual images at a relatively small input aperture having a characteristic dimension of less than or equal to about 5 mm and propagates the images to an output aperture near to the eye through which the virtual images are directed into an eye motion box (EMB) for viewing by the user. When the user’s eye is positioned in the EMB, the virtual images pass through the user’s pupil and onto the user’s retina. To fill the EMB so that the user can comfortably see the virtual images without unduly bothering to align the eye with the NED, the NED’s at least one LOE is generally configured having a relatively large, expanded output aperture through which the NED transmits the virtual images into the EMB.

[0005] A practical NED is generally required to satisfy a complex mix of ergonomic, technical, and financial constraints, and is advantageously configured to have a comfortably large EMB, to be small, lightweight, energy efficient, and to provide clear, relatively high fidelity virtual images that are absent overly obtrusive optical artifacts.

SUMMARY

[0006] An aspect of an embodiment of the disclosure relates to providing an image delivery system, also referred to a Good Image Delivery System (GOODIS), for use in a NED that projects a FOV of a virtual image to an EMB which is an advantageously high fidelity copy of a FOV of a virtual image that a display engine provides to the GOODIS. GOODIS receives the virtual image from the display engine at an input aperture and reflects light from the received virtual image from a plurality of partially reflective, optionally dielectric, mirrors, also referred to as facets, to deliver the virtual image to an expanded output aperture from which the virtual image is projected to the EMB for viewing by a user. Polarization of light received from the display engine and/or reflectivity of a dielectric coating for s and/or p polarized light for at least one facet as a function of incident angle, are configured to provide an advantageous degree of fidelity. In an embodiment each facet in a GOODIS that provides an advantageous degree of fidelity is coated with one of a same two different partially reflective optionally dielectric coatings.

[0007] Fidelity of the FOV projected into the EMB refers to an extent to which intensity of light that propagates along angular directions in the projected FOV is uniformly proportional to intensity of light that propagates along the same, or parity reversed, respective angular directions in the FOV of the virtual image that the display engine provides to the GOODIS. The FOV projected to the EMB is relatively uniformly proportional to the FOV, also referred to as an input FOV, provided by the display engine if: 1) intensity of light projected along different angular directions in the projected FOV is proportional to intensity of light projected along the same, or parity reversed, respective angular directions in the input FOV by a substantially same constant of proportionality; and 2) the constant of proportionality is relatively independent of location of the projected FOV in the EMB.

[0008] In accordance with an embodiment of the disclosure the GOODIS comprises first and second LOEs, an input aperture located on the first LOE through which light from virtual images generated by the display engine is received and an output aperture located on the second

LOE through which light from the virtual images is projected to an EMB. Each of the LOEs comprises a waveguide having two parallel, totally internally reflecting (TIR) surfaces and an array of embedded facets that are parallel to each other. The facets, in each waveguide are tilted relative to a propagation direction of the waveguide along which light entering the waveguide propagates in the waveguide. Light entering the input aperture located on the first waveguide propagates along the propagation direction of the first waveguide and is reflected out from the waveguide by the facets in the waveguide to enter the second waveguide. Light entering the second waveguide from the first waveguide propagates along the propagation direction of the second waveguide and is reflected out from the waveguide and projected to the EMB via the output aperture by the facets in the second waveguide. The propagation directions of the first and second waveguides are optionally orthogonal and the first and second waveguides cooperate to expand the input aperture along each of the orthogonal propagation directions.

[0009] For convenience of presentation it is assumed that propagation of light along the first waveguide is along an x-axis of a Cartesian coordinate system, light propagating along the second waveguide is assumed to propagate along the y-axis, and the eye box is assumed to be located along the z-axis facing the output aperture of the second waveguide. The first and second waveguides may be referred to respectively as x and y waveguides, their respective embedded facets as x and y facets, and the first and second LOE as x and y LOEs respectively. A virtual image received from the display engine at the input aperture may be referred to as an input virtual image and the image projected by GOODIS to the EMB may be referred to as an output virtual image

[0010] Light propagating in a waveguide of the GOODIS that is incident on a facet of a waveguide in the GOODIS generally comprises both s and p polarization components. S polarization refers to polarization perpendicular to a plane of incidence of the light and p refers to polarization parallel to the plane of incidence. Each facet reflects light from incident light, directly or indirectly for the case of x and y facets respectively, toward the EMB along a portion of the angular directions in the output FOV projected by GOODIS to the EMB. Let $I(\alpha_m)$ represent intensity of light propagating along an m-th angular direction α_m in the input FOV of a given virtual input image generated by the display engine. Let $P^o{}_k(p,\alpha_m)$ and $P^o{}_k(s,\alpha_m)$ respectively represent intensity of p and s light reflected by the k-th facet in the angular direction α_m of the FOV from light in the given input virtual image that is incident on the facet and let

$$TP^{o}_{k,m} \equiv [P^{o}_{k}(p,\alpha_m) + P^{o}_{k}(s,\alpha_m)] \quad (1)$$

[0011] The FOV of the output virtual image projected by GOODIS to the EMB responsive to the given virtual input image may be considered to be a relatively high fidelity copy of the FOV of the input virtual image to a (1-δ)% degree of fidelity if GOODIS satisfies a constraint:

$$[(|TP^{o}_{k,m}-TP^{o}_{j,n}|/AVG(TP^{o}_{k,m}, TP^{o}_{j,n})) < \delta\%| \; I(\alpha_m) = I(\alpha_n), \forall(j,k), \forall(m,n)] \quad (2)$$

[0012] The constraint given by expression (2) requires that for a same intensity of light propagated in the input FOV of the given input virtual image along any two different or same angular directions, the facets reflect substantially a same intensity of light toward the EMB along the same respective angular directions in the output FOV of the output virtual image. The constraint operates to preserve relative brightness of features in the input virtual image to better than δ% in the projected output virtual image projected by GOODIS to the EMB. The constraint also provides for uniformity to better than δ% of intensity of light in an output FOV of the projected output virtual image independent of location of the output FOV in the EMB. In accordance with an embodiment of the disclosure the coatings on the facets in at least one of the x-waveguide and y-waveguide are configured to advantageously satisfy the constraints.

[0013] In an embodiment the coatings may be determined responsive to iterative Monte Carlo ray tracing for different configurations of coatings and a cost function that indicates when a given configuration of coatings converges to a configuration that provides GOODIS with a desired fidelity. Among a plurality of degrees of freedom available for modeling and determining coatings for the facets in accordance with an embodiment of the disclosure are at least one or any combination of more than one of reflectivity of an optionally dielectric coating as a function of incident angle for s polarized light and/or p polarized light, a number of facets, spacing between facets and/or their respective tilt angles. A configuration of coatings may be considered to provide a desired fidelity and advantageously satisfy the constraints when the configuration satisfies a criterion responsive to the value of the cost function.

