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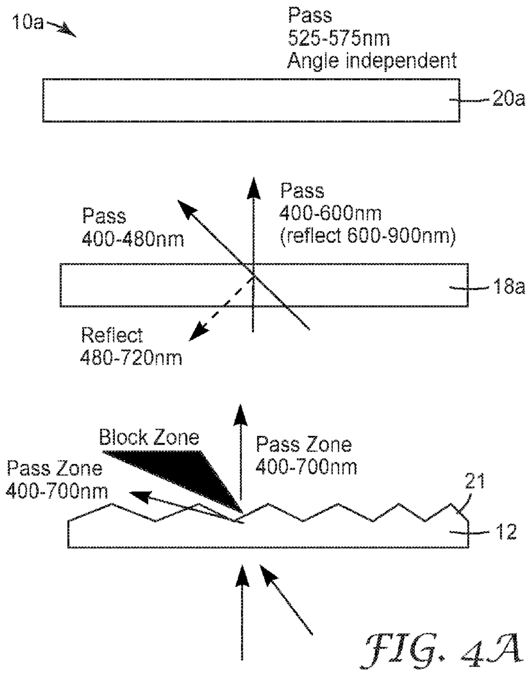

FIG. 4A

(57) Abstract: An example optical filter may include an angle blocking layer Slaving a first angular light blocking range θ_{AL} relative to a normal axis, and an interference filter adjacent the angle blocking layer having a second angular light blocking range θ_{IF} relative to the normal axis. θ_{IF} and θ_{AL} at least partially overlap. The example optical filter has a predetermined light transmission zone comprising angles from 0° to a maximum light transmission angle θ_{Tmax} relative to a normal axis of the major surface. The example optical filter has a predetermined angular light blocking zone θ_B, a union of θ_{IF} and θ_{AL}. An example optical filter may include an interference filter having an incidence angle-dependent reflection band and an absorbing layer having an absorption band. The incidence angle-dependent reflection band and the absorption band may overlap at least one wavelength at least one angle of incidence.

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OPTICAL FILTERS COMPLEMENTARY ANGULAR BLOCKING REGIONS

FIELD

[0001] The disclosure relates to optical filters and sensors including optical filters. The disclosure is also related to optical filters having complementary angular blocking regions.

BACKGROUND

[0002] Optical filters are employed in a wide variety of applications such as optical communication systems, optical sensors, imaging, scientific and industrial optical equipment, and display systems. Optical filters may include optical layers that manage the transmission of incident electromagnetic radiation, including light. Optical filters may reflect or absorb a portion of incident light, and transmit another portion of incident light. Optical layers within an optical filter may differ in wavelength selectivity, optical transmittance, optical clarity, optical haze, and index of refraction.

[0003] There are various types of optical sensors that can be used in the above applications including silicon photosensors and also CMOS image sensors. These sensors have a spectral sensitivity function that spans the visible and near infrared, and which is non-uniform over the range. Since an optical sensor has a broad spectral sensitivity function, ambient light sources can create optical noise and interfere with the function of the sensor. Unwanted light could come from a number of ambient sources including the Sun, incandescent, LEDs, OLEDs, etc. In addition to ambient sources causing problems, light sources within an optical system containing the sensor can cause a problem. For example, a pulse oximeter is a device that senses the oxygenation or deoxygenation of the blood. These devices can have two LEDs emitting at two different wavelengths, and two different sensors paired with the respective LEDs. In this case, light from the first LED could interfere with the second sensor, so an optical filter that prevents a sensor from receiving light from the wrong LED could reduce this interference.

SUMMARY

[0004] In an example, the disclosure describes an example optical filter including a major surface. The example optical filter has a predetermined light transmission zone comprising angles from 0° to a maximum light transmission angle θ_{Tmax} relative to a normal axis of the major surface. The example optical filter has a predetermined angular light blocking zone θ_B comprising angles from 90 - θ_{Tmax} to 90°. The example optical filter includes an angle blocking layer having a first angular light blocking range θ_{AL} relative to the normal axis. The example optical filter includes an interference filter adjacent the angle blocking layer. The interference filter has a second angular light blocking range θ_{IF} relative to the normal axis. θ_B is a union of θ_{IF} and θ_{AL}. θ_{IF} and θ_{AL} at least partially overlap.

[0005] In an example, the disclosure describes an example optical filter including an interference filter having an incidence angle-dependent reflection band. The example optical filter includes an absorbing layer having an absorption band. The incidence angle-dependent reflection band and the absorption band overlap at at least one wavelength at at least one angle of incidence.

[0006] The details of one or more aspects of the invention are set forth in the accompanying drawings and the description below. Other features, objects, and advantages of the invention will be apparent from the description and drawings, and from the claims.

BRIEF DESCRIPTION OF DRAWINGS

[0007] The foregoing and other aspects of this invention are made more evident in the following Detailed Description, when read in conjunction with the attached Figures.

[0008] FIGS. 1A and 1B are charts illustrating the angular transmission of example angle blocking layers.

[0009] FIG. 1C is a conceptual illustration of the band shift of an example interference filter with a change in incidence angle.

[0010] FIGS. 2A and 2B are conceptual and schematic lateral cross-sectional views of an example article including a recessed structure.

[0011] FIG. 2C is a conceptual and schematic lateral cross-sectional view of an example article including a recessed structure and an interference filter.

[0012] FIG. 2D is a conceptual and schematic lateral cross-sectional view of the reduction in thickness of an article including a recessed structure and an interference filter compared to an article including only a recessed structure.

[0013] FIGS. 3A, 3B, and 3C are charts illustrating the transmission spectra of example absorbing layers.

[0014] FIGS. 4A and 4B are schematic and conceptual exploded cross-sectional views of example optical filters including an angle blocking layer, an interference filter, and an absorbing layer.

[0015] FIG. 4C is a schematic and conceptual exploded cross-sectional view of an example optical filter including an angle blocking layer, and having an inclined pass zone.

[0016] FIG. 4D is a schematic and conceptual exploded cross-sectional view of an example optical filter including an angle blocking layer, and an interference filter, and having an inclined pass zone defined by an extended block zone.

[0017] FIG. 5A is a schematic and conceptual illustration of the angular transmission and blocking by the example optical filter of 4A.

[0018] FIG. 5B is a schematic and conceptual illustration of the angular transmission and blocking by the example optical filter of FIG. 5A.

[0019] FIG. 5C is a schematic and conceptual illustration of the angular transmission and blocking by an example optical filter.

[0020] FIG. 6A is a conceptual illustration of the band shift with a change in incidence angle of an example optical including an interference filter and an absorbing layer.

[0021] FIG. 6B is a photograph comparing light transmission and blocking by a multilayer optical film interference filter, a dye filter, and an article including a combination of the multilayer optical film interference filter and the dye filter.

[0022] FIG. 7A is a chart illustrating the transmission spectrum of the example multilayer optical film interference filter of FIG. 6B.

[0023] FIG. 7B is a chart illustrating the transmission spectrum of the absorbing layer of FIG. 6B.

[0024] FIG. 7C is a chart illustrating the transmission spectrum of an example optical filter including the interference filter of FIG. 7A and the absorbing layer of FIG. 7B.

[0025] FIG. 8A is a chart illustrating the transmission spectrum of an example multilayer optical film interference filter.

[0026] FIG. 8B is a chart illustrating the transmission spectrum of an example absorbing layer.

[0027] FIG. 8C is a chart illustrating the transmission spectrum of an example optical filter including the interference filter of FIG. 8A and the absorbing layer of FIG. 8B.

[0028] FIG. 9 is a schematic and conceptual diagram illustrating an example system including an optical filter, a source, a sensor, and a reflector.

[0029] It should be understood that features of certain Figures of this disclosure may not necessarily be drawn to scale, and that the Figures present non-exclusive examples of the techniques disclosed herein.

DETAILED DESCRIPTION

[0030] Optical filters may be used to change the spectrum of reflected or transmitted light. For example, multilayer optical films (MOFs) may be used in optical filters. MOFs can be made using multilayer thin film techniques, and, the wavelength range and other optical properties of MOFs may be a function of the range of thicknesses and refractive indices of the layers. Optical filters may also be used to control angles along which light of predetermined wavelengths are transmitted or reflected.

[0031] Variations in wavelength of the position of the band edge of a MOF reflecting band, for example, of a MOF interference filter, may lead to visually detectable optical artifacts as the incidence angle or viewing angle is changed. For example, minor caliper variations especially at the angle of transition between the pass and extinction zones of an optical filter including an interference filter may be detectable, detracting from a visually uniform transition between blocking and transmitting angles.

[0032] Such a variation may be mitigated by combining an angle limiting element, for example, a structured surface film. Structured surfaces, for example prismatic films, may achieve sharp transitions from pass to block, but may leak light at other angles which may be on the other side of the block zone. Even prismatic films with a minimal amount of leakage at high angles of incidence may exhibit visible light leakage. Further, prismatic films that have a minimal high angle light emission may require that the transition angle from pass to block be designed farther away from normal incidence than may be desired for a particular application. Additionally, a prismatic film may function best along angles transverse to the axis of the prisms, and not very well along the orthogonal plane. When used alone, prismatic films may exhibit a metallic appearance under certain conditions. Thus, while prismatic films may exhibit relatively sharp transitions from pass to block angles, they may not block a single continuous zone that encompasses high angles.

[0033] Combining an interference filter with an angle limiting element in an optical filter may overcome their respective limitations. For example, interference filters may effectively block light transmission at high angles that angle limiting elements may not block, while angle limiting elements may mitigate the band edge variations exhibited by interference filters.

[0034] Example optical filters according to the disclosure may limit the angular extent of light from a narrow wavelength source to a detector. In some examples, example optical filters may control the angular intensity distribution of light within a predetermined wavelength band. In some examples, example optical filters may include an interference filter, for example, a MOF interference filter, and an angle limiting element, for example, an angle blocking layer. The angle blocking layer may be refractive or physically block light at predetermined angles by optical phenomena, for example, absorption. The interference filter and the angle blocking layer may have complementary angular blocking regions. For example, the interference filter may block transmission of light in a first range of incidence angles relative to a normal, while the angle blocking layer may block transmission of light in a second range of incidence angles relative to the normal. At least some angles not blocked by one of the interference filter and the angle blocking layer may be blocked by the other of the interference filter and the angle blocking layer. In some examples, at least one angle blocked by the interference filter may also be blocked by the angle blocking layer. In some example, one or both of the first range of angles blocked by the interference filter and the second range of angles blocked by the angle blocking element may depend on the wavelength of light.

[0035] The optical properties of angle blocking layers and interference filters for use in example optical filters according to the disclosure are discussed below with reference to FIGS. 1A–1C.

[0036] FIGS. 1A and 1B are charts illustrating the angular transmission of example angle blocking layers. FIG. 1A is a chart illustrating the transmission light distribution pattern for an example angle blocking layer including a 3M Optical Lighting Film (3M, Saint Paul, MN) including a predetermined prism structure on one side and a smooth surface on the other side. The example angle blocking layer of FIG. 1A has a light emission or transmission zone ABN about the normal, extending to about 30° from the normal, which cuts off beyond about 30° to block light transmission beyond about 35°. The cut-off angle is denoted by the line AB. However, at angles greater than about 60 degrees, light is again transmitted. The range of angles of extinction or blocking are included in the zone ABC, or from about 35° to 60°. Thus, the example angle blocking layer of FIG. 1A exhibits light leakage in the zone CBD.

[0037] FIG. 1B is a chart illustrating the transmission light distribution pattern for an example angle blocking layer including a 3M Transmissive Right Angle Film (TRAF) (3M, Saint Paul, MN). The example angle blocking layer of FIG. 1B, shows a blocking zone similar to that of FIG. 1A, with light transmission in the A1B1N zone, followed by blocking in the C1B1A1 zone, followed by high angle light leakage in the D1B1C1 zone.

