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(54) **Title:** OPTICAL SYSTEM WITH HIGH CONTRAST

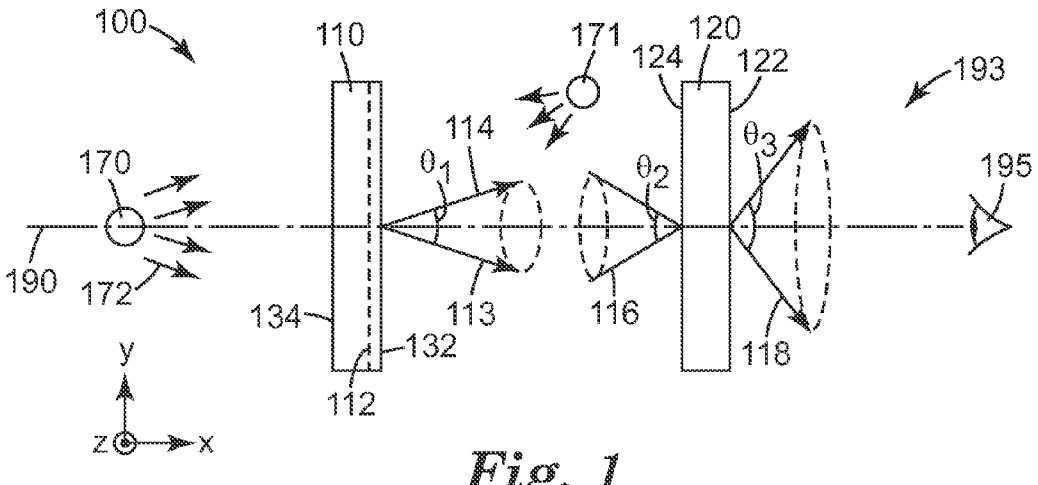


Fig. 1

(57) **Abstract:** An optical system is disclosed. The optical system includes an image forming device that forms an image in a display plane. The display plane emits image rays within an emitted cone that has an associated emitted angle. The optical system further includes an optical film that has an acceptance cone and an associated acceptance angle. The optical film receives the emitted image rays and substantially transmits the received image rays that are within the acceptance cone, and substantially blocks the image rays that are outside the acceptance cone. The acceptance angle is at least as large as the emitted angle

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OPTICAL SYSTEM WITH HIGH CONTRAST

REFERENCE TO RELATED APPLICATIONS

This application is related to commonly-assigned patent application OPTICAL SYSTEM WITH HIGH CONTRAST, having Application No. 60/990,150, having Attorney Docket No. 63819US002, and filed on the same date herewith.

FIELD OF THE INVENTION

This invention generally relates to display devices. The invention is particularly applicable to display devices where it is desirable to display an image with high contrast.

BACKGROUND

Display devices generally display information to a viewer. The performance of a display is described in terms of various characteristics of the display. One such characteristic is the ability of the display to absorb ambient light originated from various sources of light such as a light bulb in a room or on a street or the sun. Generally, ambient light that is incident on a display and not absorbed by the display is superimposed on the displayed information resulting in reduced contrast. The reduced contrast due to ambient light is generally referred to as washout. Washout is especially a concern in applications where the ambient light is very bright. For example, in outdoor applications, ambient light from the sun can significantly reduce the display contrast making it difficult for a viewer to discern the displayed information. A display, such as an instrument panel used in a motor vehicle, is particularly susceptible to washout from sun light. Typically, instrument panels in a motor vehicle are recessed in a housing to reduce ambient light access to the display. The housing is generally made black to further reduce washout by reducing the amount of light that is reflected by the housing.

Another characteristic of a display is the viewing angle. It is generally desirable that the displayed information be easily viewable over a predetermined range of viewing angles. In some cases, it is further desirable that the displayed information not be viewable outside a predetermined viewing range. In other words, it may be desirable to limit the viewability of a display to a particular and intended viewing position. For example, limiting the display viewability may be desirable for privacy considerations.

Another setting where such limitation may be desirable is where viewability of the display by a person located outside the intended viewing position may interfere with the person's ability to perform a given task. For example, in a motor vehicle, it may be desirable that a display or an instrument cluster be viewable by the driver but not by the other passengers as it may interfere with their comfort. Reflection of light that originates from an instrument display off of a windshield, a side window, or other glossy surfaces in a motor vehicle can be distracting to a driver. Typically, the recessed housing of an instrument cluster in a motor vehicle is designed to limit the viewing angle of the displayed information.

Another characteristic of a display is the overall footprint. Displays are generally desirable to have minimized depth in order to reduce the depth and/or the overall volume of the display. For example, in the case of an instrument panel in a motor vehicle, it may be desirable to minimize the recess in the instrument housing in order to save space or, for example, make room for accessories. As one display characteristic is improved, one or more other display characteristics often degrade. As a result, certain tradeoffs are made in a display device in order to best meet the performance criteria for a given display application. Thus, there remains a need for displays with improved overall performance while meeting the minimum performance criteria.

SUMMARY OF THE INVENTION

Generally, the present invention relates to optical systems. The present invention also relates to optical systems that have a small footprint and can display an image with high contrast.

In one embodiment of the invention, an optical system includes an image forming device that forms an image in a display plane. The display plane emits image rays within an emitted cone that has an emitted angle. The optical system further includes an optical film that has an acceptance cone and an associated acceptance angle. The optical film receives the emitted image rays and substantially transmits the received image rays that are within the acceptance cone, and substantially blocks the image rays that are outside the acceptance cone. The acceptance angle is at least as large as the emitted angle.

In another embodiment of the invention, an instrument cluster for displaying information to a viewing position includes a light source that emits light within an emitted

cone and an associated emitted angle. The instrument cluster further includes an optically absorptive film that is positioned adjacent to the light source and receives the emitted light. The optically absorptive film has an acceptance cone and an associated acceptance angle that is greater than the emitted angle. The optically absorptive film further has a viewing cone and an associated viewing angle that is different than the acceptance angle.

In another embodiment of the invention, an optical system includes an image forming device that has an exit face and emits image rays within an emitted cone. The exit face has a longest dimension "L1" along the exit face. The optical system further includes an optical film that has an input face that faces the exit face of the image forming device and a viewing face that is opposite to the input face and faces a viewing position. The optical film receives the emitted image rays through the input face and transmits the received image rays through the viewing face toward the viewing position. The optical film is a distance "D" from the light source. The input face of the optical film has a longest dimension "L2" along the input face. D is substantially smaller than L1 and L2.

BREIF DESCRIPTION OF DRAWINGS

The invention may be more completely understood and appreciated in consideration of the following detailed description of various embodiments of the invention in connection with the accompanying drawings, in which:

FIG. 1 is a schematic side-view of an optical system;

FIG. 2 is a schematic three-dimensional view of a cone of light rays;

FIG. 3 is a schematic plot of intensity versus angle;

FIG. 4 is a schematic three-dimensional view of a cone of light rays;

FIG. 5 is a schematic plot of transmittance versus angle;

FIG. 6 is a schematic side-view of an optical system;

FIG. 7 is a schematic front-view of an instrument panel;

FIG. 8 is a schematic three-dimensional view of an optical system;

FIG. 9 is a schematic side-view of an optical system; and

FIG. 10 is a schematic three-dimensional view of a prismatic light redirecting film.

In the specification, a same reference numeral used in multiple figures refers to the same or similar elements having the same or similar properties and functionalities.

DETAILED DESCRIPTION

The present invention is generally related to electronic display devices. The disclosures are particularly related to display devices used in an environment where it is desirable for the display to have a small foot print and absorb a substantial portion of the ambient light. The disclosures are particularly suited for display devices used outdoors or in environments with very bright ambient light.