[0014] This Summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This Summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used to limit the scope of the claimed subject matter.

BRIEF DESCRIPTION OF FIGURES

[0015] Non-limiting examples of embodiments of the disclosure are described below with reference to figures attached hereto that are listed following this paragraph. Identical features that appear in more than one figure may be labeled with a same label in multiple figures in which they appear. A label labeling an icon representing a given feature of an embodiment of the disclosure in a figure may be used to reference the given feature. Dimensions of features shown in the figures are chosen for convenience and clarity of presentation and are not necessarily shown to scale.

[0016] Fig. 1 schematically shows the geometry of a good image delivery system, a GOODIS, comprising first and second LOEs that cooperate to expand in two dimensions an input aperture located in the first LOE to an output aperture located in the second LOE, in accordance with an embodiment of the disclosure;

[0017] Fig. 2 schematically illustrates light propagation as a function of the geometry of the GOODIS shown in Fig. 1, in accordance with an embodiment of the disclosure;

[0018] Fig. 3A shows schematic graphs of reflectivity of a dielectric coating as a function of angle of incidence for p and s light incident on facets of the GOODIS in the first LOE that contribute to providing an advantageous fidelity that characterizes the GOODIS, in accordance with an embodiment of the disclosure;

[0019] Fig. 3B shows schematic graphs of reflectivity of a dielectric coating as a function of angle of incidence for p and s light incident on the facets of the GOODIS in the second LOE that contribute to providing an advantageous fidelity that characterizes the GOODIS, in accordance with an embodiment of the disclosure;

[0020] Fig. 3C shows a schematic graph of dependence of s and p polarization light reflected into the second LOE from the first LOE assuming that light from a virtual image input into the first LOE is substantially p polarized with respect to TIR surfaces of the first LOE, in accordance with an embodiment of the disclosure; and

[0021] Fig. 4 schematically illustrates operation of a GOODIS having facets coated with the dielectric coatings shown in Figs. 3A and 3B, in accordance with an embodiment of the disclosure.

DETAILED DESCRIPTION

[0022] In the discussion, unless otherwise stated, adjectives such as “substantially” and “about” modifying a condition or relationship characteristic of a feature or features of an embodiment of the disclosure, are understood to mean that the condition or characteristic is defined to within tolerances that are acceptable for operation of the embodiment for an application for which it is intended. Wherever a general term in the disclosure is illustrated by reference to an example instance or a list of example instances, the instance or instances referred to, are by way of non-limiting example instances of the general term, and the general term is not intended to be limited to the specific example instance or instances referred to. Unless otherwise indicated, the word “or” in the description and claims is considered to be the inclusive “or” rather than the exclusive or, and indicates at least one of, or any combination of more than one of items it conjoins.

[0023] Fig. 1 schematically shows a GOODIS 20 comprising an x-LOE 30 having a waveguide 31 and facets 40 embedded in the waveguide and a y-LOE 50 having a waveguide 51 and facets 60 embedded in the waveguide in accordance with an embodiment of the disclosure. For convenience of presentation features and geometry of GOODIS 20 are spatially referenced relative to a coordinate system 21.

[0024] Waveguide 31, also referred to as x-waveguide 31 is optionally a rectangular prism having relatively large parallel face surfaces 32 and 33 parallel to the xy-plane of coordinate system 21 and parallel, relatively narrow top and bottom edge surfaces 34 and 35 parallel to the xz-plane. Light from images generated by a display engine such as a display engine 70 shown in Fig. 1 is coupled into waveguide 31 optionally by a prismatic input coupler 71 through an input aperture 36 located on an end surface 37 of the x-waveguide. Light entering x-waveguide 31 through input aperture 36 is repeatedly totally internally reflected (TIR) from face surfaces 32 and 33, also referred to as TIR surfaces 32 and 33, to bounce back and forth between the TIR surfaces and propagate along the positive x-direction in the x-waveguide to reach and be incident on facets 40.

[0025] By way of example a light ray input into x-waveguide 31 propagating in a midplane 38 of the x-waveguide parallel to the xz-plane and being totally internally reflected from TIR surfaces 32 and 33 to bounce back and forth between the TIR surfaces is schematically represented by arrows 23. Optionally, upon entry into x-waveguide 31 polarization of light in light ray 23 schematically indicated by a block arrow 25 is parallel to midplane 38, and since the midplane is a plane of incidence of the light ray with TIR surfaces 32 and 33 the light ray is p polarized with respect to the plane of incidence.

[0026] Facets 40 are optionally parallel to each other and perpendicular to TIR surfaces 32 and 33 and are tilted by a tilt angle β_X relative to bottom edge surface 35 and the x-axis. A normal 41 to each facet 40 is rotated relative to the y-axis by the tilt angle β_X. Each facet 40 as described below reflects a portion of light propagating in x-waveguide 31 that is incident on the facet through bottom edge surface 35 and into waveguide 51. For example when light ray 23 is incident on a facet 40 the facet reflects a portion of the light in the light ray into y-waveguide 51. It is noted that whereas light ray 23 is p polarized with respect to TIR surfaces 32 and 33, with respect to facets 40 because the normals 41 of the facets do not lie in the midplane, the light ray comprises both p and s polarized light.

[0027] Waveguide 51, also referred to as y-waveguide 51, is also optionally a rectangular prism. The waveguide has relatively large parallel TIR face surfaces 52 and 53 parallel to the xy-plane and parallel, relatively narrow left and right edge surfaces 54 and 55 respectively that are parallel to the yz-plane. Light reflected by facets 40 in x-waveguide 31 into y-waveguide 51 is repeatedly TIR reflected from face surfaces 52 and 53 to bounce back and forth between the TIR surfaces and propagate in y-waveguide 51 along the y-axis to reach and be incident on facets 60 of the y-waveguide. Facets 60 are optionally parallel to each other and perpendicular to side surfaces 54 and 55. The facets are tilted by a tilt angle β_Y relative to TIR surface 52 and the y-axis. A normal 61 to each of facets 60 is rotated by tilt angle β_Y relative to the z-axis. Each facet 60 as described below reflects a portion of light propagating in y-waveguide 51 along the y-axis that is incident on the facet through an output aperture 57 on TIR face surface 53 to an EMB 80 for viewing by a user (not shown).