[0038] As discussed with reference to example optical articles, interference filters may be used to block light leakage exhibited by angle blocking layers, for example, light leakage at high angles.

[0039] FIG. 1C is a conceptual illustration of the band shift exhibited by an example interference filter with a change in incidence angle. Interference filters may be spectrally selective, having a transmissive wavelength range and a reflective (or blocking) wavelength range. The transition between these two ranges is a "band edge". The reflective band will shift to shorter wavelengths as the incidence angle of light changes from normal to oblique. This property of interference filters may be used to limit the angular range of light of predetermined wavelengths emitting from a source or being received by a sensor. At normal incidence, a band edge of a reflection band in the transmission spectrum of interference filter is at a longer wavelength than a predetermined communication wavelength, but close enough so that it will eclipse the communication wavelength at an intended oblique angle of incidence. For example, the interference filter may have a band edge positioned from 10-100nm higher than the LED communication wavelength at normal incidence. At oblique incidence angles, the reflection band shifts to shorter wavelengths and blocks the communication wavelength. The result is a conical reception angle.

[0040] Example optical articles according to the disclosure may utilizing such angle shifting of the interference filter in combination with the angle blocking zones of angle selective elements, with each blocking complementary angular zones.

[0041] Example optical articles according to the disclosure may be used to arrive at a thinner system that blocks an angular range that normally would have required a thicker system. For example, as described with reference to FIGS. 2A and 2B, angle limiting elements based on recesses where physical walls geometrically limit the angle of transmission may be used.

[0042] FIGS. 2A and 2B are conceptual and schematic lateral cross-sectional views of an example article including a recessed structure wall. Example article 1a shown in FIG. 2A includes an angle blocking layer 12a having a recessed structure wall 13a having a characteristic dimension L1. Recessed structure wall 13a may be a wall of a recessed structure having a polygonal, circular, ellipsoidal, or other cross section, for example, a recessed cylindrical walled structure. Recessed structure wall 13a allows transmission of an incident light 14a from a source 16 within a transmission angle of α_1, and physically or optically blocks light beyond the transmission angle α_1. Source 16 may include light sources such as guided or ambient light, sunlight, LEDs, lasers, incandescent light, fluorescent lights, compact fluorescent lights, or other direct or indirect sources of light. The magnitude of the transmission angle α_1 is related to the characteristic dimension L_1. When L_1 is lowered, α_1 increases. For example, example article 1b shown in FIG. 2B includes an angle blocking layer 12b having a recessed wall 13b having a characteristic dimension L_2 that is lesser than L_1. Consequently, a transmission angle α_2 exhibited by example article 1b is wider than α_1. Therefore, for achieving a relatively narrower transmission angle, for example, α_1, a relatively higher characteristic dimension of the recessed structure wall, for example, L_1 of recessed structure wall 13a, may be required. However, increasing the characteristic dimensions of recessed structures will lead to an increase in the thickness of article 1a, which may not be desirable.

[0043] FIG. 2C is a conceptual and schematic lateral cross-sectional view of an example article 10 including the angle blocking layer 12b having the recessed structure wall 13b and an interference filter 18. The recessed structure wall 13b having the shorter characteristic dimension L_2 (compared to L_1 of recessed structure wall 13a) blocks higher light angles (beyond α_2), while interference filter 18 blocks lower transmission angles (for example, between α_1 and α_2, effectively narrowing the transmission angle to α_1. Thus, example article 10 may be as thin as article 1b, while providing the narrower transmission angle α_1 associated with the thicker article 1a, instead of the wider transmission angle α_2 associated with article 1b.

[0044] FIG. 2D is a conceptual and schematic lateral cross-sectional view of the reduction in thickness of an article including the recessed structure wall 13b having lower characteristic dimension L_2 and the interference filter 18. In contrast, an article including only the recessed structure wall 13a has the higher characteristic dimension L_1, for achieving similar transmission angles of light to a sensor 20 on a substrate 19.

[0045] In some examples, example optical filters may include a spectrally selective absorber having a complementary wavelength blocking range to the interference filter. For example, wavelengths that are not blocked by one of the spectrally selective absorber and the interference filter may be blocked by the other of the interference filter and the spectrally selective absorber. Spectrally selective absorbers may include dyed PET films, or "gel filters" which may have sharp absorption spectra.

[0046] FIGS. 3A, 3B, and 3C are charts illustrating the transmission spectra of example absorbing layers. FIG. 3A is a chart illustrating the transmission spectrum of an example absorbing layer including a red dyed PET film. The film exhibits a spectrally sharp cut-off, between 500 and 600nm. FIG. 3B is a chart illustrating the transmission spectrum of an example absorbing layer including a dark yellow green dyed PET film. FIG. 3C is a chart illustrating the transmission spectrum of an example absorbing layer including a blue dyed PET film. The films of FIGS. 3B and 3C exhibit a spectral leak, which can vary from 20-60% in transmission intensity and can be positioned at different wavelengths in the visible spectrum.

[0047] Example optical filters according to the disclosure may optionally include an absorbing layer, in addition to an interference filter and an angle blocking layer, as described with reference to the example optical filters of FIGS. 4A and 4B. FIGS. 4A and 4B are schematic and conceptual exploded cross-sectional views of example optical filters including an angle blocking layer, an interference filter, and an absorbing layer.

[0048] Example optical filter 10a of FIG. 4A includes an angle blocking layer 12 and an interference filter 18a for selectively transmitting light from source 16. Angle blocking layer 12 may include angle limiting or selective elements or other angle limiting features, for example, a plurality of angle limiting features 21 including one or more of recessed walls, prisms, Fresnel structures, Fresnel rings, recesses, louvers, channels, or microreplicated features. In some examples, the louvers may include faces that are normal, or substantially perpendicular, to a major surface of angle blocking layer 12. The plurality of angle limiting features 21 may include one or more of substantially uniform features, symmetric features, asymmetric features, lines or grooves of features, or arrays of features. In some examples, angle blocking layer 12 may include plurality of angle limiting features 21 disposed on a refractive substrate. For example, the refractive substrate may include a turning film, a brightness enhancing film, or a microstructure optical film. In some examples, plurality of angle limiting features 21 may include a first subplurality of angle limiting features that limit light angles in a first plane, and a second subplurality of angle limiting features that limit light angles in a second plane. For example, the second plane may be orthogonal to the first plane. In some examples, the first and second subpluralities of angle limiting features may effectively act to restrict light within asymmetric light distributions, for example, an elliptical light pattern. In some examples, angle blocking layer 12 may include a prismatic film, as shown in FIG. 4A. Angle blocking layer 12 may exhibit a transmission zone centered about normal incidence, and an off-axis block zone, followed by a high angle transmission zone, for example, as described with reference to FIGS. 1A and 1B. In the transmission zones, all visible wavelengths may be transmitted.

[0049] In some examples, interference filter 18a may include a MOF, for example, a birefringent MOF. In some examples, interference filter 18a may include an isotropic film, for example 3M Condor Film (3M, Saint Paul, MN), or a film formed by vapor deposition or supttering. In some examples, the MOF may act as a colored mirror, reflecting selected wavelengths, and transmitting selected wavelengths. In some examples, interference filter 18a may reflect light in a 600-900nm band at normal incidence, which shifts to shorter wavelengths off-axis or at oblique angles, for example, as discussed with reference to FIG. 1C. For example, band edge positions may shift to about 80% of their normal incidence value at an angle of about 60 degrees.

[0050] In some examples, optical filter 10a may optionally include an absorbing layer 20a. In some examples, absorbing layer 20a may include a spectrally selective absorber. In some examples, as shown in FIG. 4A, interference filter 18a may be disposed between absorbing layer 20a and angle blocking layer 12. In some examples, absorbing layer 20a may only allow transmission of a predetermined wavelength band, for example, transmission of 525-575nm, and absorb or otherwise block other wavelengths. In some examples, the transmission band of absorbing layer 20 may not be angularly shifting or otherwise angle-dependent. For example, the only light in the transmission band that reaches absorbing layer 20a may be within a limited cone angle centered around normal incidence, and the only light emitted from absorbing layer 20a may be green (or another predetermined color associated with a predetermined wavelength band), and of a limited angular extent. Light outside this wavelength range is absorbed.

[0051] In some examples, optical filter 10a may operate across a predetermined wavelength band, for example, including visible wavelengths (for example, between about 400 and about 700 nm), ultraviolet wavelengths (for example, less than about 400 nm), and infrared and near-infrared wavelengths (for example, between about 700 and about 2000 nm).

[0052] The optical properties of optical filter 10a may be tuned by changing the properties of one or both of interference filter 18a, and absorbing layer 20a, without needing to change angle blocking layer 12. For example, optical filter 10b of FIG. 4B includes the angle blocking layer 12 and an interference filter 18b. Interference filter 18b may pass light in a 400-700nm band at normal incidence, pass light in a 400-630nm at an oblique angle, and reflect light in a 630-700nm band at oblique angles. Absorbing layer 20b may pass light in a angle-independent band of 630-700nm. Thus, while example optical filter 10a of FIG. 4A may be a green transmitting stack, example optical filter 10b of FIG. 4B may be a red transmitting stack. Thus, optical properties of example optical filters according to the disclosure may be changed without having to remanufacture or procure new batches of angle blocking layers 12, that may be expensive, by instead relatively inexpensively changing interference filters or absorbing layers.

[0053] In some examples, the pass zone may be defined about an axis normal or substantially perpendicular to a major surface of an optical article, for example, as shown in FIGS. 4A and 4B. However, in other examples, the pass zone may be defined about a non-perpendicular axis, for example, an inclined axis between about 1 degrees and less than about 90 degrees. FIG. 4C is a schematic and conceptual exploded cross-sectional view of an example optical filter 10c including an angle blocking layer 12a, and having an inclined pass zone. For example, the pass zone may be defined about an inclined axis 23a, as shown in FIG. 4C. Angle blocking layer 12a may include a plurality of angle limiting features 21a configured to define an inclined pass zone, for example, an inclined pass or transmission cone. In some examples, the plurality of angle limiting features 21a may include features described with respect to the plurality of angle limiting features 21 of FIG. 4A. In some examples, the plurality of angle limiting features 21a may include louvers that are non-perpendicular, inclined, or tilted so that the transmission or pass zone is defined about inclined axis 23a, as shown in FIG. 4C.

[0054] FIG. 4D is a schematic and conceptual exploded cross-sectional view of an example optical filter 10d including angle blocking layer 12c, and interference filter 18a, and having an inclined pass zone defined by an extended block zone, about an inclined axis 23b. The extended block zone includes a block zone resulting from interference filter 18a, in addition to the block zone resulting from the plurality of angle limiting features 21, for example, including tilted louvers similar to those in FIG $c.

[0055] The optical transmission and blocking properties of optical filter 10a of FIG. 4A may be understood with reference to FIG. 5A. FIG. 5A is a schematic and conceptual illustration of the angular transmission and blocking of light from source 16 by example optical filter 10a of 4A. The light distribution pattern is shown at the top portion of the figure. There is a central zone, or pass zone 22, where green light is transmitted. Line AB denotes a transition angle from pass to block which is provided for by angle blocking layer 12. Line AC denotes the angle at which the reflecting band of interference filter 18a has shifted sufficiently to (combined with the absorbing layer 20a), block light. Line AD denotes the angle at which angle blocking layer 12 begins to transmit light again, which is then blocked by the combination of interference filter 18a and absorber layer 20a. The angular zone denoted by DAB may provide a buffer zone for interference filter 18a (including areas having manufacturing caliper variations) to shift into position that may not be visually detectable. This buffer zone may thus prevent perception of a non-uniformity arising from interference filter 18a as the band edge encroaches into the transmission zone. FIG. 5B is a schematic and conceptual illustration of the angular transmission and blocking by optical filter 10a of FIG. 5A. θ_{IF} is the angular range blocked by interference filter 18a. θ_{AL} is the angular range blocked by angle blocking layer 12. θ_{Trans} is the half-angle angular transmission range, relative to a normal axis to a major surface of optical filter 10a. Thus, pass zone 22 extends about the normal axis, in a cone defined by the half-angle θ_{Trans}. Half-angle θ_{Trans} may extend to a maximum transmission angle θ_{Tmax} relative to the normal axis of a major surface 17 of optical filter 10a.