FIG. 1 shows a schematic side-view of an optical system 100 for displaying an image to a viewing position 193 that may include a viewer 195. Optical system 100 is centered on an optical axis 190 and includes an image forming device 110 that is capable of forming an image in a display plane 112 that is located within device 110. The display plane emits image rays 113 within an emitted cone 114 defined as the smallest axially symmetric cone that includes all the emitted image rays that have an intensity that is at least half the maximum intensity I_{max} of the emitted image rays. Emitted cone 114 has an associated emitted cone θ_1.

For example, FIG. 2 shows a schematic of a cone of image rays 210 that includes an image ray 214 having a maximum intensity I_{max}. All the other image rays within cone 210 have intensities not less than $I_{max}/2$. For example, FIG. 3 shows a schematic plot of intensity versus angle for the image rays that lie in a cross-section 216 of cone 210 where cross-section 216 includes image ray 214 having maximum intensity I_{max} and limiting rays 218 and 219. In FIG. 3, point 317 at angle θ_{11} corresponds to image ray 214, point 318 at angle θ_{13} corresponds to limiting image ray 218, and point 319 at angle θ_{12} corresponds to limiting image ray 219. All the image rays between angles θ_{12} and θ_{13} have light intensities that are not less than $I_{max}/2$. In some cases, cone 210 can have a symmetry, such as an axial symmetry or a plane symmetry. In some cases, cone 210 is asymmetric, meaning that is does not have any symmetries.

In FIG. 2, cone 114 is the smallest axially symmetric cone that includes cone of image rays 210. Cone 114 has axial symmetry about an axis, such as optical axis 190. Referring back to FIG. 1, each image ray in the axially symmetric emitted cone 114 has an optical intensity that is at least $I_{max}/2$.

Optical system 100 further includes an optical film 120 that has an input side 124 facing image forming device 110 and display plane 112, and a viewing side 122 opposite

input side 124. Optical film 120 has a maximum optical transmittance of T_{max} and an acceptance cone 116 defined as the largest axially symmetric cone where each incident ray within the cone has an optical transmittance not less than half of T_{max}. Acceptance cone 116 has an associated acceptance angle θ_2.

For example, FIG. 4 shows a schematic of an incident cone 410 of light rays incident on optical film 120 that includes a ray 420 having maximum transmittance T_{max}. Cone 116 is the largest axially symmetric cone where each ray in the cone has an optical transmittance that is not less than $T_{max}/2$. For example, FIG. 5 shows a schematic plot of transmittance versus angle for the incident rays that lie in a cross-section 430 of cone 116 where cross-section 430 includes incident ray 420 having maximum transmittance T_{max} and limiting incident rays 412 and 413. In FIG. 5, point 510 at angle θ_{21} corresponds to incident ray 420, point 511 at angle θ_{22} corresponds to limiting incident ray 412, and point 512 at angle θ_{23} corresponds to limiting incident ray 413. All the incident rays between angles θ_{22} and θ_{23} have transmittance values that are not less than $T_{max}/2$. In some cases, incident cone 410 of all the image rays can have a symmetry such as an axial symmetry or a plane symmetry. In some cases, incident cone 410 is asymmetric, meaning that is does not have any symmetries.

In FIG. 4, cone 116 is the largest axially symmetric cone that can be included in cone 410. Cone 116 has axial symmetry about an axis, such as optical axis 190. Referring back to FIG. 1, each incident image ray in the axially symmetric cone 116 is transmitted by optical film 120 with an optical transmittance that is at least $T_{max}/2$.

In optical system 100 shown in FIG. 1, optical film 120 receives emitted image rays 113 from input side 124 of the optical film. Optical film 120 substantially transmits the received image rays that are inside incident cone 116 and substantially blocks image rays outside incident cone 116. As used herein, optical film 120 having a maximum optical transmittance T_{max} is said to substantially transmit an image ray if the optical transmittance of the image ray is at least $T_{max}/2$. Furthermore, optical film 120 substantially blocks an image ray if the optical transmittance of the image ray is less than $T_{max}/2$.

In general, emitted and acceptance angles θ_1 and θ_2, respectively, can have any value that is desirable in an application. In some cases, acceptance angle θ_2 is at least as large as emitted angle θ_1. In such cases, there may be no need to include an optical

element that has an optical power, such as collimating lenses and/or mirrors, between optical film 120 and image forming device 110. In some cases, there may be one or more optical elements with no optical power such as a plane mirror, a polarizer, a color or intensity filter, or a retarder between optical film 120 and image forming device 110.

In some cases, display plane 112 and optical film 120 are separated along optical axis 190 by a distance less than about 10 cm, or by a distance less than about 5 cm, or by a distance less than about 2 cm, or by a distance less than about 5 cm, or by a distance less than about 0.5 cm.

The exemplary optical system 100 shown in FIG. 1 is centered on optical axis 190. In general, the optical system may or may not be centered on an optical axis. For example, in some cases, optical film 120 may be shifted up or down so that it no longer is centered on the optical axis. In some cases, at least one of the emitted and acceptance cones is not centered on optical axis 190 even where all the optical elements in optical system 100 are centered on the optical axis. In some cases, at least one of the emitted and acceptance cones is centered on optical axis 190.

Optical axis 190 is not folded in the exemplary optical system shown in FIG. 1. In general, the optical axis may or may not be folded. For example, in some cases, the optical axis may be folded to reduce the overall footprint by, for example, using one or more folding mirrors.

Optical film 120 receives the image rays emitted by display plane 112 from input side or face 124 and transmits the received image rays through a viewing side or face 122 that is positioned opposite input side 124. Viewing side 122 displays the image received by optical film 120 to viewing area 193. Light is transmitted by optical film 120 within a viewing cone 118 which is the largest axially symmetric cone that includes all the transmitted image rays that have an intensity that is at least half the maximum intensity I_{max} of all the transmitted image rays. Viewing cone 118 has an associated viewing angle θ_3.

In some cases, image forming device 110 can be a reflective display, a transmissive display, or an emissive display, or a combination of different display types, such as a transflective display. A reflective display 110 requires front lighting, meaning illumination of the reflective display from a front side 132 of the display. In some cases, a front light source may be an ambient light 130 which can be, for example, sunlight or

room light. In some cases, front lighting can be provided by a light source 171 that is a part of, for example, optical system 100 and illuminates reflective display 110 from front side 132 of the display. In some cases, a reflective display can include an LCD or a digital micro-mirror array display, such as a Digital Light Processor (DLP) display from Texas Instruments, Inc.

A transmissive display 110 requires back lighting, meaning illumination of the transmissive display from a back side 134 of the display. In some cases, transmissive display 110 can include a backlight as a component of the display. For example, transmissive display 110 can be a liquid crystal display that includes a backlight that includes, for example, a lightguide, a light source, a reflective film, a diffuser, and one or more light redirecting films. In some cases, optical system 100 can include a light source 170 that emits light 172 that has no information or image content and that illuminates transmissive display 110 from back side 134 of the display.

In some cases, image forming device 110 can be an emissive display, meaning that the display includes a plurality of light emitting elements, such as emissive pixels, that can also form an image. In general, an emissive display does not require front or back lighting.

FIG. 6 shows a schematic side-view of an optical system 600 that is centered on an optical axis 690 and includes a liquid crystal display(LCD) 610 and an optical film 620 for displaying an image to a viewing position 693 that may include a viewer 695. LCD 610 includes a liquid crystal panel 614, a backlight 612 for providing light to panel 614, and a front cover 616. LCD 600 is an image forming device capable of forming an image in a display plane 612 which can be positioned, for example, within liquid crystal panel 614.

Display plane 612 emits image rays 613 within an emitted cone 614 defined as the smallest axially symmetric cone that includes all the emitted image rays that have an intensity that is at least half the maximum intensity I_{max} of all of the emitted image rays. Emitted cone 614 has an associated emitted angle θ_1 which is the full angle subtended by cone 614.