[0028] GOODIS 20 as shown in Fig. 1 has height h, width w, and thickness of depth d. X-waveguide 31 has height h_1 and y-waveguide 51 height h_2. Both waveguides optionally have a same width substantially equal to the width w of GOODIS and a same thickness or depth, d. Height h may be equal to $(h_1 + h_2)$. By way of numerical example, in an embodiment h may have a value between about 30 mm (millimeters) and about 50 mm, height h between 30 mm and about 50 mm, and depth between about 1.0 mm to about 3 mm. Height $h_1$of x-waveguide 31 in an embodiment may be between about 10 mm and about 20 mm, and height h_2 may be between about 10 mm and 40 mm. X-waveguide 31 may have between about 20 and about 30 facets 40 tilted at a tilt angle β_x between about 25^o and about 65^o. Y-waveguide 51 may have between about 8 and about 12 facets 60 tilted at a tilt angle β_y between about 20^o and about 70^o.

[0029] Fig. 2 schematically illustrates propagation of light rays from virtual images generated by display engine 70 that are coupled into GOODIS 20 by input coupler 71 to travel along x-waveguide 31 and be reflected into y-waveguide 51 by facets 40 and thereafter by facets 60 in the y-waveguide toward EMB 80.

[0030] In x-waveguide 31 a triangular cluster of arrows converging to a point on a facet 40 from which the facet reflects light rays into y-waveguide 51 represents a cross section in the xy-plane of a FOV comprising angular directions along which light rays received from display engine 70 are incident on the facet. By way of example, three FOV xy cross sections represented by triangular clusters 101, 102, and 103 of angular propagation directions of light rays are shown in Fig. 2 for a selection of facets 40 individualized by labels 40-1, 40-2, and 40-3 respectively. A light ray in a FOV xy cross section 101, 102, and 103 represented by a solid arrow 121 is reflected into y-waveguide 51 along an angular direction represented by a solid arrow 131 for which facets 60 in the y-waveguide successfully reflect light into EMB 80. However, not all light from light rays in the FOV of the virtual image that are incident on a facet 40 and reflected into y-waveguide 51 are successfully reflected into EMB 80. A dashed arrow 122 in a FOV cross section 101, 102, or 103 represents a light ray that facet 40-1, 40-2 or 40-3 respectively reflects into y-waveguide 51 along an angular direction represented by a dashed arrow 132 for which facets 60 reflect light that misses EMB 80. Solid arrows 131 representing angular directions of light rays from which light is successfully reflected into EMB 80 by facets 60 are shown pointing into output aperture 57. Dashed arrows 132 representing angular directions of light rays from which facets 60 reflect light that fails to reach EMB 80 are shown pointing towards regions outside of output aperture 57.

[0031] Shaded areas 401, 402, and 403 in Fig. 2 schematically indicate ranges of angular directions along which facets 40-1, 40-2, and 40-3 respectively reflect light rays from which facets 60 successfully reflect light into EMB 80. Median angular directions in ranges 401, 402, and 403 along which the facets respectively reflect incident light rays are indicated by relatively long solid arrows 131 in the ranges. The median angular directions for ranges 401, 402, and 403 are directed along angles θ_1, θ_2, and θ_3, relative to normals 41 of facets 40-1, 40-2 and 40-

3 respectively. Angles θ_1, θ_2, θ_3, are angles of incidence and reflection of light rays that are reflected along the median angular directions in ranges. As a result of the locations of facets 40-1, 40-2 and 40-3 relative to outlet aperture 57, and as schematically shown in Fig. 2, $\theta_1 > \theta_2 > \theta_3$. Quite generally, a median angular direction of incidence and corresponding angular direction of reflection along which a facet 40 reflects light rays and from which subsequently facets 60 successfully reflect light to EMB 80 decreases with distance of the facet from input aperture 36.

[0032] Similarly, median angular directions of light that facets 60 reflect into EMB 80 from light rays reflected into y-waveguide 51 by facets 40 decrease with distance of facets 60 from bottom surface 35 of x-waveguide 31. The median angular directions for a selection of facets 60 are represented by solid arrows 151. Angles of reflection between the median angular directions 151 and normals 61 for the selection of facets 60 are labeled φ_1, φ_2, and φ_3, where a larger subscript identifies an angle associated with a facet 60 further from bottom surface 35.

[0033] The above discussion indicates that different facets of GOODIS 20 reflect different angular portions of an input FOV of a virtual image from display engine 70 into EMB 80. And in general, to achieve a high fidelity output image, the farther a facet 40 in x-waveguide 31 is from input aperture 36 the larger should be reflectivity of the facet for light from portions of the input FOV having smaller angles of incidence, AOI, on the facet, which the facet reflects to larger values of x in the EMB. . Similarly, the farther a facet 60 in y-waveguide 51 is from bottom edge surface 35 of x-waveguide 31, the larger should be reflectivity of the facet for light from portions of the input FOV having smaller AOIs on the facet, which the facet reflects to larger values of y in the EMB.

[0034] Let an “x” index such as k(x) designate a facet 40 in x-waveguide 31 and let the value of the index increase with distance of the designated facet 40 from input aperture 36. Similarly, let a “y” index, such as k(y) designate a facet 60 in y-waveguide 51 and let the value of the index increase with distance of the designated facet 60 from surface 35. The constraints for provision of a high fidelity output virtual image expressed by expressions (2) and (3) may be written to express constraints on facets 40, which may also be referred to as x-facets 40,

$$[(|TP^{o}_{k(x),m}-TP^{o}_{j(x),n}|/AVG(TP^{o}_{k(x),m},TP^{o}_{j(x),n}))< \delta\%|\ I(\alpha_m) = I(\alpha_n),\ \forall(j(x),k(x)),\ \forall(m,n)] \quad (3)$$

Similarly the constraints on facets 60, optionally referred to as y-facets 40, may be written

$$[(|TP^{o}_{k(y),m}-TP^{o}_{j(y),n}|/AVG(TP^{o}_{k(y),m},TP^{o}_{j(y),n}))< \delta\%|\ I(\alpha_m) = I(\alpha_n),\ \forall(j(y),k(y)),\ \forall(m,n)] \quad (4)$$

[0035] Constraints (3) and (4) are complex constraints that are typically relatively difficult to satisfy without having a different dedicated reflective coating for each x-facet 40 and each y-facet 60. In accordance with an embodiment GOODIS advantageously uses differences in reflectivity for p and s light to provide coatings on facets 40 and 60 to provide an advantageous fidelity for virtual images that GOODIS provides EMB 80. In an embodiment x-facets 40 of waveguide 31 are provided a same partially reflective coating that provides reflectivity for p and s light as a function of angle of incidence AOI shown by a graph 540 in Fig. 3A. In an embodiment y-facets 60 of waveguide 51 are provided a same coating that provides reflectivity for p and s light as a function of angle of incidence AOI shown by a graph 560 in Fig. 3B.