[0056] While optical filter 10a includes angle blocking layer 12 between interference filter 18a and source 16, in some examples, interference filter 18a may face source 16, and angle blocking layer 12 may be disposed away from source 16. FIG. 5C is a schematic and conceptual illustration of the angular transmission and blocking by an example optical filter 10d in which interference filter 18a faces source 16.

[0057] In some examples, optical filter 10a includes major surface 17. Optical filter 10a may have a predetermined light transmission zone comprising angles from 0° to a maximum light transmission angle θ_{Tmax} relative to a normal axis of major surface 17. Optical filter 10a may have a predetermined angular light blocking zone θ_B including angles from 90 - θ_{Tmax} to 90°. In some examples, optical filter 10a includes angle blocking layer 12 having a first angular light blocking range θ_{AL} relative to the normal axis. In some examples, optical fitler 10a includes interference filter 18a adjacent angle blocking layer 12. The interference filter may have a second angular light blocking range θ_{IF} relative to the normal axis. θ_B is a union of θ_{IF} and θ_{AL}. For example, θ_B includes all angles that belong to either θ_{IF} or θ_{AL}. In some examples, θ_{IF} and θ_{AL} at least partially overlap. For example, at least one angle or a range of angles may belong to both θ_{IF} and θ_{AL}. In some examples, at least one angle in θ_{AL} is greater than one angle in θ_{IF}. In some examples, at least one angle in θ_{IF} is greater than one angle in θ_{AL}. In some examples, one or both of θ_{IF} and θ_{AL} are wavelength-dependent. For example, at least one angle in one or both of θ_{IF} and θ_{AL} may increase or decrease when the wavelength of incident light increases or decreases. In some examples, interference filter 18a may include one or both of a birefringent multilayer optical film or an isotropic film. In some examples, angle blocking layer 12 may include a plurality of angle limiting features 21. In some examples, the plurality of angle limiting features 21 includes one or more of prisms, Fresnel structures, Fresnel rings, recesses, louvers, channels, or microreplicated features.

[0058] In some examples, the plurality of angle limiting features 21 may have a characteristic dimension, and θ_{AL} may have a predetermined relationship with the characteristic dimension. For example, θ_{AL} may narrow when the characteristic dimension increases, and broaden when the characteristic dimension decreases. For example, θ_{AL} may be narrower when the characteristic dimension is smaller. In some examples, angle blocking layer 12 may include one or both of a turning film or a brightness enhancing film. In some examples, angle blocking layer 12 may have a predetermined light leakage angular transmission zone. In some examples, interference filter 18a may have a characteristic transmission spectrum comprising a reflection band, wherein the reflection band has a band edge that shifts lower when an angle of incidence is reduced. In some examples, the reflection band of interference filter 18a may include a wavelength transmitted through a predetermined light leakage angular transmission zone of angle blocking layer 12.

[0059] In some examples, optical filter 18a may include a wavelength selective or spectrally selective absorber. In some examples, the spectrally selective absorber may include a dye or a pigment that absorbs predetermined wavelengths. In some examples, interference filter 18a may include the wavelength selective absorber. In some examples, angle blocking layer 12 includes the wavelength selective absorber.

[0060] In some examples, optical filter 18a may include absorbing layer 20a including the wavelength selective absorber. In some examples, absorbing layer 20a may be between interference filter 18a and angle blocking layer 12. In some examples, interference filter 18a may be between absorbing layer 20a and angle blocking layer 12. In some examples, angle blocking layer 12 may be between the absorbing layer and the interference filter.

[0061] In some examples, optical filter 10a may not include a separate angle blocking layer 12, and may instead include interference filter 18a and absorbing layer 20a. FIG. 6A is a conceptual illustration of the band shift with a change in incidence angle of an example optical including an interference filter and an absorbing layer. As shown in FIG. 6A, a transmissive bandpass between an absorbing band of absorbing layer 20a and a reflection band of interference filter 18a may have a width $\Delta\lambda$ at normal incidence. As the angle of incidence increases, one or both of the respective bands may shift, for example, a downshift of the reflection band of interference filter 18a, eventually closing the band gap. FIG. 6B is a photograph comparing light transmission and blocking by an interference filter including a MOF, an absorbing layer including a dye, and an article including a combination of the interference filter and the absorbing layer. As shown in FIG. 6B, the combination substantially blocks the transmission of light, even though the absorbing layer and the interference filter individually transmit at least some light.

[0062] The spectral properties of the example article of FIG. 6B may be understood with reference to FIGS. 7A–7C. FIG. 7A is a chart illustrating the transmission spectrum of the example multilayer optical film interference filter of FIG. 6B. FIG. 7B is a chart illustrating the transmission spectrum of the absorbing layer of FIG. 6B. FIG. 7C is a chart illustrating the transmission spectrum of an example optical filter including the interference filter of FIG. 7A and the absorbing layer of FIG. 7B. As shown in FIG. 7C, combining the interference filter and the absorbing layer results in a notch filter at normal incidence at about 640nm. As another example, FIGS. 8A-8C illustrate the spectral properties of an example green angle selective optical filter. FIG. 8A is a chart illustrating the transmission spectrum of an example multilayer optical film interference filter, at different angles, showing the angle shift. FIG. 8B is a chart illustrating the transmission spectrum of an example absorbing layer. FIG. 8C is a chart illustrating the transmission spectrum of an example optical filter including the interference filter of FIG. 8A and the absorbing layer of FIG. 8B. As shown in FIG. 8C, combining the interference filter of FIG. 8A and the absorbing layer of FIG. 8B results in transmission of green at normal incidence, and extinction of green at oblique angles.

[0063] In some examples, angle blocking layer 12 may include both a plurality of angle blocking features and a spectrally selective absorber. In some examples, angle blocking layer 12 may include only one of the plurality of angle limiting features or the spectrally selective absorber. For example, absorbing layer 20a may replace angle blocking layer 12.

[0064] In some examples, optical filter 18a may include interference filter 12 having an incidence angle-dependent reflection band, and absorbing layer 20a having an absorption band, wherein the incidence angle-dependent reflection band and the absorption band overlap at at least one wavelength at at least one angle of incidence. In some examples, interference filter 18a may have a characteristic transmission spectrum including the incidence angle-dependent reflection band. For example, the angle-dependent reflection band may have a band edge that shifts lower when an angle of incidence is reduced. In some examples, the angle-dependent reflection band of interference filter 18a includes a wavelength transmitted by absorbing layer 20a. In some examples, interference filter 18a may include a wavelength selective absorber. In some examples, absorbing layer 18a may include a wavelength selective absorber.

[0065] Example optical filters according to the disclosure may be used in systems where it is desirable to limit angles of light. FIG. 9 is a schematic and conceptual diagram illustrating an example system 30 including optical filter 10a, source 16, sensor 20, and a reflector 31. While in some examples, system 30 may include all of source 16, sensor 20, and reflector 31, as shown in FIG. 9, in other examples, system 30 may include only one or two of source 16, sensor 20, or reflector 31.

[0066] While system 30 may include one or more of optical filter 10a, source 16, or sensor 20, in some examples, system 30 may include any optical filter, source, or sensor according to the disclosure. For example, system 30 may include one or more of a narrow wavelength light source, a visible source, an ultraviolet source, or a near infrared or infrared source, an LED, a laser, or other suitable wavelength sources. In some examples, the source may exhibit a spectral spike of FWHM < 40nm. A particular system for sensing and communications may include a specific communication wavelength. For example, the source may include a mono wavelength LED such as a green, red, or near IR LED that can have emission around 20nm full width half max. In some examples, system 30 may include more than one type of LED emitting at more than one wavelength.

[0067] System 30 may include one or more of a visible light sensor, ultraviolet sensor, near infrared or infrared sensor, a broadband sensor, a narrowband sensor, LIDAR sensor, CMOS sensor, proximity sensor, gesture sensor, camera sensor, an image sensor, a CCD sensor, a time of flight sensor, an iris scanner, or other sensors.

[0068] In some examples, system 30 may include sensor 20 and optical filter 10a. Optical filter 10a may limit the angle of light received by sensor 20. For example, optical filter 10a may block light from noise sources that may transmit light at angles beyond a pass or transmission zone. In some examples, system 30 may include sensor 20, optical filter 10a, and source 16.

[0069] In some examples, system 30 may include reflector 31. Reflector 31 may define one or more of a specular reflecting surface, a diffuse reflecting surface, or a retroreflective surface. For example, reflector 31 may include a reflective layer, or a reflecting body or object. While in the example configuration of system 30 shown in FIG. 9, reflector 31 is disposed adjacent sensor 20 and opposite source 16, in other examples, reflector 31 may be located at any suitable location. For example, sensor 20 and source may both be disposed opposite reflector 31 across optical filter 10a, so that reflector 31 reflects light from source 16 to sensor 20. In some examples, system 30 may not include sensor 20, and reflector 31 may reflect light from source 16 across optical filter 10a. In some examples, system 30 may include neither reflector 31 and optical filter 10a, and reflector 31 may reflect ambient light across optical filter 10a.

[0070] In some examples, system 30 may include source 16 and optical filter 10a. In some examples, system 30 may limit the emission angle emitted by source 16 for privacy or for ergonomic reasons. For example, system 30 may reduce glare directed towards a car driver from a stop light or a brake light. Example optical articles, for example, optical filter 10a, may be used in example systems 30, for example, including vehicle display systems where interior glare control is needed, as a privacy feature for displays such as automatic teller machines, as a traffic control film for traffic signals, or in a center high mounted stop lamp (CHIMSL).

[0071] Thus, example optical filters according to the disclosure may be used to achieve light distribution patterns that have sharp transitions from a color (such as red or green) to black as a function of angle, and which can maintain extinction of light even at high angles of incidence and all azimuthal angles. Such light distribution patterns may not be possible using only structured surfaces or other articles. Example optical filters according to the disclosure may exhibit one or more of the following properties: 1) a single continuous pass zone and a single continuous block zone for light of predetermined wavelengths; 2) a conical transmission pattern of predetermined cone angle; 3) extinction or blocking at high angles of incidence; 4) a sharp transition from the pass to the block zone; 5) uniformity in appearance over a large area even at the transition angle; 6) No to low shift in perceived hue over the transition from pass to block; 7) good performance in a plane transverse to the prism axis. Example optical filters according to the disclosure may be prepared by combining existing commercial products to tune optical properties, leading to reduced manufacturing cost.

[0072] Various examples of the invention have been described. These and other examples are within the scope of the following claims.

CLAIMS:

1. An optical filter comprising:

a major surface, wherein the optical filter has a predetermined light transmission zone comprising angles from 0° to a maximum light transmission angle θ_{Tmax} relative to a normal axis of the major surface, wherein the optical filter has a predetermined angular light blocking zone θ_B comprising angles from 90 - θ_{Tmax} to 90°;

an angle blocking layer having a first angular light blocking range θ_{AL} relative to the normal axis; and

an interference filter adjacent the angle blocking layer, wherein the interference filter has a second angular light blocking range θ_{IF} relative to the normal axis, wherein θ_B is a union of θ_{IF} and θ_{AL}, wherein θ_{IF} and θ_{AL} at least partially overlap.