Optical film 620 includes an input side 627 facing image forming device 610 and display plane 612, and a viewing side 629 opposite input side 627 and facing viewing position 693. Optical film 620 has a maximum optical transmittance of T_{max} and an acceptance cone 616 defined as the largest axially symmetric cone where each incident ray

within the cone has an optical transmittance not less than half of T_{max}. Acceptance cone 616 has an associated acceptance angle θ_2 which is the full angle subtended by cone 616. In some cases, acceptance angle θ_2 is equal to or greater than emitted angle θ_1. In such cases, optical film 620 may be positioned adjacent LCD 612 with no or very little loss in collecting the image rays emitted by the LCD.

Optical film 620 substantially transmits the received image rays that are inside acceptance cone 616 and substantially blocks image rays outside acceptance cone 616, where a ray is substantially transmitted if the optical transmittance for the ray is at least one half of the maximum transmittance of the optical film, and a ray is substantially blocked if the optical transmittance for the ray is less than one half of the maximum transmittance of the optical film.

Optical film 620 further includes an optically absorptive layer 624 disposed on a first substrate 626, a second substrate 628, and a plurality of optically transparent beads 622 partially embedded in optically absorptive layer 624. The embedded portions of beads 622 are on the viewing side of optical film 620 and the non-embedded portions of beads 622 are on the input side of optical film 620. In some cases, an index of refraction of beads 622, for example in the visible range of the electromagnetic spectrum, is in a range from about 1.3 to about 2.6, or from about 1.5 to about 2.6, or from about 1.5 to about 2.4, or from about 1.5 to about 2.1, or from about 1.5 to about 1.9.

In some cases, the optical absorption coefficient of optically absorptive layer 624, for example in the visible, is at least 0.1 inverse microns, or at least 0.2 inverse microns, or at least 0.4 inverse microns, or at least 0.6 inverse microns.

Image rays incident on optical film 620 are transmitted by the film primarily through beads 622, where the beads effectively function as focusing lenses. In some cases, absorptive layer 624 is optically opaque, meaning that the transmittance of the absorptive layer is less than about 1%. In some cases, absorptive layer 624 can be partially transmissive. In such cases, the transmittance of the absorptive layer is less than about 20%, or less than about 10%, or less than about 5%.

Acceptance angle θ_2 is a function, in part, of bead index, absorption coefficient of the beads, and the size of the gaps between the beads and optically transparent substrate 626 as described in, for example, US Patent No. 5,563,738.

Image rays received by optical film 620 are transmitted toward viewing position 693 within a viewing cone 618 with an associated viewing angle θ_3, where viewing cone 618 is the largest axially symmetric cone that includes all the transmitted image rays that have an intensity that is at least half the maximum intensity I_{max} of the transmitted image rays. In some cases, viewing angle θ_3 is different than acceptance angle θ_2. In some cases, viewing angle θ_3 is greater than acceptance angle θ_2. In some cases, viewing angle θ_3 is not greater than acceptance angle θ_2.

In general, at least a portion of emitted image rays 613 received by the optical film is transmitted through beads 622. In some cases, most of the light transmitted by optical film 620 is transmitted through beads 622. In some cases, optical film 620 substantially blocks the received image rays outside acceptance cone 616 primarily by absorbing the image rays.

In some cases, acceptance angle θ_2 is less than about 70 degrees, or less than about 60 degrees, or less than about 50 degrees, or less than about 40 degrees, or less than about 30 degrees.

In some cases, optical system 600 can have a small footprint when, for example, acceptance angle θ_2 is greater than or substantially greater than emitted angle θ_1. In some cases, θ_2-θ_1 is at least 5 degrees, or at least 10 degrees, or at least 15 degrees, or at least 20 degrees, or at least 25 degrees, or at least 30 degrees, or at least 35 degrees, or at least 40 degrees. In some cases, LCD 610 is designed so that image rays 613 emitted by the LCD are within an emitted cone 614 with an emitted angle θ_1 where θ_1 is no more than 40 degrees, or no more than 30 degrees, or no more than 25 degrees, or no more than 20 degrees, or no more than 15 degrees, or no more than 10 degrees.

In some cases, substrates 626 and/or 628 can have high optical transmission. The substrates can be optically clear or diffuse. A diffusive substrate 626 can be a bulk diffuser and/or a surface diffuser. Bulk diffusion can be achieved by, for example, incorporating particles in the substrate. Surface diffusion can be achieved by, for example, making the surface of the substrate matte. Substrates 626 and/or 628 can be flexible or rigid and may have a colorant to modify, for example optimize, the color of the light exiting optical film 620 toward viewing position 693. Substrates 626 and/or 628 can be any material that is suitable in an application, such as polyethylene terapthalate (PET), polycarbonates, acrylics, and glass.

In some cases, substrates 626 and 628 primarily provide support for the other components, such as absorptive layer 624, in optical film 620. In some cases, at least one of substrates 626 and 628 provides one or more additional optical functions. For example, substrate 628 can be an optical diffuser, an absorbing polarizer, a reflective polarizer, or any other film with a function that may be desirable in an application. For example, in some cases, substrate 628 can be a polymeric multilayer optical film (MOF) reflective polarizer that substantially reflects light of one polarization and substantially transmits light of a second polarization orthogonal to the first polarization. In such cases, image forming device 610 can be a device, such as an LCD, that emits a polarized image that is parallel to a pass axis of MOF 628. In some cases, the first and second polarizations can be orthogonal linear polarizations. An example of a linear reflective polarizer is Dual Brightness Enhancing Film (DBEF) available from Minnesota Mining and Manufacturing Company of Saint Paul, Minnesota. In some cases, the first and second polarizations can be orthogonal circular polarizations, in which case, substrate 628 may also include a ¼ wave retarder. An example of a reflective circular polarizer is a cholesteric film, such as Nipocs film available from Nitto-Denko of Japan. Other exemplary reflective polarizers include DRPF reflective polarizers also available from 3M Company. In some cases, a reflective polarizer 628 can reflect light of one polarization substantially over the entire visible range.

In some cases, such as when substrate 628 is a reflective polarizer, in the absence of image rays 613, viewing side 629 has a metallic appearance, such as a metallic silver appearance.

In the exemplary optical system 600, substrate 628 is attached to substrate 626. In some cases, substrate 628 may be a separate film, separated from substrate 626 by, for example, an air gap.

Beads 622 can be made of any material that is suitable in an application such as a material that is clear and highly optically transmissive to visible light. Examples of suitable materials for beads 622 include various types of glass, polymeric materials including polymethylmethacrylate (PMMA), polystyrene, and mixtures of two or more different materials.

In some cases, beads 622 are substantially spherical. In general, beads 622 can have any shape that may be suitable in an application, such as oval or other desired shapes.

For example, beads 622 can include uniformly oriented oval beads to asymmetrically spread light along the horizontal and vertical directions. In some cases, the diameter range of beads 622 and the thickness of optically absorptive layer 624 are chosen so that most beads are only partially embedded in layer 624 to increase optical transmittance of optical film 620 while maintaining high image contrast displayed by optical system 600.

In some cases, optical transmittance of optical film 620 for normal incidence from input side 627 is in a range from about 30% to about 40%, and for normal incidence from viewing side 629 is in a range from about 5% to about 15%. In some cases, specular optical reflectance of optical film 620 for normal incidence from input side 627 is less than about 1% or less than about 0.5%, and for normal incidence from viewing side 629 is less than about 5%. In some cases, an anti-reflection coating on the viewing side can reduce the reflection from this side to less than about 1% or less than about 0.5%.