[0036] Facets 40 and 60 having AOI dependent partially reflective coatings that exhibit reflectivities shown in graphs 540 and 560 respectively may be manufactured using any of various materials and manufacturing processes. For example, the facets may be produced by depositing partially reflective coatings on surfaces of preformed prisms and bonding the prisms together. The prisms may be fabricated by grinding and polishing a silicate material, such as BK-7, to a desired shape, or by injection molding a suitable polymer or sol-gel. The coatings may be formed from any of various suitable materials such as by way of example, Hafnium dioxide (HfO_2), Magnesium fluoride (MgF_2) and/or Tantalum pentoxide (Ta_2O_5).

[0037] In an embodiment, display engine 70 and/or prismatic input coupler 71 are configured to provide virtual images to GOODIS 20 for which light from the virtual images are substantially p polarized with respect to planes of incidence of the light on TIR face surfaces 32 and 33 upon entry of the light into x-waveguide 31. For p polarized light in the input to x-waveguide 31 and reflectivity of facets 40 as shown in Fig. 3A, as a result of dependence of polarization of light reflected by facets 40 on angle of incidence of the light, dependence of polarization of light reflected by facets 40 into y-waveguide 51 on angles of incidence on facets 60 is substantially as shown by a graph 550 in Fig. 3C. sssssss

[0038] Graph 550 shows that for the p-polarized light input into x-waveguide 31 and reflected by facets 40 having reflectivity shown in Fig. 3A light entering y-waveguide has a p component close to about 4 times greater than an s component at angles of incidence on y-waveguide facets of about 40 degrees. As shown by graph 3B reflectivity of facets 60 for p and s light respectively decreases and increases with angle of incidence. As a result the preponderance of p polarized light entering y-waveguide 51 and dependence of reflectivity of p and s light advantageously promotes homogeneity along the y-axis of intensity of light projected by facets 60 in a same given angular direction into EMB 80.

[0039] For example reflectivities given by graphs 540 and 560 and p polarized virtual images input into x-waveguide 31 in accordance with an embodiment of the disclosure, GOODIS 20 provides virtual images at EMB 80 that exhibit advantageous fidelity that is greater than about 70% along both the x and y directions. For 80% fidelity the output virtual images conserves relative brightness of a virtual input image provided by display engine 70 and prismatic input coupler to within about 30% and spatial uniformity in the EMB of intensity of light projected along a same angular direction into the EMB to within about 30%.

[0040] Fig. 4 schematically illustrates operation of GOODIS 20 and facets 40 and 60 in providing an output virtual image 85 in EMB 80 characterized by an advantageous fidelity for an input virtual image 75 characterized by a substantially uniform brightness indicated by a uniform shading of the input virtual image. Values for reflectivity of p and s polarized light for x-facets 40-1 and 40-3 relevant to portions of input and output virtual images 75 and 85 that the facets reflect toward EMB 80 are indicated in copies of graphs 540 connected to median AOI angles θ_1 and θ_3. Values for reflectivity of p and s polarized light for facets 60 that are respectively closest to and farthest from surfaces 35 relevant to portions of input and output virtual images 75 and 85 that the facets reflect toward EMB 80 are indicated in copies of graphs 560 connected to median AOI angles ϕ_1 and ϕ_3. Whereas output virtual image 85 may not exhibit perfect fidelity, uniformity of shading of the output virtual image is intended to schematically indicate that the output virtual image evidences a fidelity of about 70% and preserves relative intensity and spatial uniformity to about 30% along both the x and y directions.

[0041] It is noted that whereas the above description references an embodiment of a GOODIS 20 that employs only two different reflective coatings, an embodiment of the disclosure is not limited to a same single partially reflective coating for x-facets 40 and a different same single partially reflective coating for y-facets 60. For example, a GOODIS 20 in accordance with an embodiment may have a different partially reflective p and s coating for each of two or more groups of facets 40. Similarly, a GOODIS 20 in accordance with an embodiment may have a different partially reflective p and s coating for each of two or more groups of facets 60. In general, with increase in the number of partially reflective coatings having different respective p and s AOI dependencies, fidelity of virtual images provided by a GOODIS in accordance with an embodiment of the disclosure increases. It is also noted that whereas Figs. 3C and 4 assume that light entering x-waveguide 31 is p polarized relative to TIR surfaces 32 and 33 (Fig. 1) practice of embodiments of the disclosure is not limited to p polarized input. Different relative intensities of p and s polarization light input to x-waveguide 31 may be coordinated with different reflectivities of facets 40 and 60 to provide advantageous fidelity output images provided by a GOODIS in accordance with an embodiment of the disclosure.

[0042] In the description and claims of the present application, each of the verbs, "comprise" "include" and "have", and conjugates thereof, are used to indicate that the object or objects of the verb are not necessarily a complete listing of components, elements or parts of the subject or subjects of the verb.

[0043] Descriptions of embodiments of the disclosure in the present application are provided by way of example and are not intended to limit the scope of the disclosure. The described embodiments comprise different features, not all of which are required in all embodiments. Some embodiments utilize only some of the features or possible combinations of the features. Variations of embodiments of the disclosure that are described, and embodiments comprising different combinations of features noted in the described embodiments, will occur to persons of the art. The scope of the invention is limited only by the claims.

CLAIMS

1. An image delivery system (IDS) for a near eye display (NED), the IDS comprising:

first waveguide comprising an input aperture for receiving an input virtual image provided by a display engine and a first plurality of first facets positioned to reflect light from the received input virtual image out from the first waveguide;

a second waveguide configured to receive the light reflected out from the first waveguide and comprising a second plurality of second facets positioned to reflect the received light out from the second waveguide to project an output virtual image responsive to the input into an eye motion box (EMB); and

a partially reflective coating formed on each facet selected from a number of different partially reflective coatings less than a total number of facets equal to a sum of the number of facets in the first and second pluralities;

wherein the output virtual image exhibits a fidelity of 80% or better in reproducing the input virtual image.

2. The IDS according to claim 1 wherein the number of different partially reflective coatings is less than or equal to about 20.

3. The IDS according to claim 2 wherein the number of different partially reflective coatings is less than or equal to about 15 for the first waveguide and less or equal to about 5 for the second waveguide.

4. The IDS according to claim 3 wherein the number of different partially reflective coatings is equal to two and comprises first and second different reflective coatings.

5. The IDS according to claim 4 wherein all the first facets are coated with the first coating.

6. The IDS according to claim 5 wherein all the second facets are coated with the second coating.

7. The IDS according to claim 5 or claim 6 wherein reflectivity of the first coating for s polarized light decreases substantially monotonically with increase in angle of incidence on the first facets from about 40^{o} to about 76^{o}.