2. The optical filter of claim 1, wherein at least one angle in θ_{AL} is greater than one angle in θ_{IF}.

3. The optical filter of claim 1 or 2, wherein at least one angle in θ_{IF} is greater than one angle in θ_{AL}.

4. The optical filter of any one of claims 1 to 3, wherein one or both of θ_{IF} and θ_{AL} are wavelength-dependent.

5. The optical filter of any one of claims 1 to 4, wherein the interference filter comprises one or both of a birefringent multilayer optical film or an isotropic film.

6. The optical filter of any one of claims 1 to 5, wherein the angle blocking layer comprises a plurality of angle limiting features.

7. The optical filter of claim 6, wherein the plurality of angle limiting features comprises one or more of prisms, Fresnel structures, Fresnel rings, recesses, louvers, channels, or microreplicated features.

8. The optical filter of claims 6 or 7, wherein the plurality of angle limiting features has a characteristic dimension, and wherein θ_{AL} has a predetermined relationship with the characteristic dimension.

9. The optical filter of claim 8, wherein θ_{AL} is narrower when the characteristic dimension is smaller.

10. The optical filter of any one of claims 6 to 9, wherein the angle blocking layer comprises one or both of a turning film or a brightness enhancing film.

11. The optical filter of any one of claims 1 to 10, wherein the angle blocking layer has a predetermined light leakage angular transmission zone.

12. The optical filter of any one of claims 1 to 10, wherein the interference filter has a characteristic transmission spectrum comprising a reflection band, wherein the reflection band has a band edge that shifts to lower wavelengths when an angle of incidence is reduced.

13. The optical filter of claim 12, wherein the reflection band of the interference filter includes a wavelength transmitted through a predetermined light leakage angular transmission zone of the angle blocking layer.

14. The optical filter of any one of claims 1 to 13, further comprising a wavelength selective absorber.

15. The optical filter of claim 14, wherein the interference filter comprises the wavelength selective absorber.

16. The optical filter of claim 14, wherein the angle blocking layer comprises the wavelength selective absorber.

17. The optical filter of claim 14, further comprising an absorbing layer comprising the wavelength selective absorber.

18. The optical filter of claim 17, wherein the absorbing layer is between the interference filter and the angle blocking layer.

19. The optical filter of claim 17, wherein the interference filter is between the absorbing layer and the angle blocking layer.

20. The optical filter of claim 17, wherein the angle blocking layer is between the absorbing layer and the interference filter.

21. An optical filter comprising:

an interference filter having an incidence angle-dependent reflection band; and

an absorbing layer having an absorption band, wherein the incidence angle-dependent reflection band and the absorption band overlap at at least one wavelength at at least one angle of incidence.

22. The optical filter of claim 21, wherein the interference filter comprises one or both of a birefringent multilayer optical film or an isotropic film.

23. The optical filter of claims 21 or 22, wherein the interference filter has a characteristic transmission spectrum comprising the incidence angle-dependent reflection band, wherein the angle-dependent reflection band has a band edge that shifts lower when an angle of incidence is reduced.

24. The optical filter of claim 23, wherein the angle-dependent reflection band of the interference filter includes a wavelength transmitted by the absorbing layer.

25. The optical filter of any one of claims 21 to 24, wherein the interference filter comprises a wavelength selective absorber.

26. The optical filter of any one of claims 21 to 25, wherein the absorbing layer comprises a wavelength selective absorber.

27. The optical filter of any one of claims 21 to 26, further comprising an angle blocking layer.

28. A system comprising:

a sensor; and

an optical filter of any one of claims 1 to 27.

29. The system of claim 28, further comprising a light source.

30. The system of any one of claims 28 and 29, further comprising a reflector, wherein the reflector defines one or more of a specular reflecting surface, a diffuse reflecting surface, or a retroreflective surface.

31. A system comprising:

a light source; and

an optical filter of any one of claims 1 to 27.

32. The system of claim 31, further comprising a reflector, wherein the reflector defines one or more of a specular reflecting surface, a diffuse reflecting surface, or a retroreflective surface.

33. A system comprising:

a reflector, wherein the reflector defines one or more of a specular reflecting surface, a diffuse reflecting surface, or a retroreflective surface; and

an optical filter of any one of claims 1 to 27.