In some cases, optically absorptive layer 624 can include a light absorptive material dispersed in an optically clear binder. In some cases, light absorptive materials can include carbon black, light absorptive dyes such as black dyes. In some cases, an optically clear binder include thermoplastics, radiation cured or thermoset acrylates, epoxies, silicone-based materials, or pressure sensitive adhesives.

FIG. 7 shows a schematic front-view of an instrument panel 700 in, for example, a motor vehicle or an air plane. Instrument panel 700 includes one or more instrument clusters 710 for displaying information to a viewer, such as a driver, a pilot, or a passenger. An instrument cluster can include an optical system similar to any optical system disclosed herein, such as optical system 100 or optical system 600. An advantage of using optical system 600 in an instrument cluster is that a substantial portion of ambient light 720 incident on the instrument cluster is absorbed by the optically absorptive layer 624, thereby reducing or eliminating washout and increasing contrast of any information or image that is being displayed by the instrument cluster.

In some cases, an instrument cluster can include an image forming device that includes display graphics, such as alphanumerics 731 and right arrow indicator 732. In some cases, an instrument cluster in a motor vehicle can include an optical system 600 where image forming device 610 is capable of displaying a high contrast movie to, for example, the passengers in the motor vehicle.

Another advantage of using optical system 600 in an instrument panel is reduced footprint when, for example, emitted angle θ_1 is substantially less than acceptance angle θ_2. In such cases, optical film 620 can be positioned adjacent or nearly adjacent to image forming device 610, where the separation between the two can be less than 2 cm, or less than 1 cm, or less than 0.5 cm, or less than 0.2 cm.

FIG. 8 shows a schematic three-dimensional view of an optical system 800 for displaying an image or information to a viewing area 893 that can include a viewer 895. Optical system 800 is centered on an optical axis 890 and includes an image forming device 810 similar to image forming device 110 and an optical film 820 similar to optical film 120. Image forming device 810 includes an exit face 850 and emits image rays 813 within an emitted cone 814. Exit face 850 has a longest dimension "L_1" along the exit face. In the exemplary optical system shown in FIG. 8, the exit face is rectangular and the longest dimension is length L_1 of diagonal 815 of the exit face. In general, exit face can have any shape that may be desirable in an application and the longest dimension of the exit face can be along any direction. Emitted cone 814 has an associated emitted angle θ_1.

Optical film 820 includes an input face 824 that faces exit face 850 of image forming device 810 and a viewing face 822 opposite input face 824 that faces viewing area 893. Optical film 820 receives emitted image rays 813 through input face 824 of the optical film and transmits the received image rays through viewing face 822 of the optical film toward viewing position 893. Input face 824 has a longest dimension "L_2" along the input face. In the exemplary optical system shown in FIG. 8, the input face is rectangular and the longest dimension is length L_2 of diagonal 835 of the input face. In general, input face can have any shape that may be desirable in an application and the longest dimension of the input face can be along any direction. Optical film 820 has an acceptance cone 816 that has an acceptance angle θ_2 where, in some cases, θ_2 can be equal to or greater than θ_1.

The distance between exit face 850 of image forming device 810 and input face 824 of optical film 820 is "D". In some cases, distance "D" is substantially smaller than L_1 and L_2. In some cases, distance D is at least 2 times less than the smaller of L_1 and L_2, or at least 4 times less than the smaller of L_1 and L_2, or at least 8 times less than the smaller of L_1 and L_2, or at least 10 times less than the smaller of L_1 and L_2, or at least 20 times less than the smaller of L_1 and L_2, or at least 30 times less than the smaller of L_1 and L_2, or at least 40 times less than the smaller of L_1 and L_2, or at least 50 times less than the

smaller of L_1 and L_2, or at least 100 times less than the smaller of L_1 and L_2, or at least 500 times less than the smaller of L_1 and L_2.

In some cases, optical system 800 does not include any optical elements with optical power between image forming device 810 and optical film 820.

In some cases, image forming device 810 can include permanent or replaceable graphics, such as pictures, maps, or icons. In some cases, image forming device 810 can include an electronic display such as a liquid crystal display (LCD), a cathode ray tube (CRT), a plasma display, an electroluminescent display, an OLED, or an electrophoretic display.

FIG. 9 shows a schematic side-view of an optical system 900 for displaying an image to a viewing position 990 that can include a viewer 995. Optical system 900 includes a housing 901 that includes an interior 902, a reflective interior surface 905, and a first opening 907. Optical system 900 further includes a spatial light modulator (SLM) 950 that is positioned proximate or near first opening 907 and a light source 920 that is disposed within the interior of housing 901 and emits light 922. Reflective interior surface 905 of housing 902, in part, recycles and homogenizes light that is emitted by light source 920. In some cases, light 922 does not contain any images, data or information. SLM 950 modulates light 922 to form transmitted image rays 962. Modulated image rays 962 carry information, data, or an image. In some cases, image rays 962 are substantially polarized. For example, the image rays can be substantially linearly or circularly polarized. In some cases, image rays 962 are substantially un-polarized.

Optical system 900 also includes a first light redirecting film 930 that is disposed proximate first opening 907 between SLM 950 and light source 920, and a second light redirecting film 940 disposed proximate first opening 907 between first light redirecting film 930 and SLM 950. Light directing films 930 and 940 recycle at least a portion of light 922 that is emitted by light source 920. In some cases, one or both light redirecting films can be a prismatic film, such as prismatic films described in, for example, U.S. Patent Nos. 4,906,070 and 5,056,892.

FIG. 10 shows a schematic three-dimensional view of a prismatic light redirecting film 1000 that can be used as light directing film 930 and/or light directing film 940 in FIG. 9. Film 1000 has a major first surface 1010 and a microstructured second major surface 1020. Film 1000 further includes a plurality of linear prisms 1015 each of which

has two side surfaces, such as side surfaces 1021 and 1022, and extends linearly along the y-axis. Film 1000 has a prismatic cross-section in the xz-plane. Film 1000 further has a plurality of peaks 1001 and grooves 1002. In some cases, peaks 1001 have a same height as measured from a common reference plane 1025 placed any where between first and second major surfaces 1010 and 1020, respectively. In some other cases, peaks 1001 can have different heights as described in, for example, U.S. Patent No. 5,771,328 and/or the height of a peak for a prism can vary along the extended direction of the prism as described in, for example, U.S. Patent No. 6,354,709.

The operation of light directing film 1000 is described in, for example, U.S. Patent No. 5,056,892. In summary, a light ray, such as ray 1031, that strikes structured surfaces 1021 or 1022 at incident angles larger than the critical angle are totally internally reflected back. On the other hand, a light ray, such as ray 1032, that is incident on surfaces 1021 or 1022 at angles less than the critical angle is partly transmitted (such as ray 1032a) and partly reflected (such as ray 1032b). An end result is that, when employed in a display, such as a liquid crystal display or optical system 900, light directing film 1000 can improve on-axis (along the x-axis) transmission by recycling light that is totally internally reflected.

Referring back to FIG. 9, in some cases, the linear prisms in light redirecting films 930 and 940 can extend along different directions. For example, the linear prisms in light redirecting film 930 can extend along the y-axis and the linear prisms in light redirecting film 940 can extend along the z-axis.

Spatial light modulator 950 can be any type SLM that can be suitable in an application. For example, SLM 950 can be a liquid crystal display, a grating-type light valve, or a digital micro-mirror device. In some cases, image rays 962 are modulated and transmitted by SLM 950 within an emitted cone 960 that has an associated emitted angle θ_1.

Optical system 900 further includes an optically absorptive film 970 that is disposed proximate first opening 907 between SLM 950 and viewing position 990. Optically absorptive film 970 receives image rays 960 that are modulated and emitted by SLM 950 and transmits and displays the received image rays to viewing position 990.