8. The IDS according to claim 7 wherein reflectivity of the first coating for p polarized light increases substantially monotonically with increase in angle of incidence on the first facets from about 40^{o} to about 76^{o}.

9. The IDS according to claim 8 wherein for angles of incidence on the first facets between about 40^{o} to about 76^{o} s reflectivity is greater than p reflectivity.

10. The IDS according to any of claims claim 5-9 wherein reflectivity of the second coating for s polarized light decreases substantially monotonically with decrease in angle of incidence on the second facets less than about 40^{o}.

11. The IDS according to claim 10 wherein reflectivity of the second coating for p polarized light increases substantially monotonically with decrease in angle of incidence on the second facets less than about 50^{o}.

12. The IDS according to claim 11 wherein for angles of incidence on the second facets less than about 50^{o} s reflectivity is greater than p reflectivity.

13. A system for providing a virtual image to an EMB, the system comprising:
an IDS according to any of the preceding claims; and
apparatus that provides the IDS with an input virtual image.

14. The system according to claim 13 wherein the apparatus that provides the input virtual image configures polarization of light in the input virtual image so that light from the input virtual image incident on a second facet of the IDS has a component of p polarized light greater than a component of s polarized light.

15. The system according to claim 14 wherein intensity of the p polarized light is greater than three times that of the s polarized light.

16. A method of controlling fidelity of a copy of virtual image generated by a display engine projected to an eye motion box (EMB) of a near eye display (NED), the method comprising:

controlling a ratio between s polarized light and p polarized light provided by the display engine as a function of an angular direction of propagation of the light in a FOV of the image; and

reflecting the light into the EMB from a plurality of facets having reflectivity responsive to the ratio between the s and polarized light.

17. The method according to claim 16 wherein controlling the ratio comprises providing intensity of p polarized light to be substantially greater than intensity of s polarized light.

18. The method according to claim 17 wherein reflectivity of the facets for s polarized light decreases substantially monotonically with decrease in angle of incidence on the facets less than about 40^{o}.

19. The method according to claim 18 wherein reflectivity of the facets for p polarized light increases substantially monotonically with decrease in angle of incidence on the facets less than about 50^{o}.

20. The method according to claim 19 wherein for angles of incidence on the facets less than about 50^{o} s reflectivity is greater than p reflectivity.

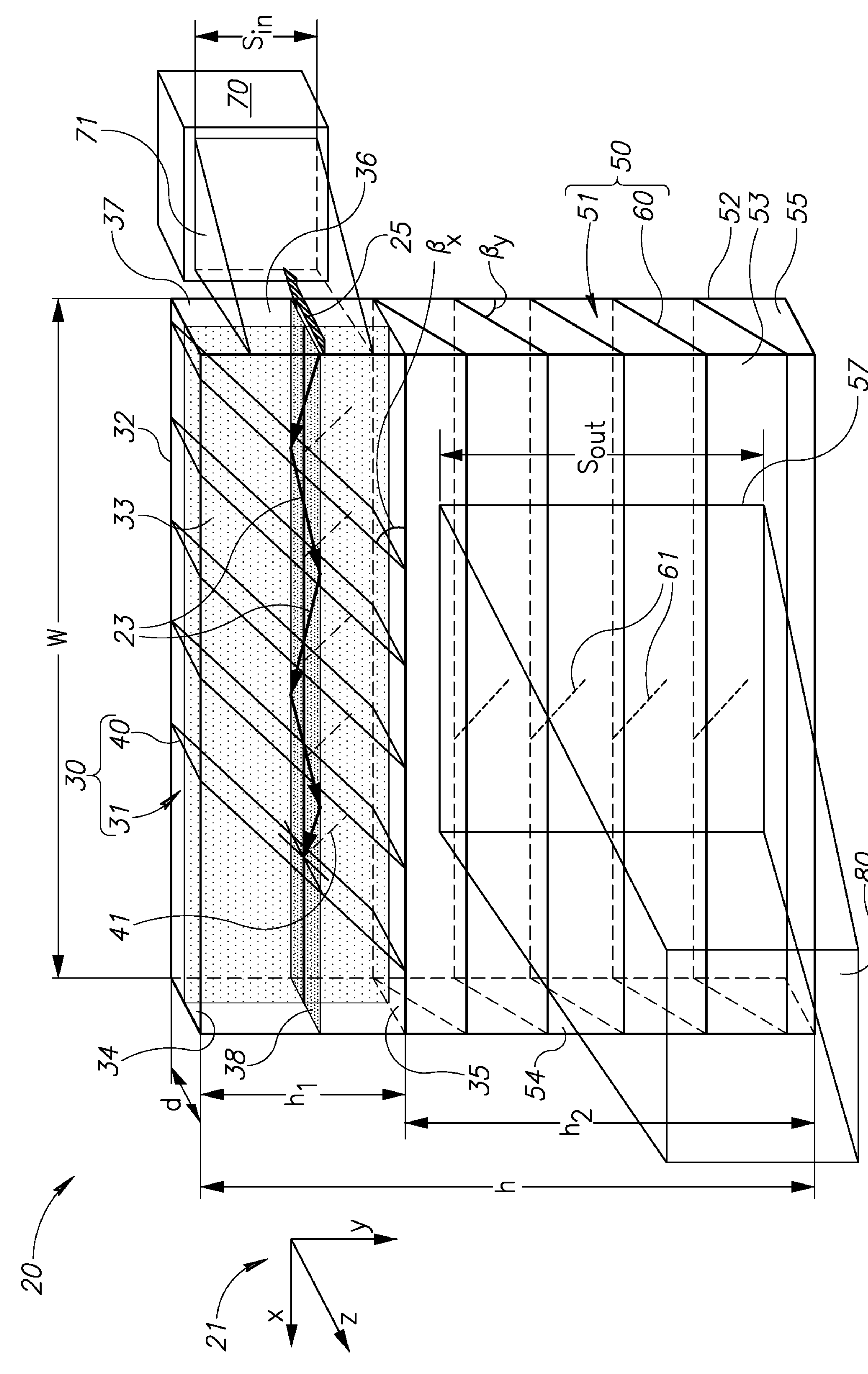
S_in
70
71
37
36
25
β_x
β_y
50
51
60
52
53
55
W
32
33
23
S_out
57
61
30
40
31
41
80
34
38
35
54
d
h_1
h_2
h
20
21
x
y
z