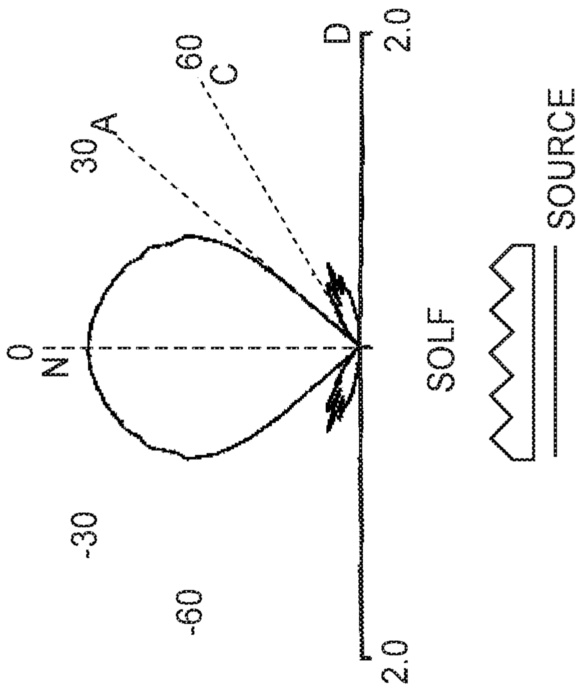


FIG. 1A

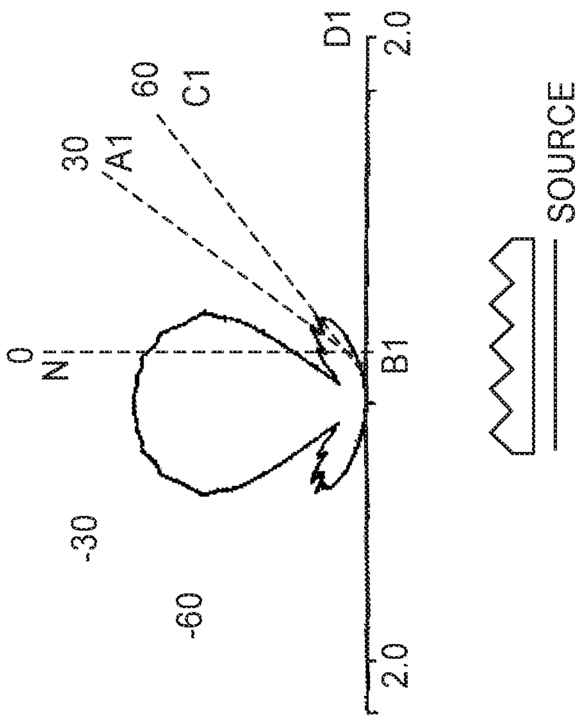


FIG. 1B

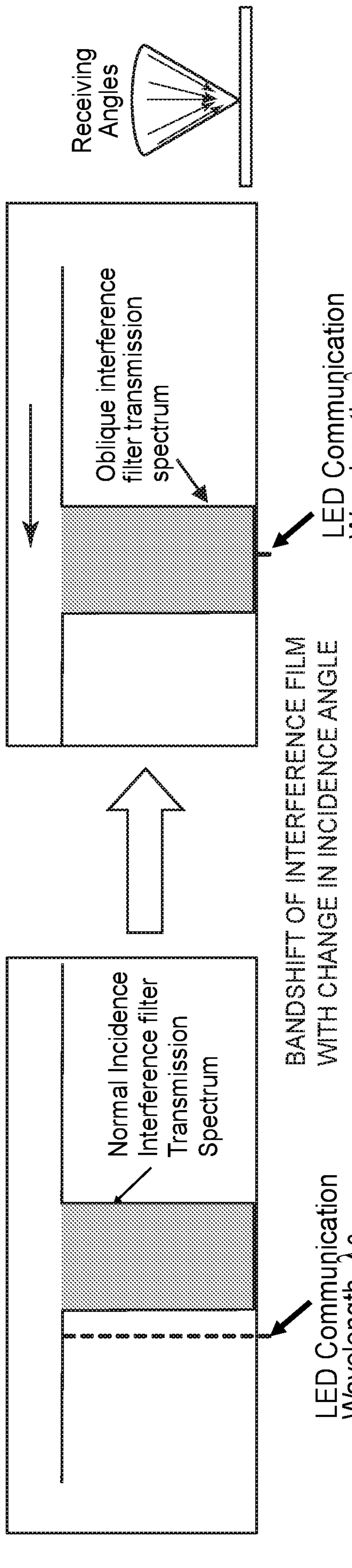


FIG. 1C

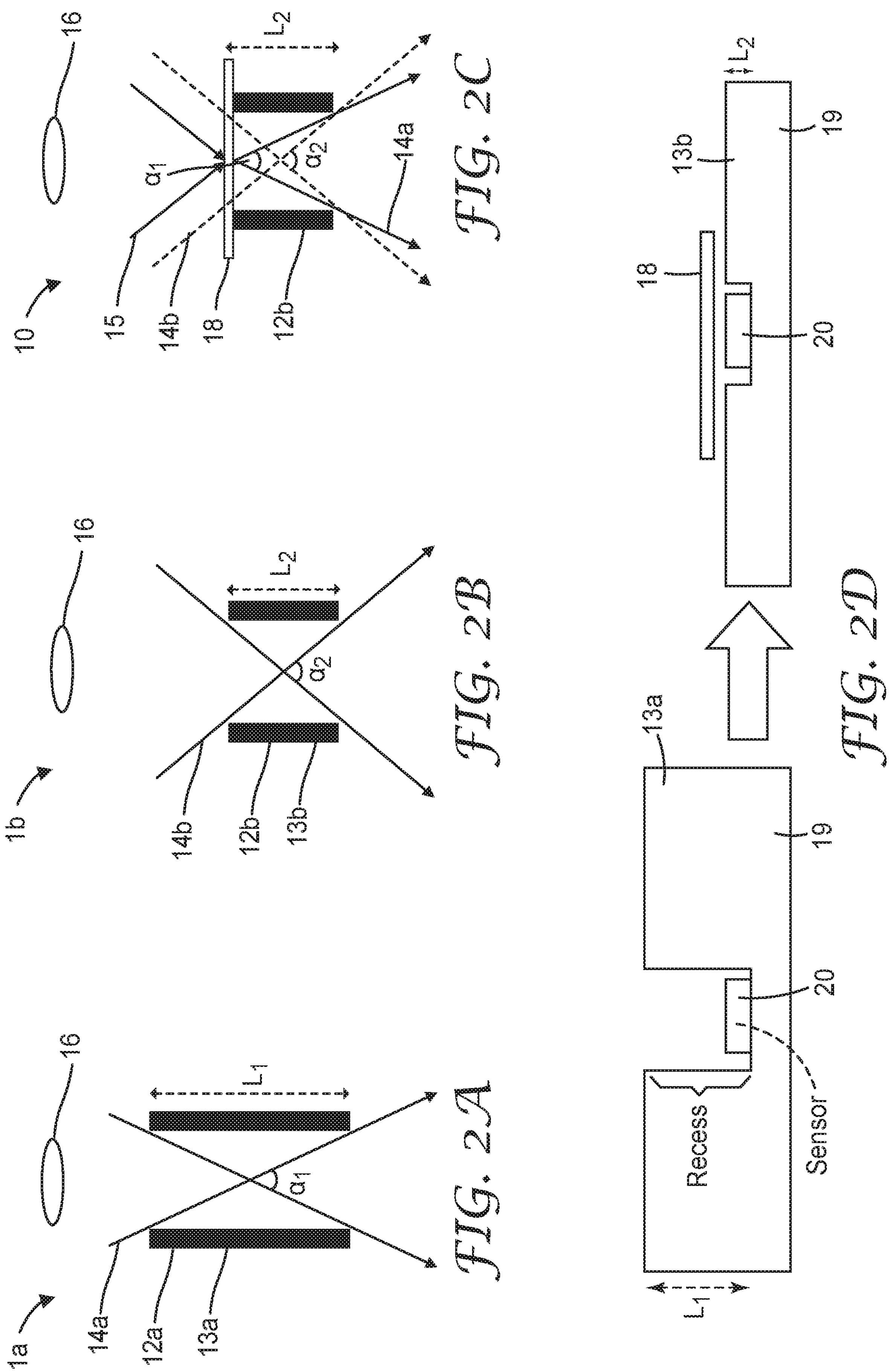


FIG. 2A

FIG. 2B

FIG. 2C

FIG. 2D

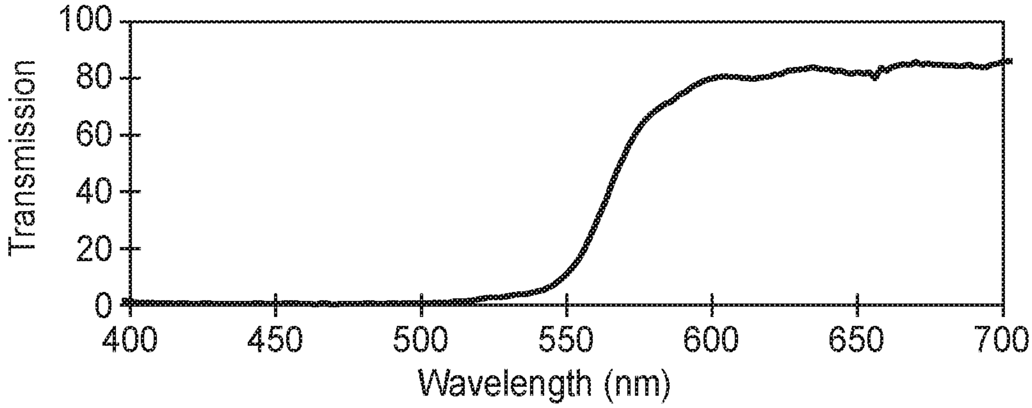


FIG. 3A

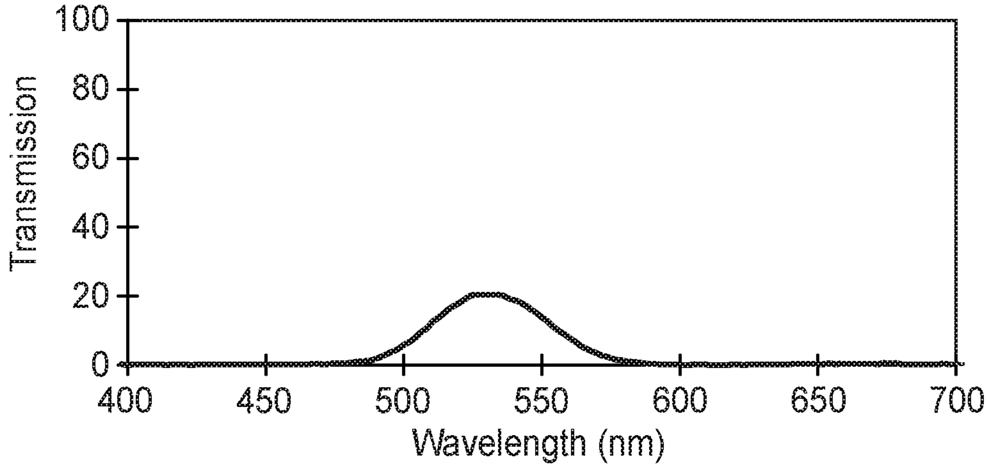


FIG. 3B

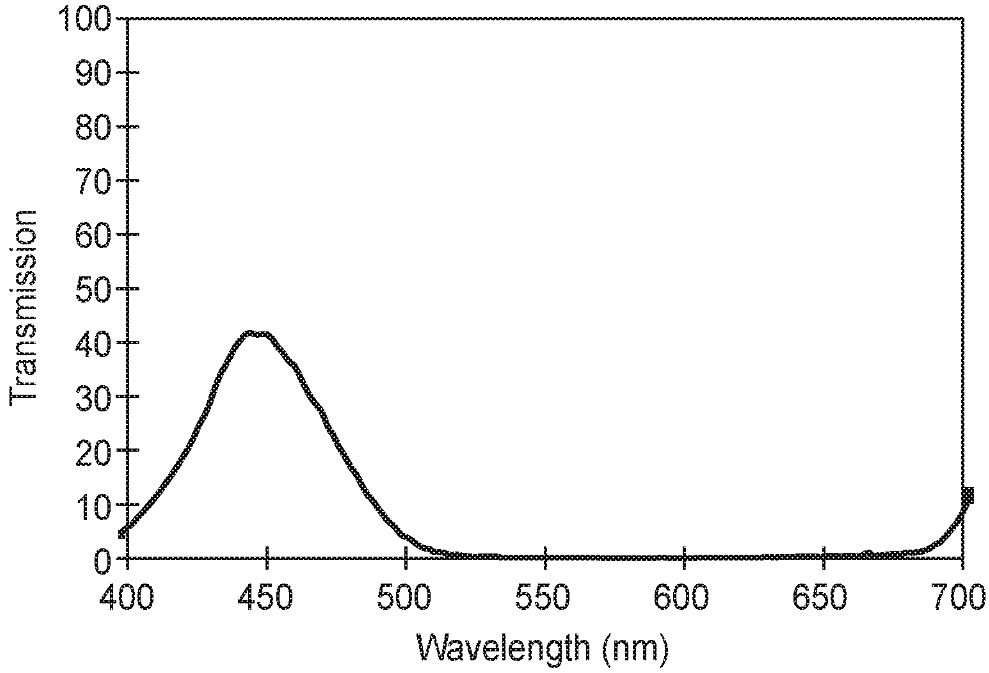


FIG. 3C

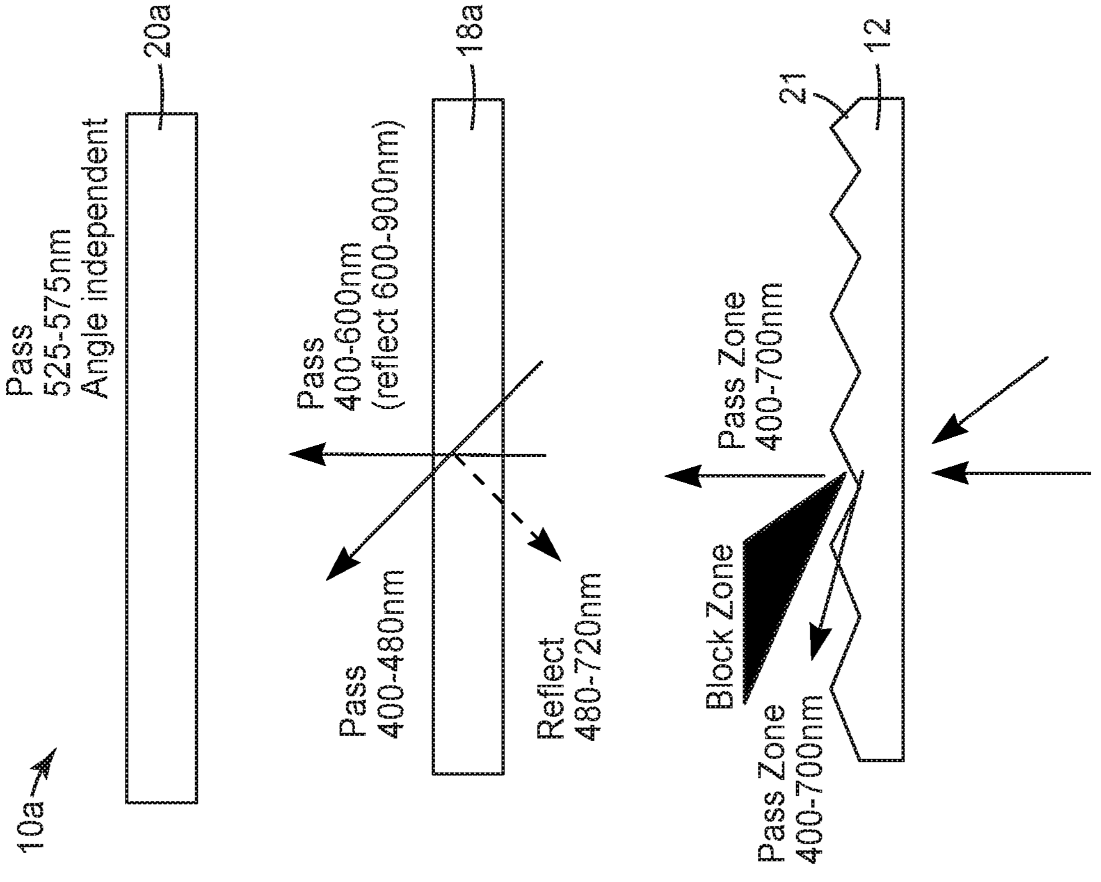

10a
20a
Pass
525-575nm
Angle independent
18a
Pass
400-600nm
(reflect 600-900nm)
Pass
400-480nm
Reflect
480-720nm
21
12
Pass Zone
400-700nm
Block Zone
Pass Zone
400-700nm

FIG. 4A

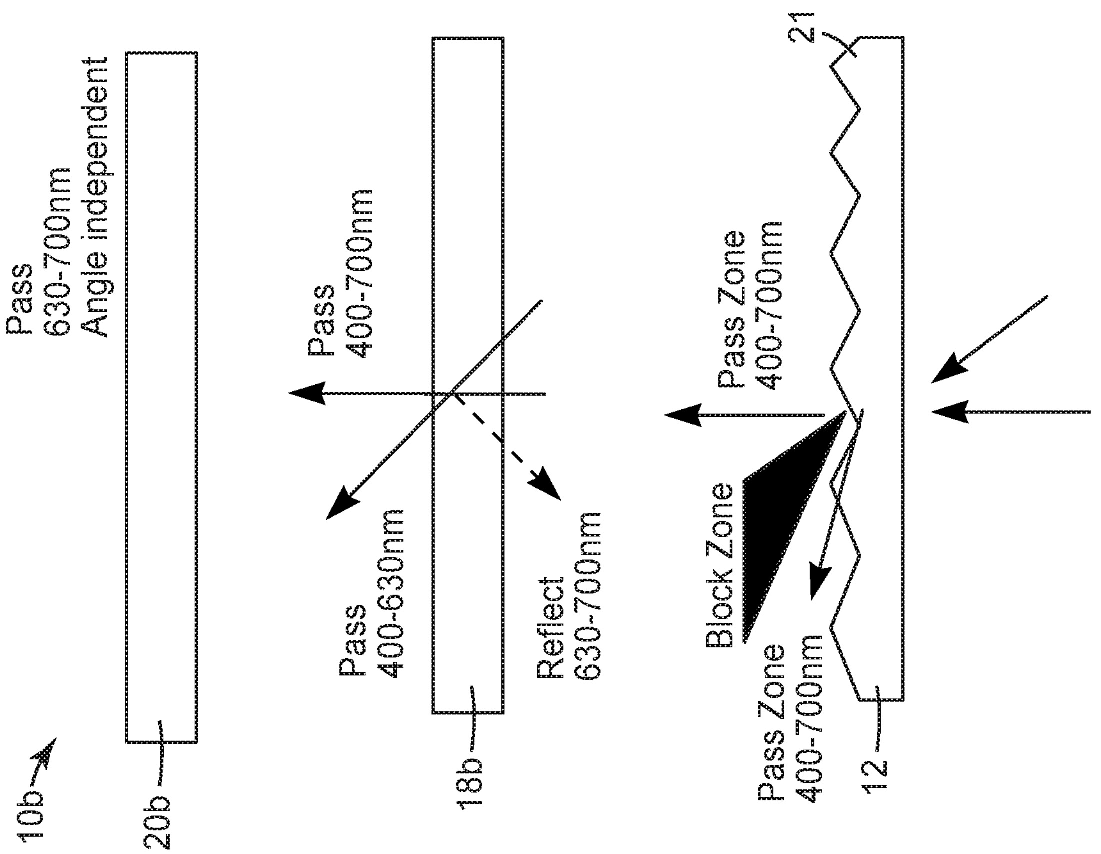

10b
20b
Pass
630-700nm
Angle independent
18b
Pass
400-700nm
Pass
400-630nm
Reflect
630-700nm
21
12
Pass Zone
400-700nm
Block Zone
Pass Zone
400-700nm