In some cases, optically absorptive film 970 has an input acceptance cone 960 that has an input acceptance angle θ_2. In some cases, θ_2 is equal to θ_1. In some cases, θ_2

is greater than θ_1. In some cases, θ_2 is greater than θ_1 by at least 5 degrees, or by at least 10 degrees, or by at least 15 degrees, or by at least 20 degrees, or by at least 30 degrees, or by at least 40 degrees.

In some cases, the spacing between optically absorptive film 970 and SLM 950 can be less than 2 cm, or less than 1 cm, or less than 0.5 cm, or less than 0.2 cm. In some cases, an input face 972 of optically absorptive film 970 is in physical contact with an output face 952 of SLM 950.

In some cases, optical system 900 does not include any optical elements with optical power, such as collimating lenses and/or mirrors, between light source 920 and optically absorptive film 970. In some cases, there may be one or more optical elements with no optical power such as a plane mirror, a polarizer, a color or intensity filter, or a retarder between light source 920 and optically absorptive film 970.

In some cases, input face 972 of optically absorptive 970 includes a plurality of optically transparent beads 974 partially embedded in a light absorbing layer (not explicitly shown in FIG. 9). In some cases, optically absorptive film 970 transmits light into a viewing cone 976 that has a viewing angle θ_3. In some cases, θ_3 is different than θ_2. For example, in some cases, θ_3 is smaller than θ_2.

In some cases, the exterior 904 of housing 901 is black. Reflective interior surface 905 of housing 901 can be made reflective by using any method that may be suitable in an application. For example, interior surface 905 can be coated with a light reflecting material such as white paint or white powder, and/or by a reflective metal such as Al by for example vapor deposition. In some cases, such as when surface 905 is coated with a flat light scattering white paint, reflective interior surface 905 is diffusively reflective.

In some cases, interior surface 905 is made reflective by applying a reflective film 903 to the surface. For example, reflective film 903 can be an aluminized film or a multi-layer polymeric reflective film, such as a reflective polarizing film or a Vikuiti ESR film available from 3M Company, St. Paul, Minnesota. In some cases, reflective film 903 is laminated to the interior surface of housing 901. In some cases, housing 901 can be made, at least in part, from a reflective film. In some cases, reflective film 903 is specularly reflective. In some cases, reflective film 903 is diffusively reflective.

Light source 920 can be any type light source that may be desirable in an application. Exemplary light source include mercury arc light sources, fluorescent light

sources, and light emitting diode (LED) light sources. In some cases, light source 920 can include a plurality of light emitting elements, such as two or more LEDs.

Optical system 900 further includes a cover 980 for covering housing 901, optically absorptive film 970, and the other components in the optical system. In some cases, cover 980 can be permanently attached to optically absorptive film 970. In some cases, cover 980 can be "releasably attached" to optically absorptive film 970, meaning that the attached cover can be removed from the absorptive film without any noticeable damage to the cover and/or the film where the detached cover can be subsequently reattached to the film in approximately the same previous attachment location.

In some cases, cover 980 is permanently attached to optically absorptive film 970 and the combination is releasably attached to housing 901. In some cases, such as in the case where optical system 900 is part of an instrument panel of a motor vehicle, the cover may be releasably attached to the instrument panel.

As used herein, terms such as "vertical", "horizontal", "above", "below", "left" , "right", "upper" and "lower", "front" and "back", "clockwise" and "counter clockwise" and other similar terms, refer to relative positions as shown in the figures. In general, a physical embodiment can have a different orientation, and in that case, the terms are intended to refer to relative positions modified to the actual orientation of the device. For example, even if the construction in FIG. 1 is flipped as compared to the orientation in the figure, arrow indicator 732 is still considered to be to a "right" arrow indicator.

All patents, patent applications, and other publications cited above are incorporated by reference into this document as if reproduced in full. While specific examples of the invention are described in detail above to facilitate explanation of various aspects of the invention, it should be understood that the intention is not to limit the invention to the specifics of the examples. Rather, the intention is to cover all modifications, embodiments, and alternatives falling within the spirit and scope of the invention as defined by the appended claims.

What is claimed is:

1. An optical system, comprising:

an image forming device forming an image in a display plane, the display plane emitting image rays within an emitted cone having an emitted angle; and

an optical film having an acceptance cone and an associated acceptance angle, the optical film receiving the emitted image rays from an input side of the optical film facing the display plane, the optical film substantially transmitting the received image rays inside the acceptance cone and substantially blocking image rays outside the acceptance cone, the acceptance angle being at least as large as the emitted angle.

2. The optical system of claim 1 being centered on an optical axis.

3. The optical system of claim 2, wherein the optical axis is not folded.

4. The optical system of claim 2, wherein the display plane and the optical film are separated along the optical axis by a distance less than about 10 cm.

5. The optical system of claim 2, wherein the display plane and the optical film are separated along the optical axis by a distance less than about 5 cm.

6. The optical system of claim 2, wherein the display plane and the optical film are separated along the optical axis by a distance less than about 1 cm.

7. The optical system of claim 2, wherein the emitted and acceptance cones are centered on the optical axis.

8. The optical system of claim 1, wherein the optical film further comprises a viewing side opposite the input side, the viewing side displaying an image transmitted by the optical film to a viewing area.

9. The optical system of claim 8, wherein the optical film further comprises:

an optically absorptive layer; and

a plurality of optically transparent beads partially embedded in the optically absorptive layer, the embedded portion of the beads being on the viewing side of the optical film, such that at least a portion of the received emitted image rays is transmitted through the beads.

10. The optical system of claim 9, wherein the optically transparent beads are substantially spherical.

11. The optical system of claim 9, wherein an index of refraction of the optically transparent beads is in a range from about 1.5 to about 1.9.

12. The optical system of claim 9, wherein an absorption coefficient of the optically absorptive layer is at least 0.4 inverse micron.

13. The optical system of claim 1, wherein the optical film substantially blocks the image rays outside the acceptance cone primarily by absorbing the image rays.

14. The optical system of claim 1, wherein the image forming device comprises a liquid crystal display.

15. The optical system of claim 14, wherein the display plane is within the liquid crystal display.

16. The optical system of claim 1, wherein the acceptance angle is less than about 30 degrees.

17. The optical system of claim 1, wherein the optical film has a viewing cone and an associated viewing angle different than the acceptance angle.

18. An instrument cluster for displaying information to a viewing position, comprising:

a light source emitting light within an emitted cone and an associated emitted angle;

an optically absorptive film adjacent the light source and receiving the emitted light, the optically absorptive film comprising:

an acceptance cone and an associated acceptance angle greater than the emitted angle; and

a viewing cone and an associated viewing angle different than the acceptance angle.

19. The instrument cluster of claim 18, wherein the optically absorptive film comprises a plurality of optically transparent beads partially embedded in an optically absorptive layer and partially exposed to the light source, wherein at least a portion of the received light is transmitted through the beads.

20. The instrument cluster of claim 18, further comprising display graphics.

21. An optical system, comprising:

an image forming device having an exit face and emitting image rays within an emitted cone, the exit face having a longest dimension "L_1" along the exit face;

an optical film having an input face facing the exit face of the image forming device and a viewing face opposite the input face and facing a viewing position, the optical film receiving the emitted image rays through the input face and transmitting the received image rays through the viewing face toward the viewing position, the optical film being a distance "D" from the light source, the input face of the optical film having a longest dimension "L_2" along the input face, D being substantially smaller than L_1 and L_2.