FIG.1

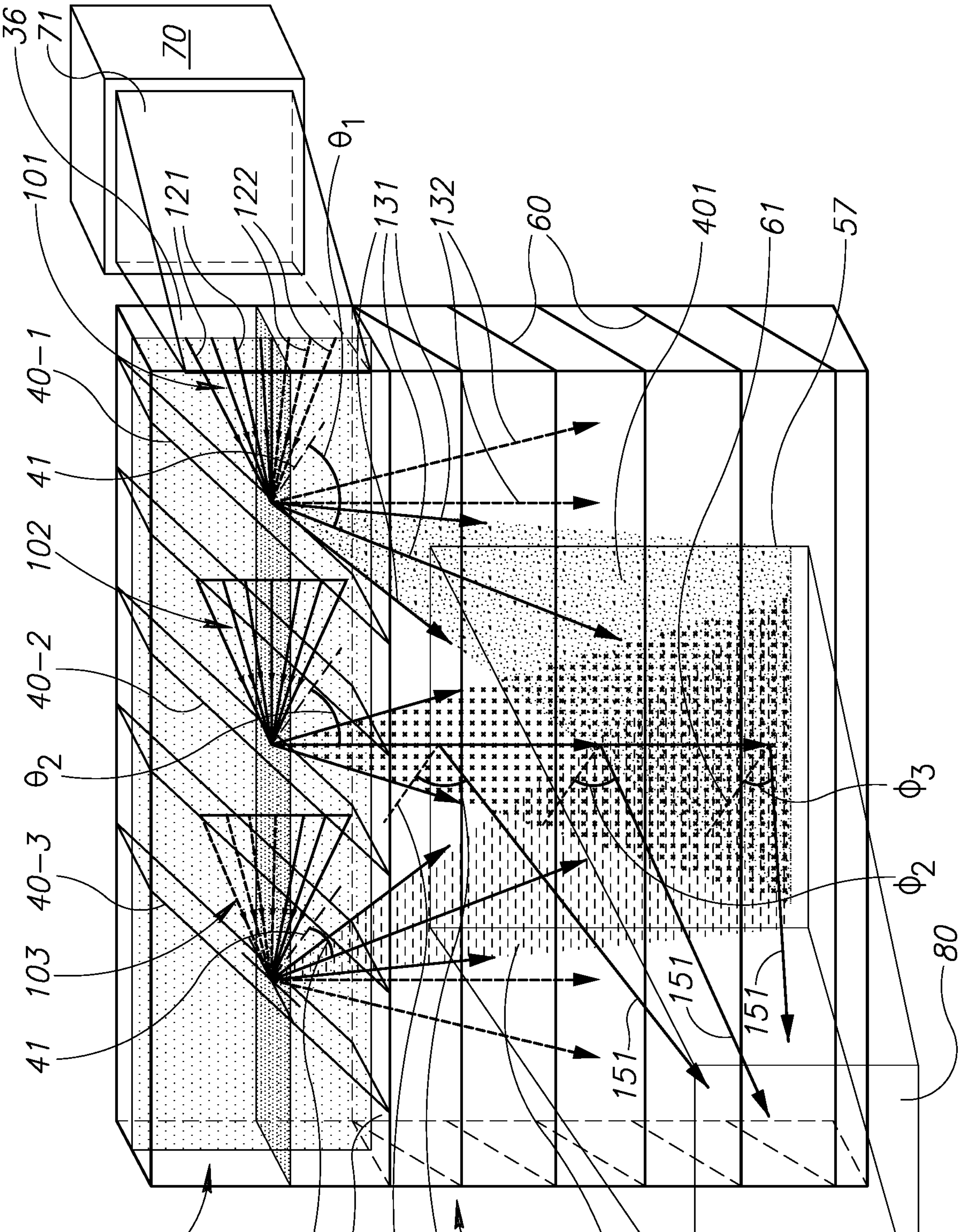
70
71
36
101
121
122
θ1
131
132
60
401
61
57
40-1
41
102
40-2
θ2
40-3
103
41
φ3
φ2
151
80
31
θ3
35
61
φ1
51
403
x
y
z

FIG.2

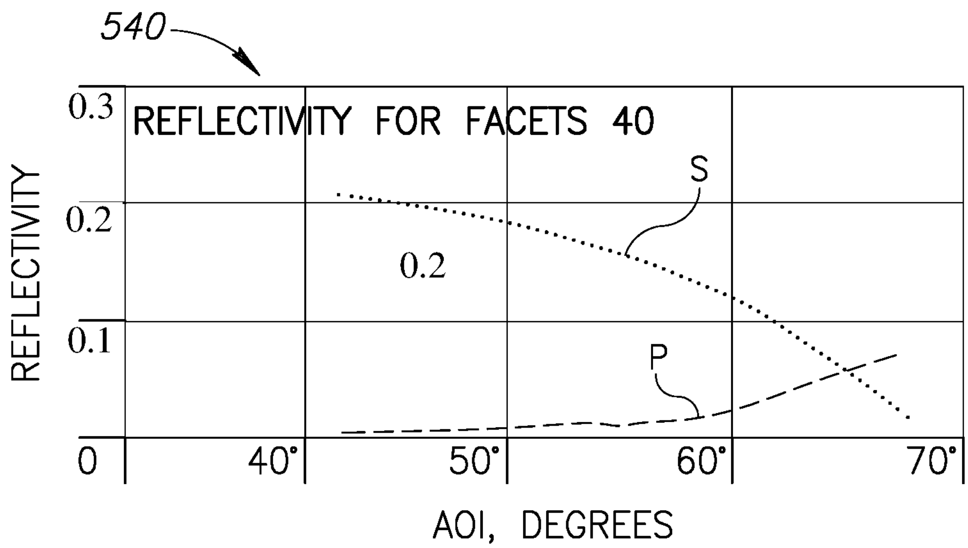
540
REFLECTIVITY FOR FACETS 40
REFLECTIVITY
0.3
0.2
0.1
0
S
P
0.2
40°
50°
60°
70°
AOI, DEGREES