FIG. 4B

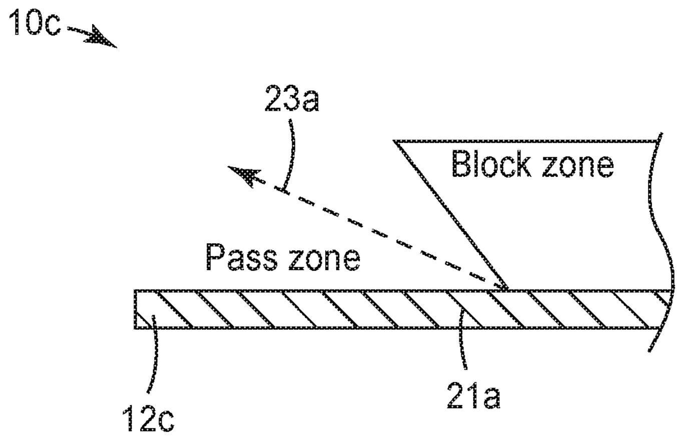

10c
23a
Block zone
Pass zone
12c
21a

FIG. 4C

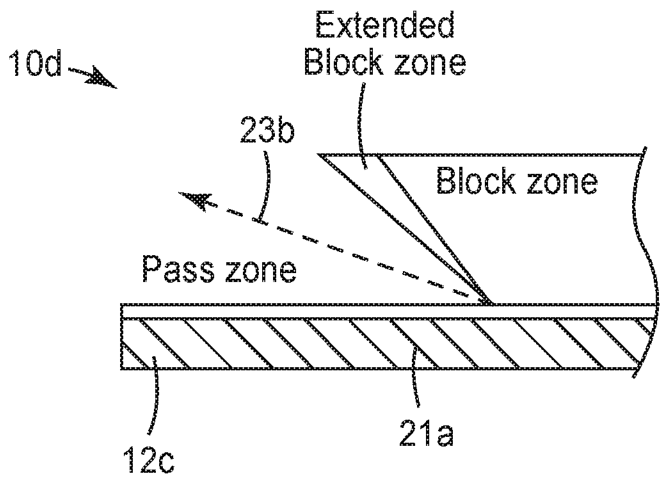

Extended
Block zone
10d
23b
Block zone
Pass zone
12c
21a

FIG. 4D

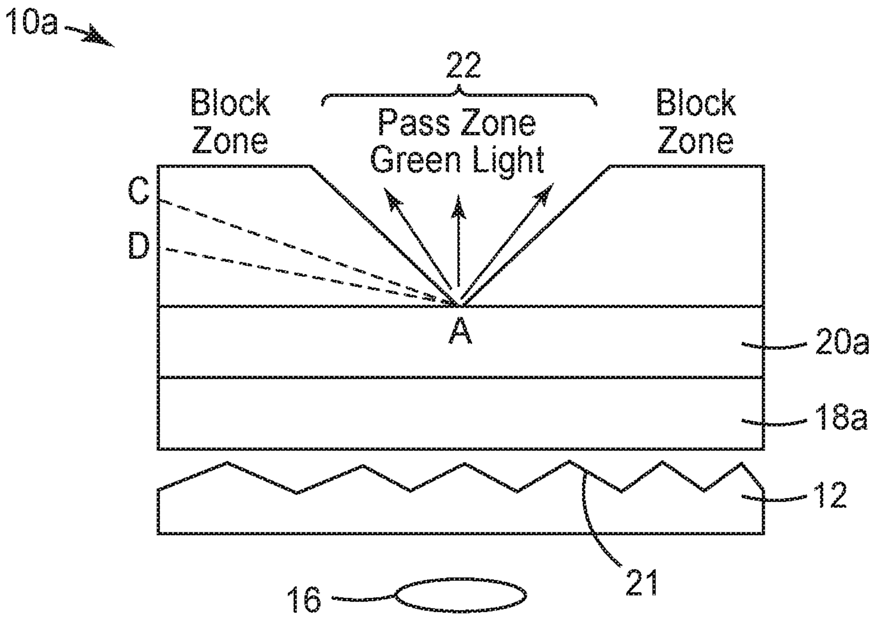

10a
22
Block Zone
Pass Zone Green Light
Block Zone
C
D
A
20a
18a
12
21
16

FIG. 5A

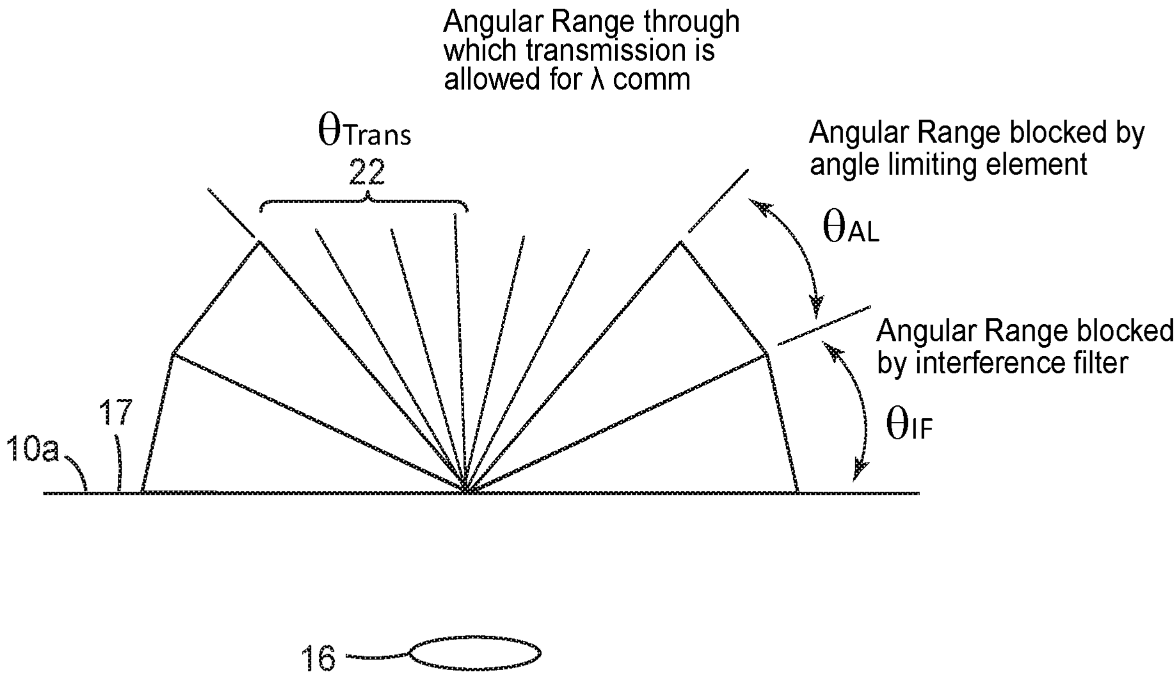
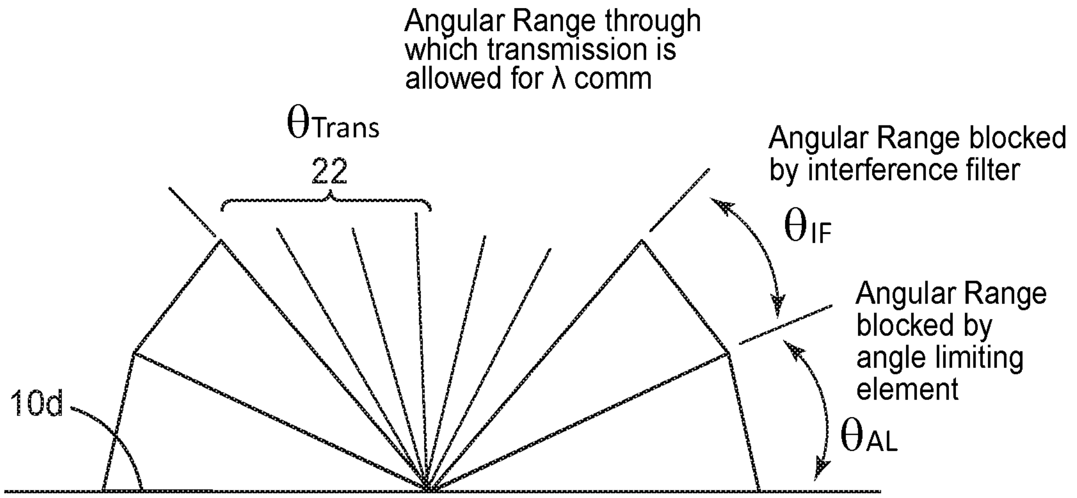

Angular Range through which transmission is allowed for λ comm
θTrans
22
Angular Range blocked by angle limiting element
θAL
Angular Range blocked by interference filter
θIF
17
10a
16

FIG. 5B



Angular Range through which transmission is allowed for λ comm
θTrans
22
Angular Range blocked by interference filter
θIF
Angular Range blocked by angle limiting element
θAL
10d

FIG. 5C

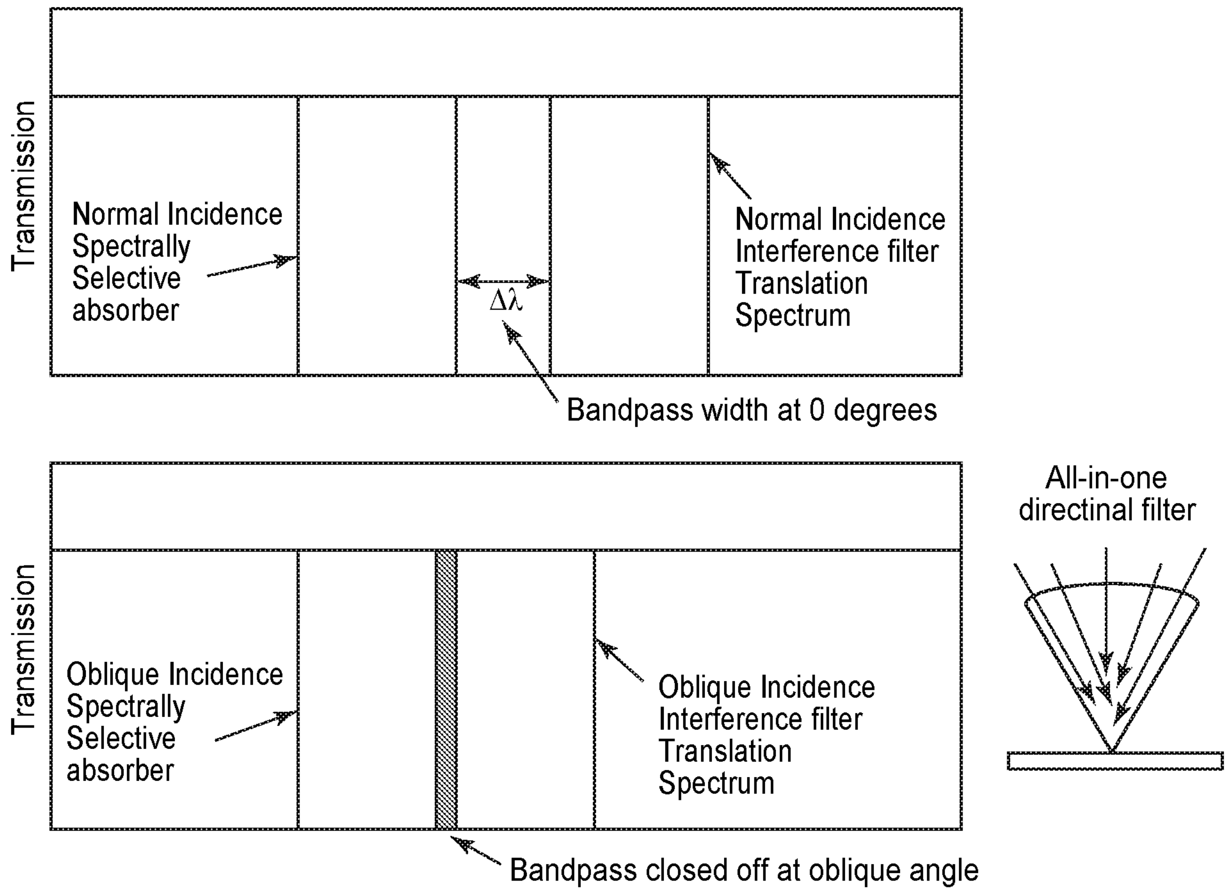

Transmission
Normal Incidence Spectrally Selective absorber
Δλ
Normal Incidence Interference filter Translation Spectrum
Bandpass width at 0 degrees
Transmission
Oblique Incidence Spectrally Selective absorber
Oblique Incidence Interference filter Translation Spectrum
Bandpass closed off at oblique angle
All-in-one directinal filter