22. The optical system of claim 21, wherein D is at least 10 times less than the smaller of L_1 and L_2.

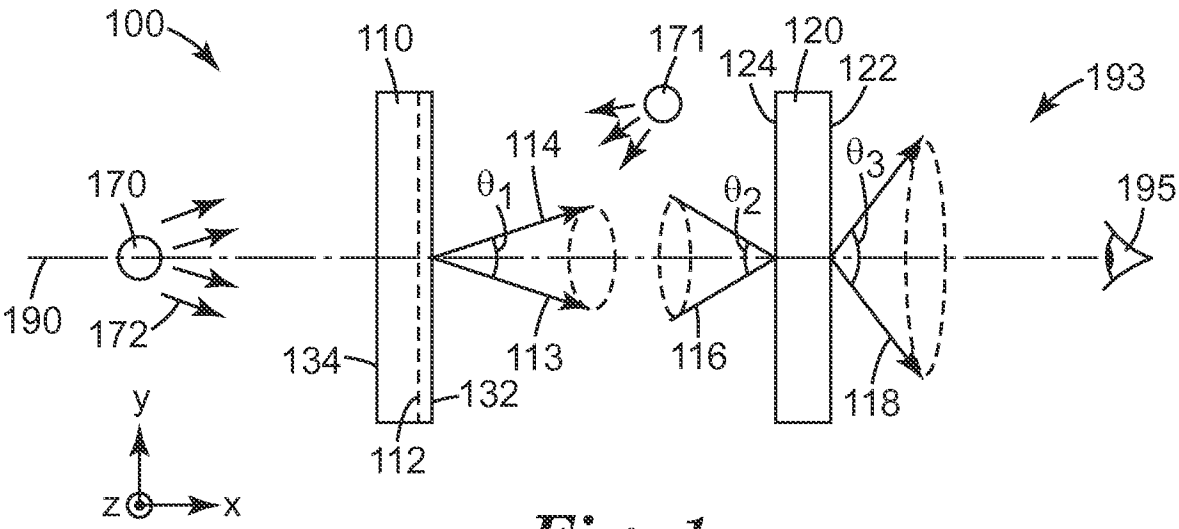


Fig. 1

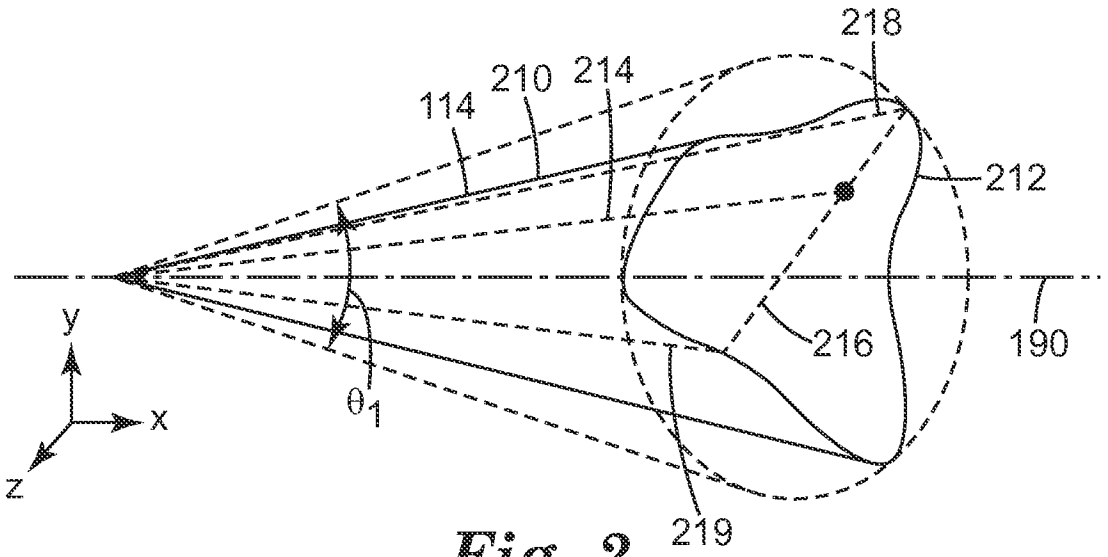


Fig. 2

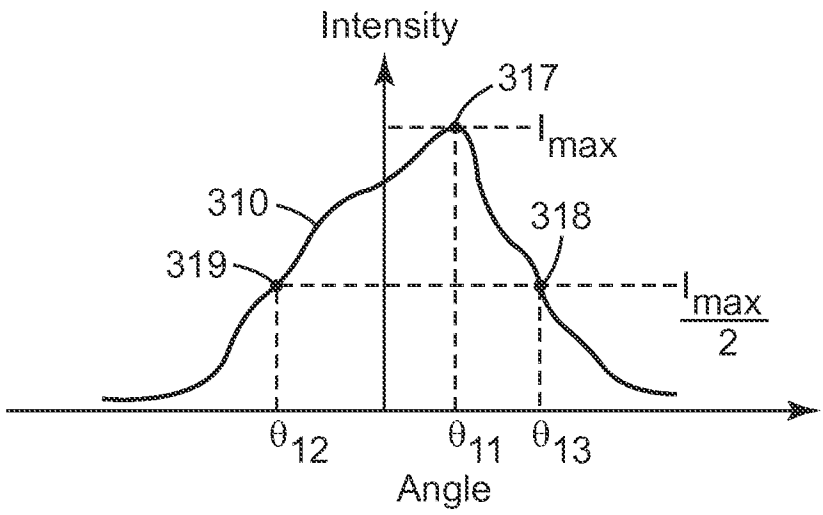


Fig. 3

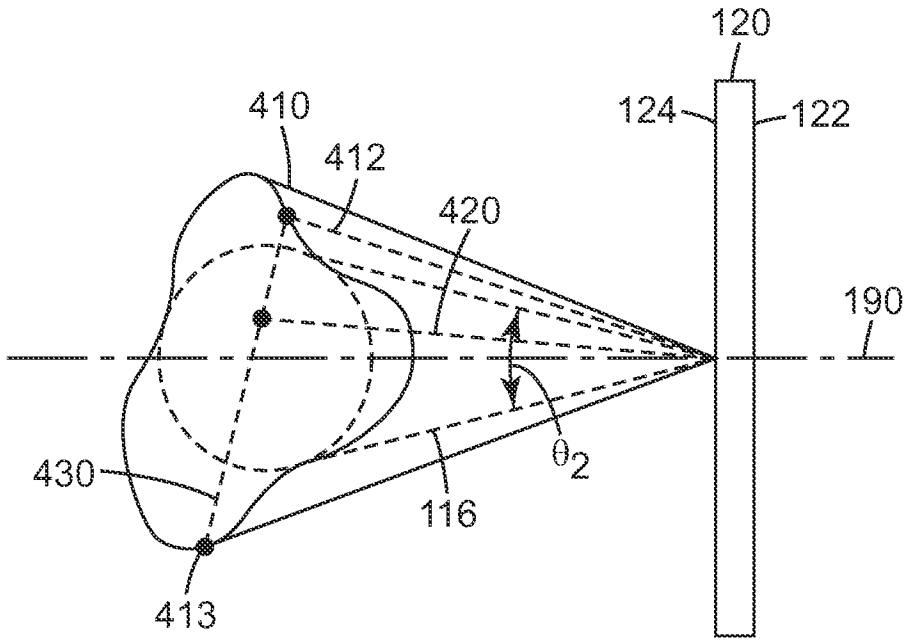

120
124
122
410
412
420
190
430
116