FIG.3A

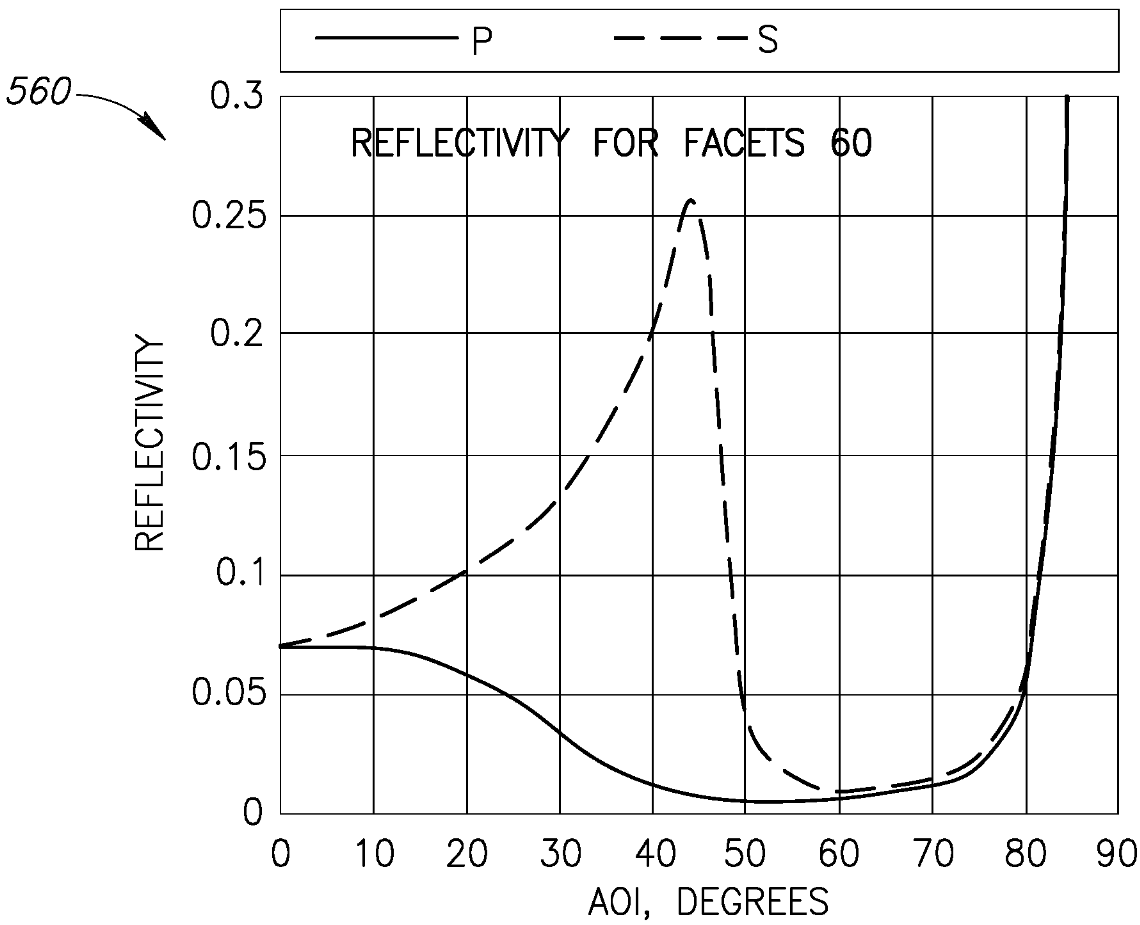
560
P
S
REFLECTIVITY FOR FACETS 60
REFLECTIVITY
0.3
0.25
0.2
0.15
0.1
0.05
0
0
10
20
30
40
50
60
70
80
90
AOI, DEGREES

FIG.3B

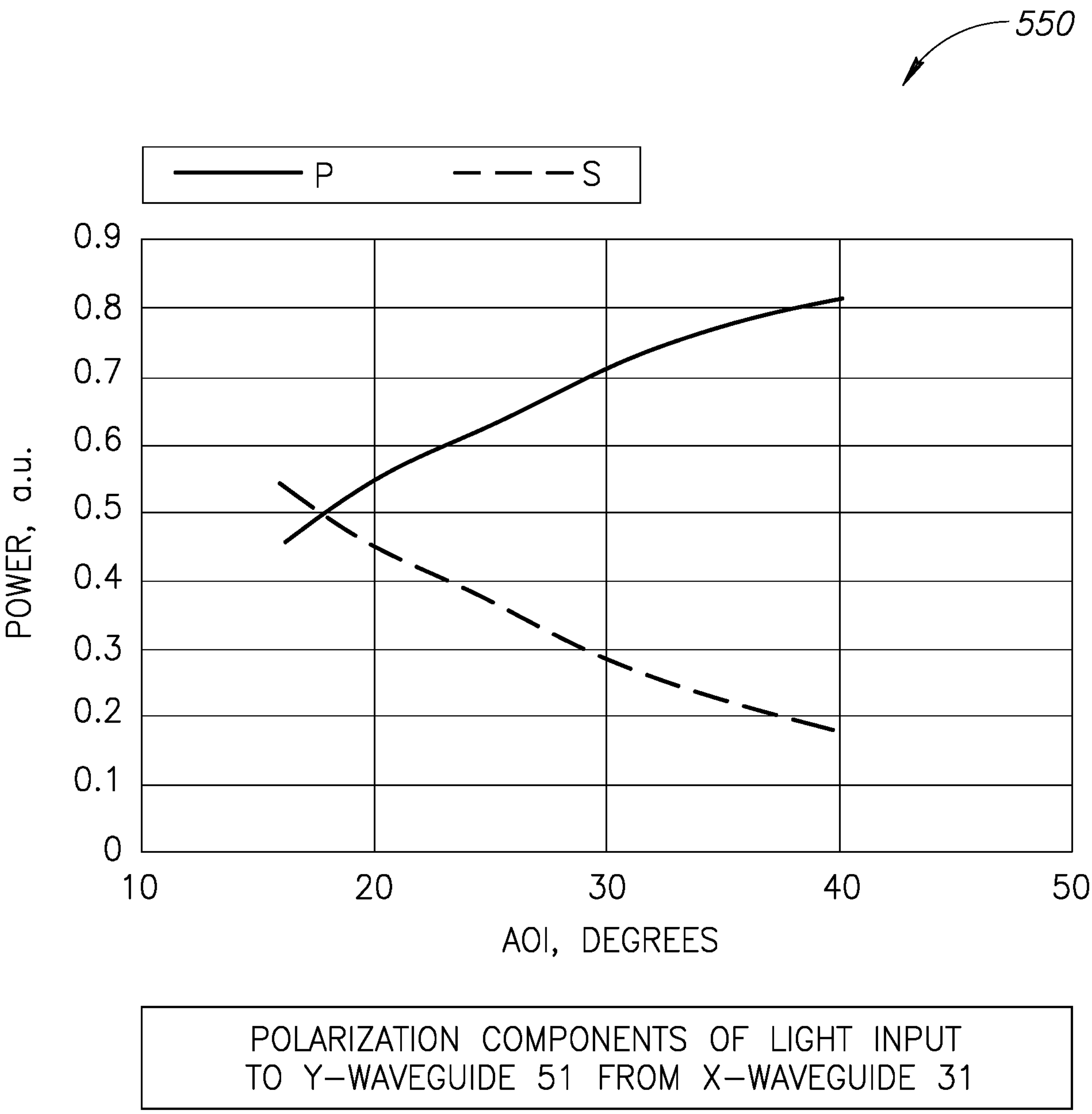
550
P
S
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
POWER, a.u.
10
20
30
40
50
AOI, DEGREES
POLARIZATION COMPONENTS OF LIGHT INPUT
TO Y-WAVEGUIDE 51 FROM X-WAVEGUIDE 31