FIG. 6A

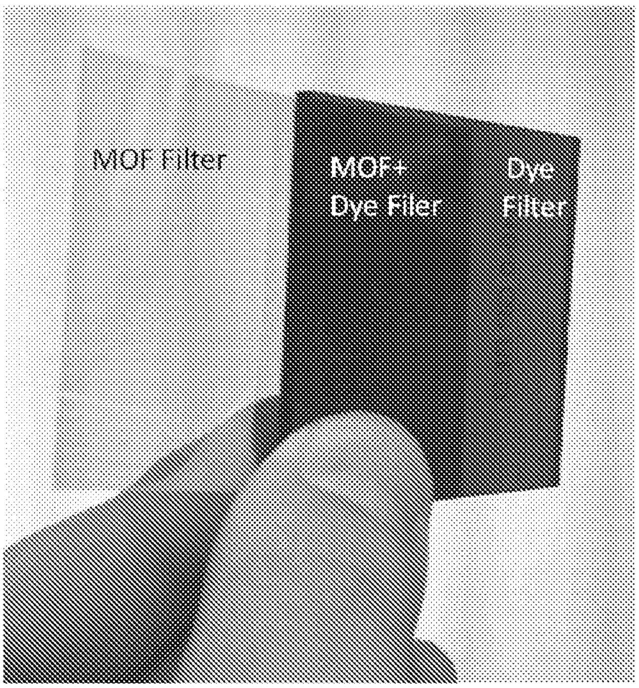

MOF Filter
MOF+ Dye Filer
Dye Filter

FIG. 6B

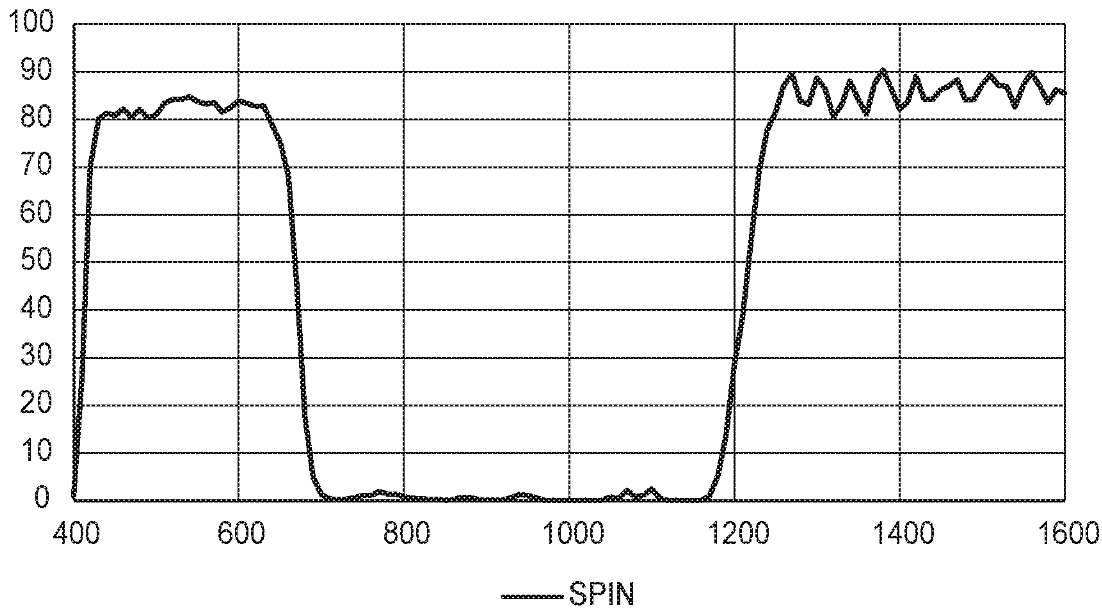

100
90
80
70
60
50
40
30
20
10
0
400
600
800
1000
1200
1400
1600
SPIN

FIG. 7A

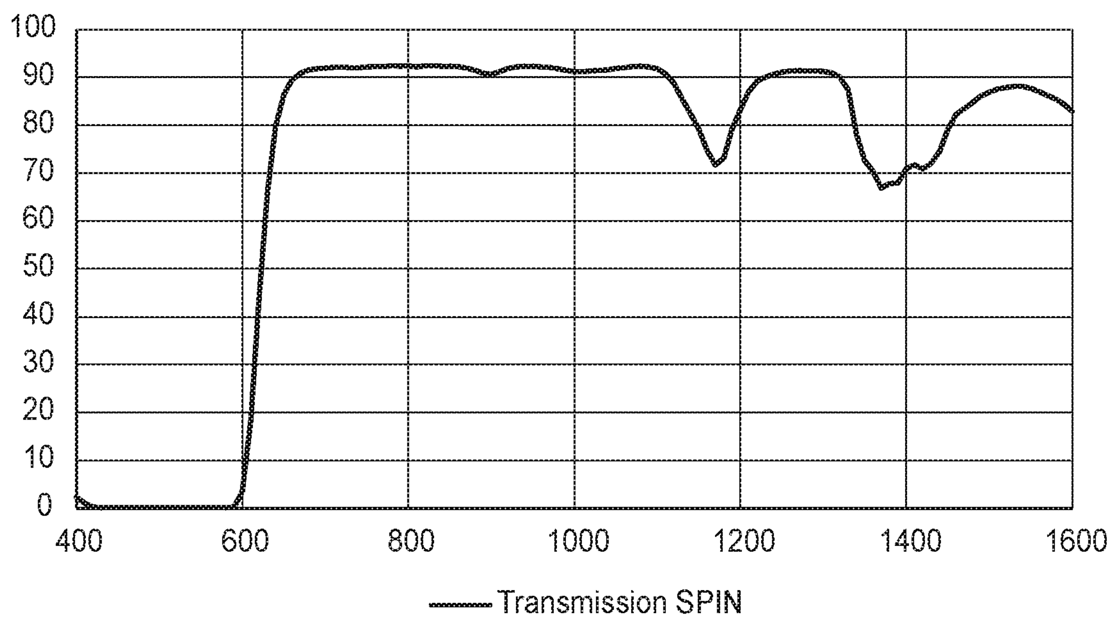

100
90
80
70
60
50
40
30
20
10
0
400
600
800
1000
1200
1400
1600
Transmission SPIN

FIG. 7B

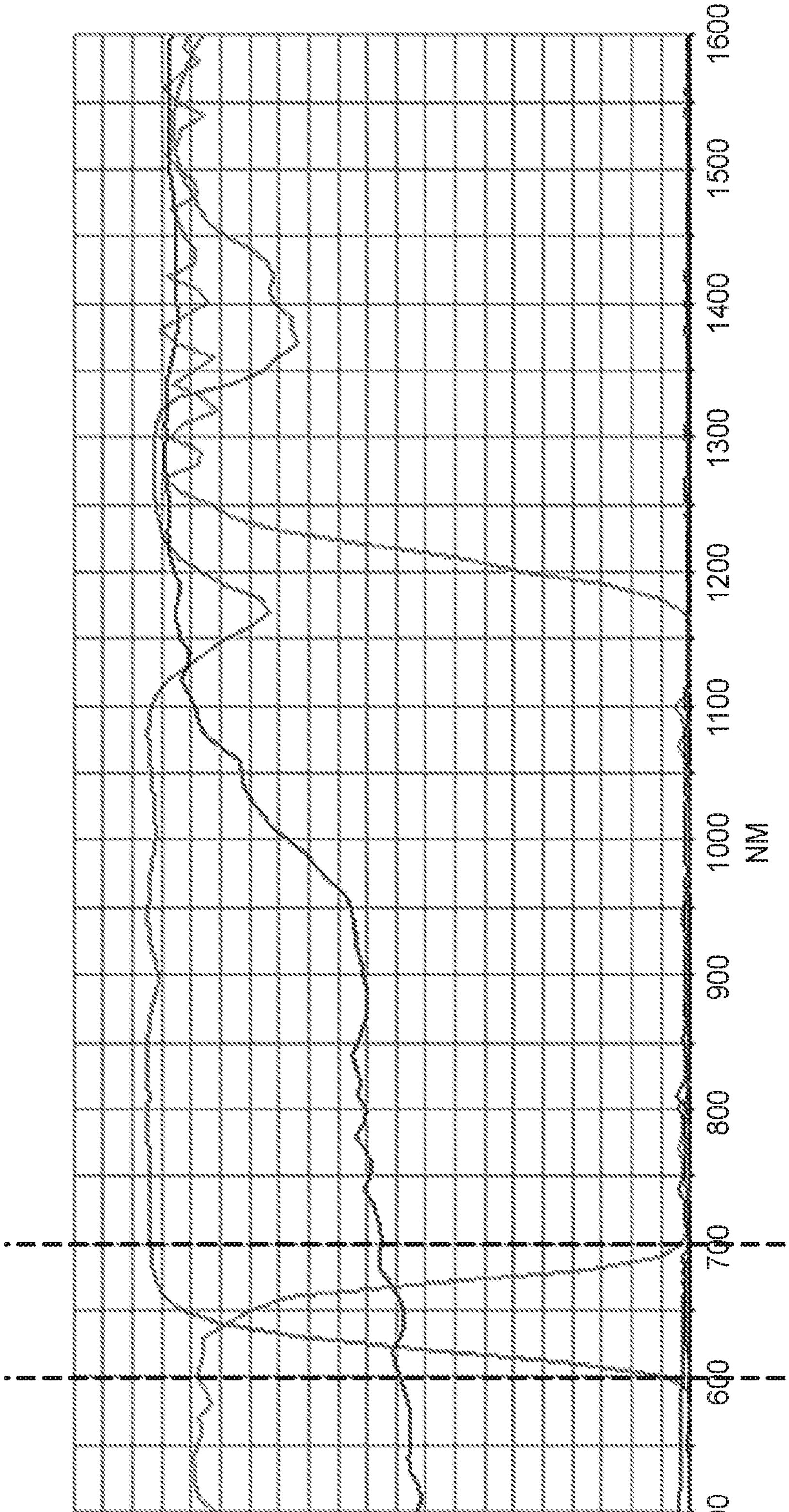

%T
100
90
80
70
60
50
40
30
20
10
0
NM
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600