θ2
413

Fig. 4

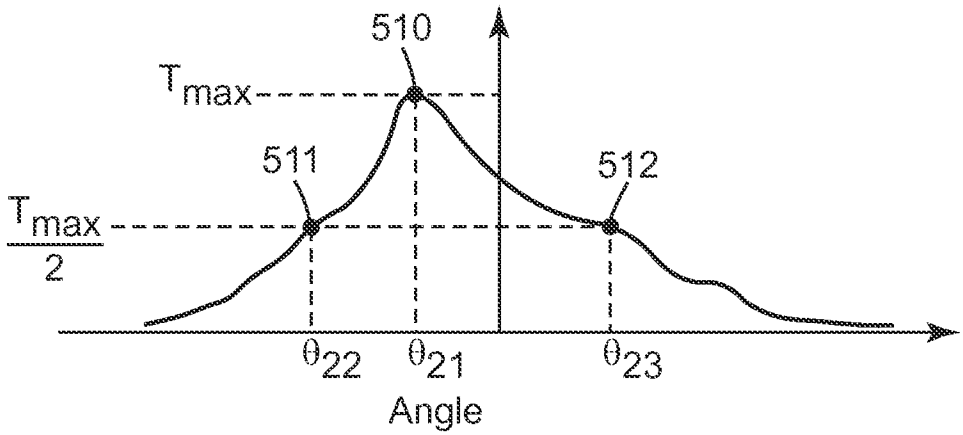

510
Tmax
511
512
Tmax
2
θ22
θ21
θ23
Angle

Fig. 5

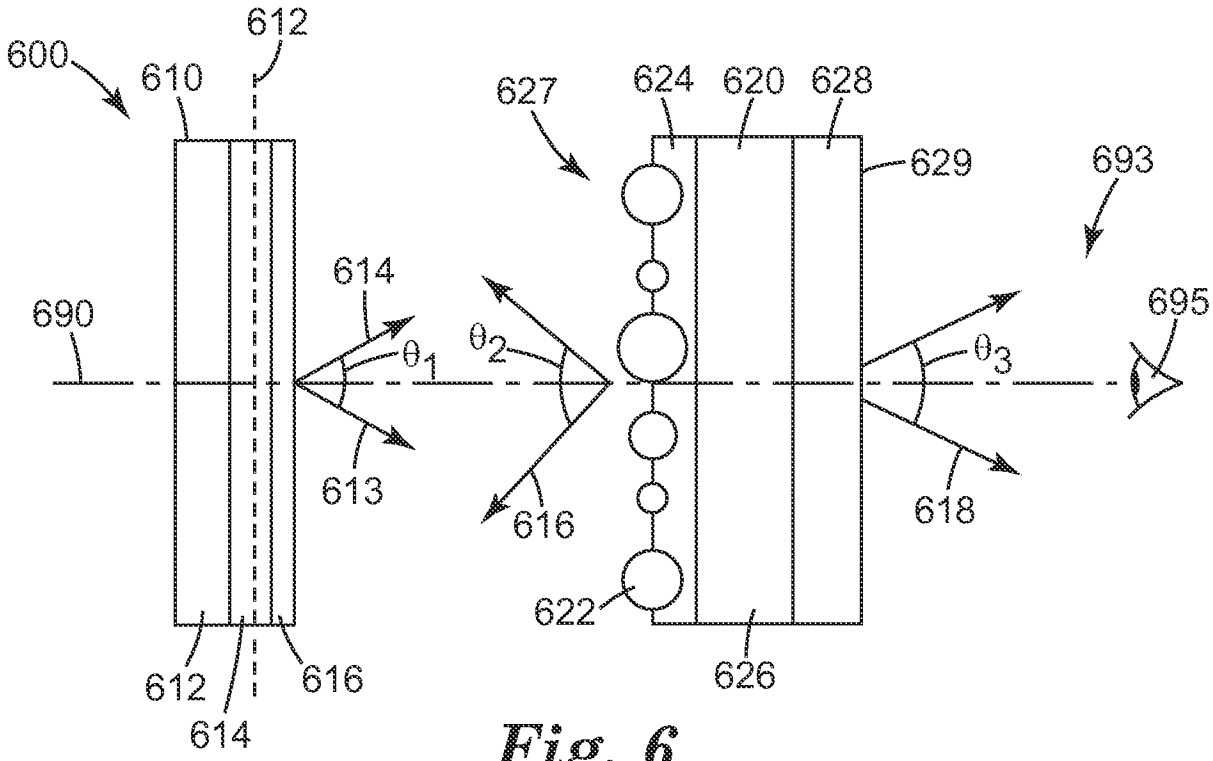

600
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627
624
620
628
629
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614
690
θ1
θ2
θ3
695
613
616
618
622
612
614
616
626