FIG.3C

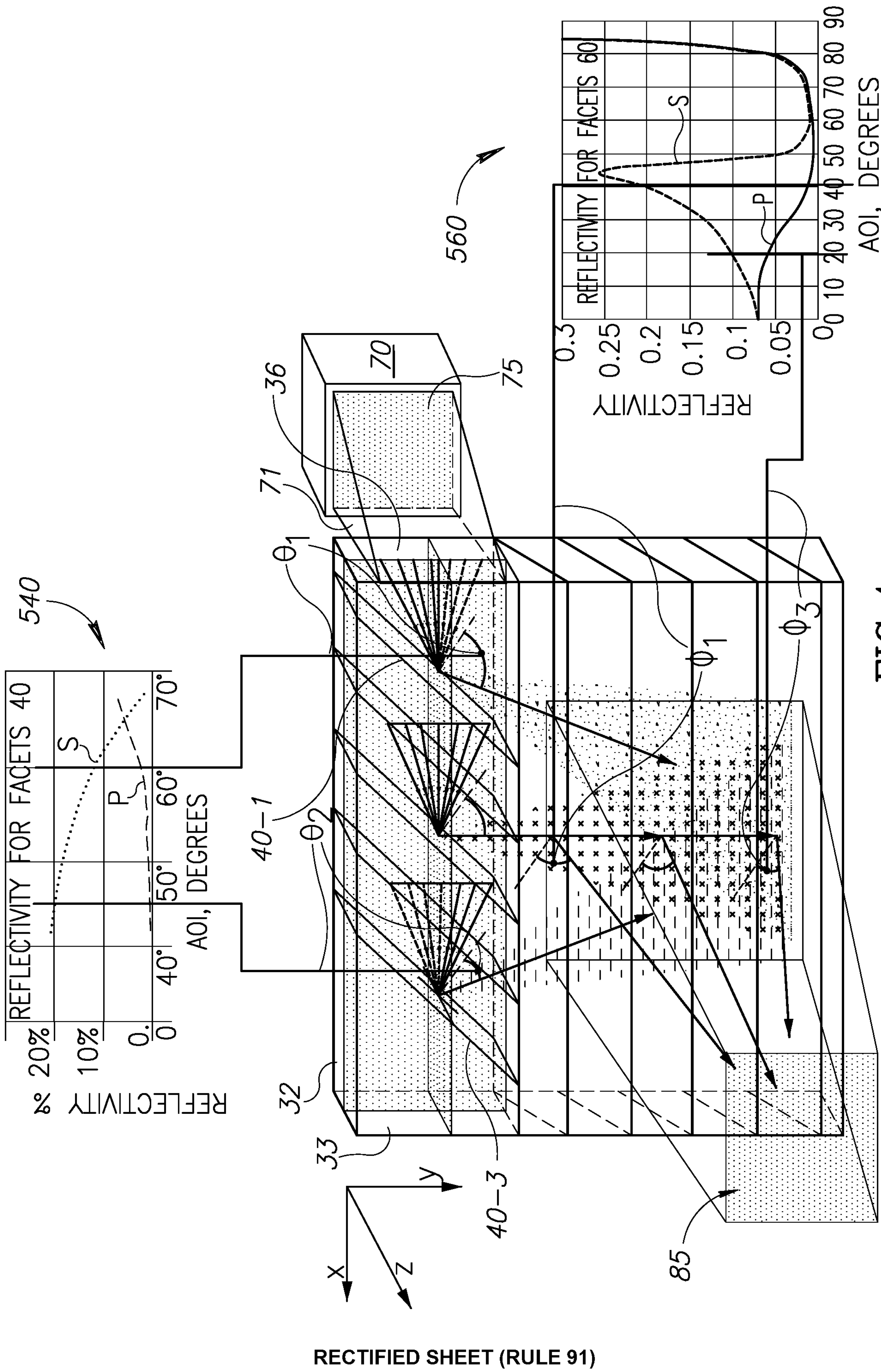
540
REFLECTIVITY FOR FACETS 40
REFLECTIVITY %
20%
10%
0.
0
40°
50°
60°
70°
AOI, DEGREES
S
P
560
REFLECTIVITY FOR FACETS 60
REFLECTIVITY
0.3
0.25
0.2
0.15
0.1
0.05
0
0 10 20 30 40 50 60 70 80 90
AOI, DEGREES
70
75
36
71
θ1
θ2
40–1
40–3
32
33
φ1
φ3
85
x
y
z

FIG.4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IL2021/050651

A. CLASSIFICATION OF SUBJECT MATTER
IPC (20210101) G02B 6/00, G02B 27/01, G02B 27/14, F21V 8/00
CPC (20130101) G02B 6/00, G02B 27/01, G02B 27/0172, G02B 27/145, G02B 6/0061, G02B 6/0055, G02B 2027/0178
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)
IPC (20210101) G02B 6/00, G02B 27/01, G02B 27/14, F21V 8/00
CPC (20130101) G02B 6/00, G02B 27/01, G02B 27/0172, G02B 27/145, G02B 6/0061, G02B 6/0055, G02B 2027/0178

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)
Databases consulted: Google Patents, Orbit, Similari (AI-based)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2019227215 A1 LUMUS LTD [IL] 25 Jul 2019 (2019/07/25) the entire document, especially para. [0002], [0098]-[0101]; figs. 4, 5, 25, 26B	1-6,13
Y		7-12,14
X	US 2014126051 A1 LUMUS LDT [IL] 08 May 2014 (2014/05/08) the entire document especially par. [0003], [0103]; figs. 3, 4, 5, 22.	16-20
Y		7-12,14
A	CN 109239835 A CHENGDU IDEALSEE TECHNOLOGY CO LTD 18 Jan 2019 (2019/01/18) the entire document	1-20

☐ Further documents are listed in the continuation of Box C.   ☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"D" document cited by the applicant in the international application
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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
01 Sep 2021	02 Sep 2021
Name and mailing address of the ISA: Israel Patent Office Technology Park, Bldg.5, Malcha, Jerusalem, 9695101, Israel Email address: pctoffice@justice.gov.il	Authorized officer LEVI Moria Telephone No. 972-73-3927214

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INTERNATIONAL SEARCH REPORT
Information on patent family members

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PCT/IL2021/050651

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