Fig. 6

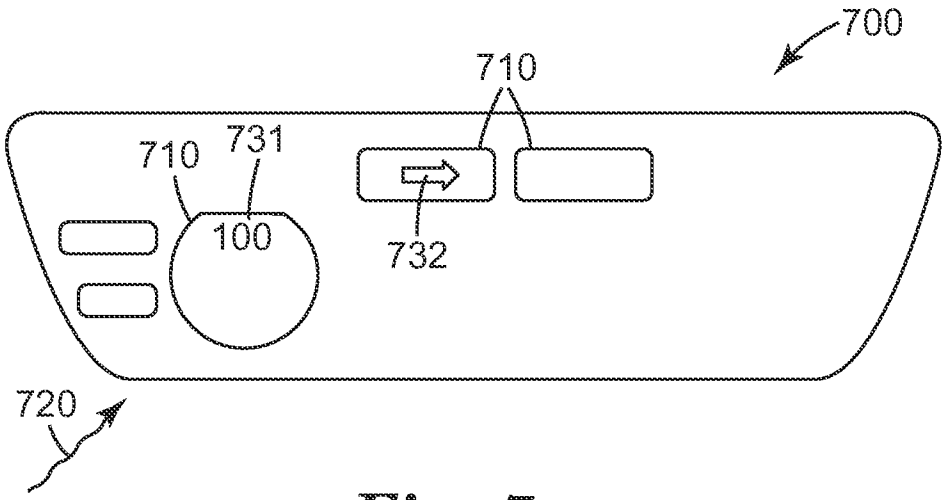

700
710
710
731
100
732
720

Fig. 7

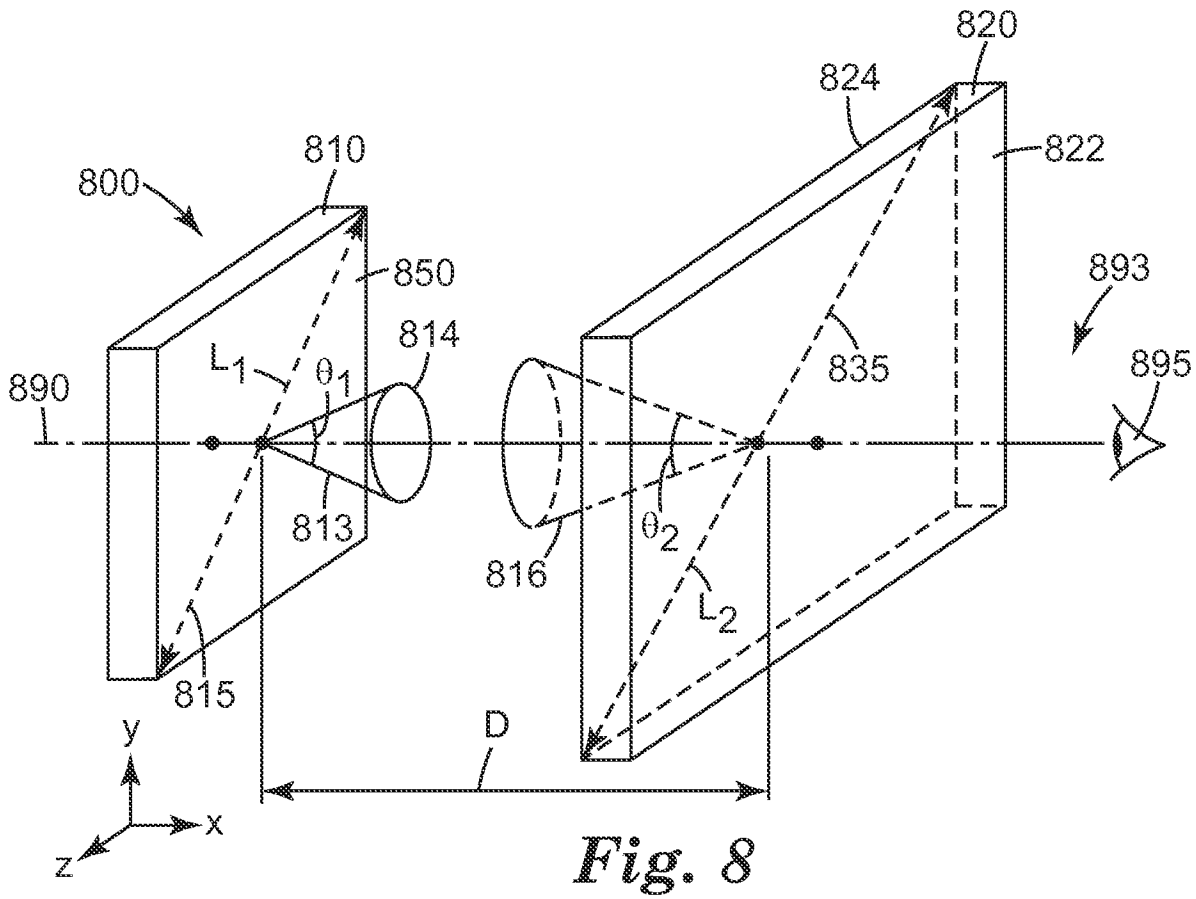

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824
822
810
800
850
893
814
835
895
890
L1
θ1
813
θ2
816
L2
815
D
y
x
z

Fig. 8

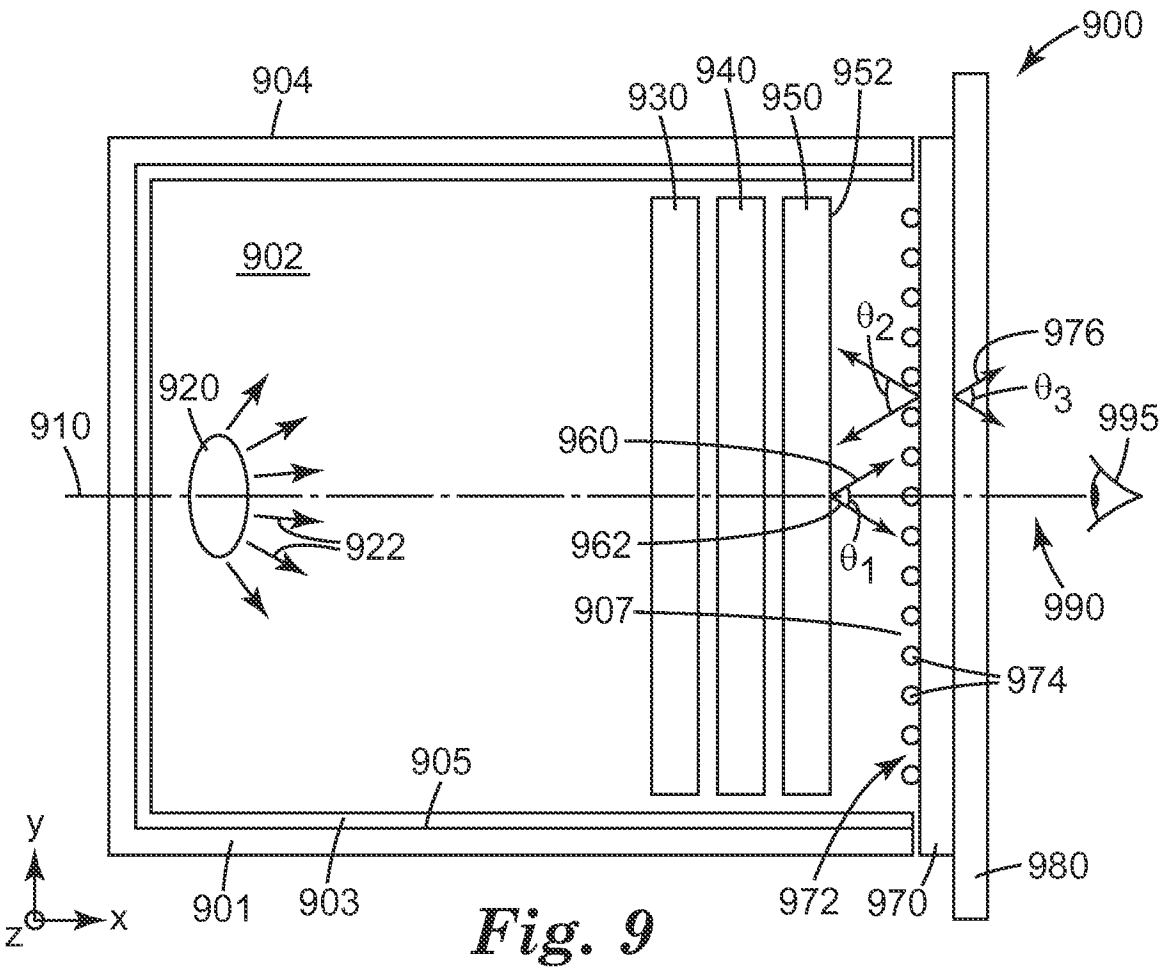

900
904
930
940
950
952
902
θ2
976
θ3
920
910
960
995
922
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θ1
907
990
974
905
980
y
x
z
901
903
972
970

Fig. 9

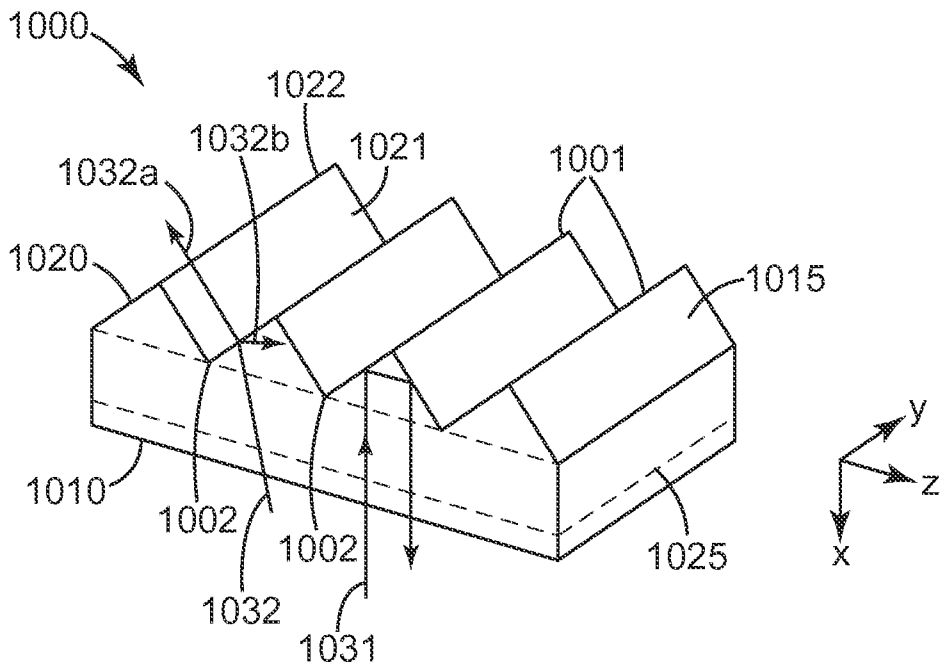

1000
1022
1032b
1021
1001
1032a
1020
1015
1010
1002
1002
1025
1032
1031
y
z
x

Fig. 10