FIG. 7C

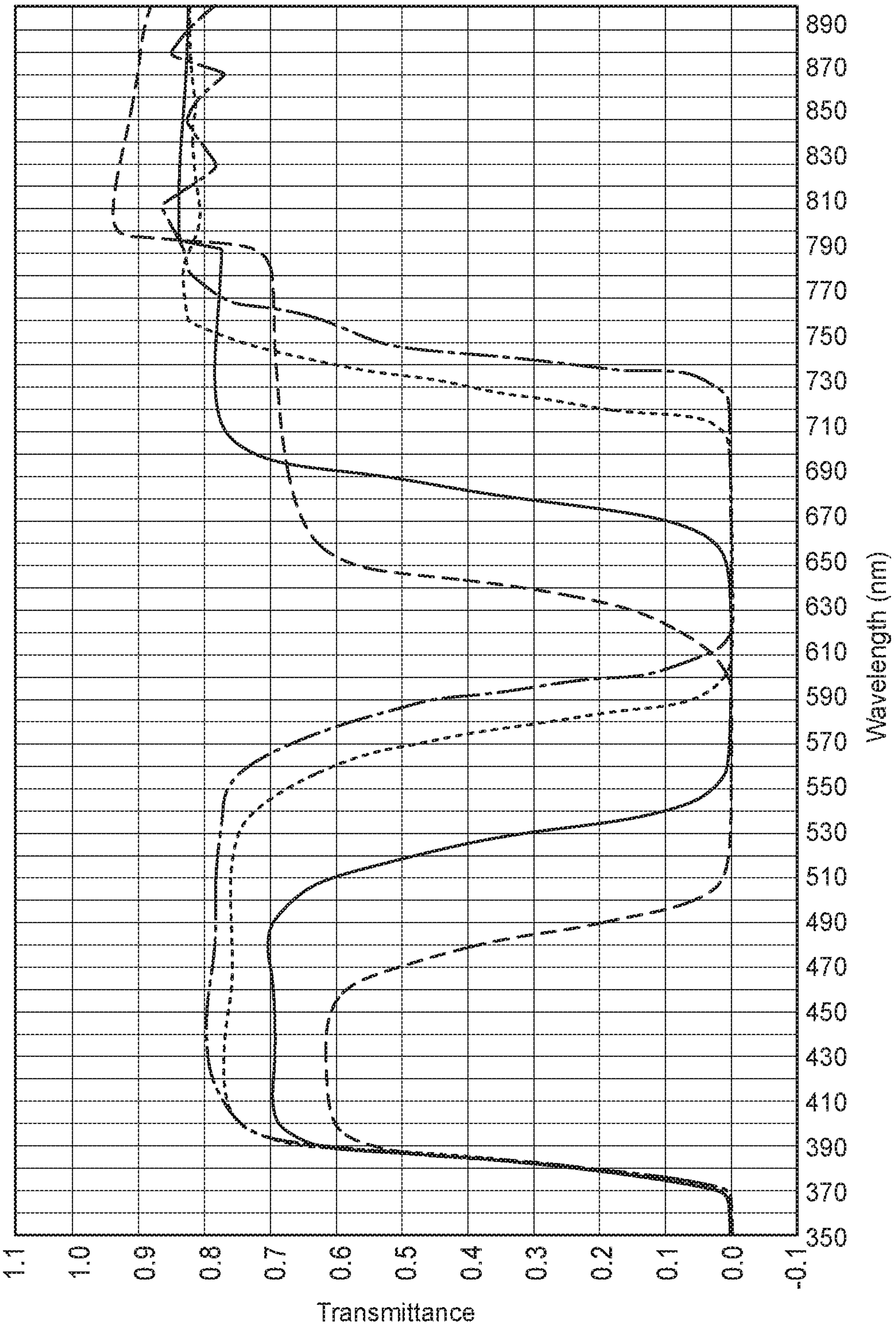

Transmittance
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
Wavelength (nm)
350
370
390
410
430
450
470
490
510
530
550
570
590
610
630
650
670
690
710
730
750
770
790
810
830
850
870
890

FIG. 8A

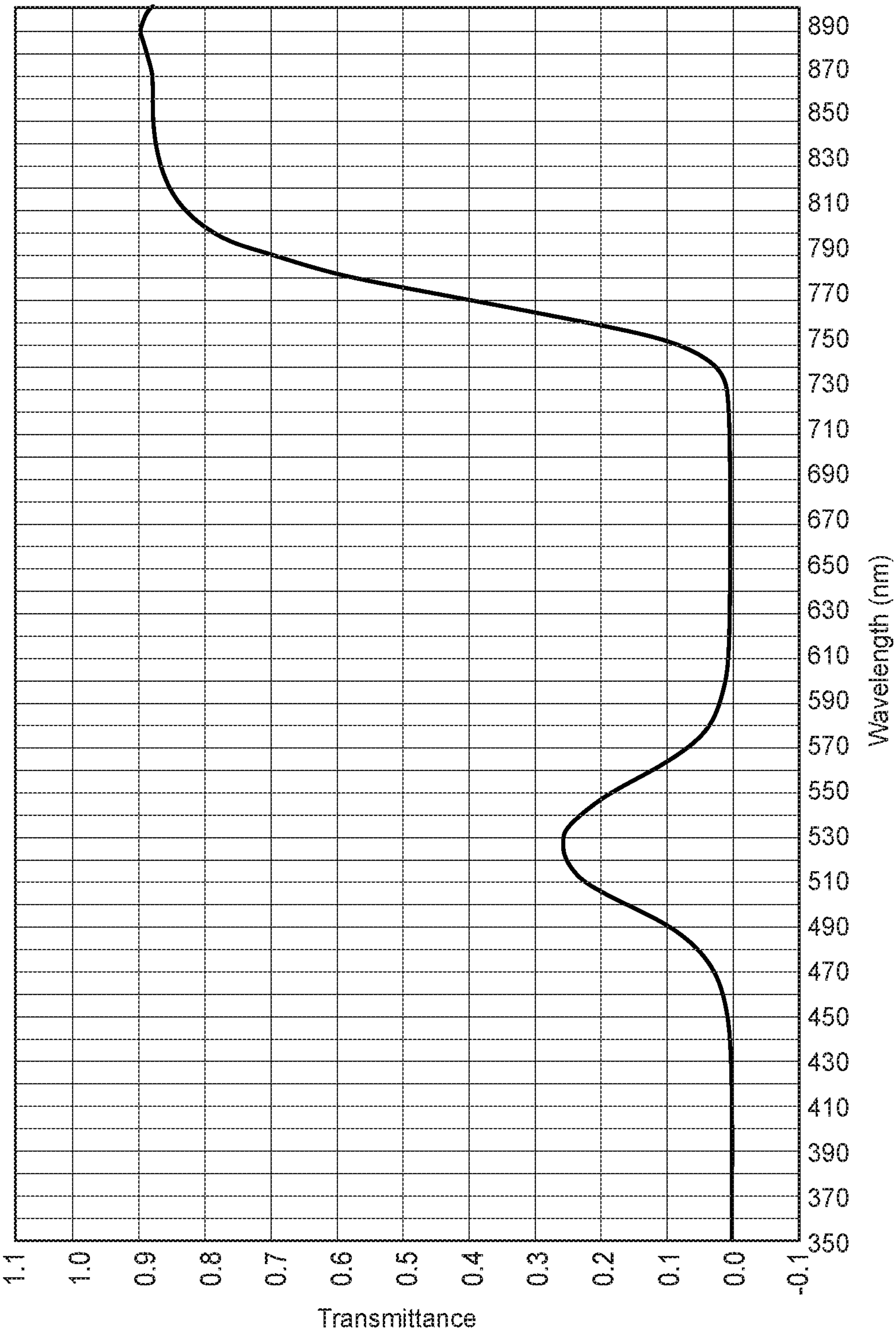

Transmittance
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
Wavelength (nm)
350
370
390
410
430
450
470
490
510
530
550
570
590
610
630
650
670
690
710
730
750
770
790
810
830
850
870
890

FIG. 8B

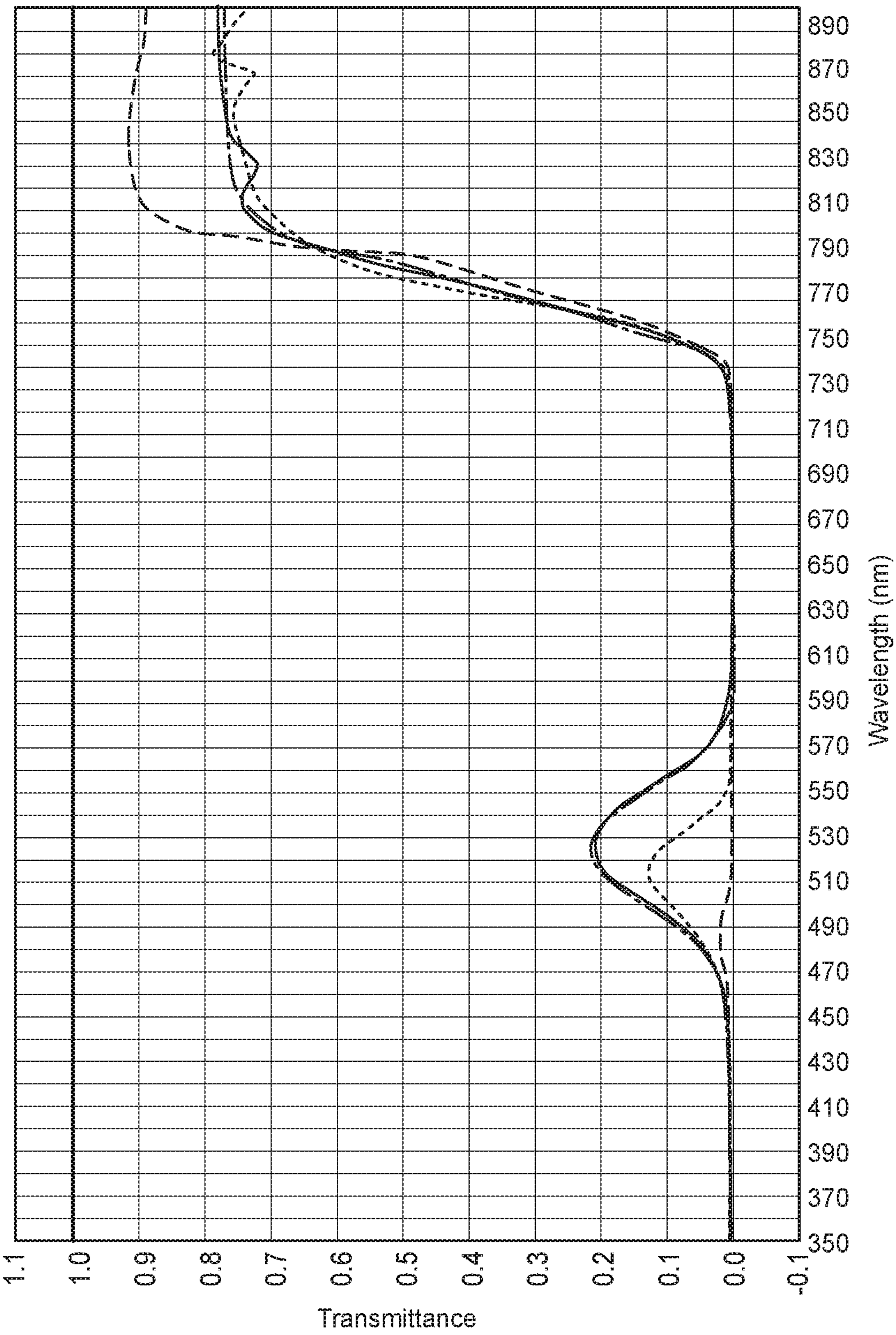

Transmittance
Wavelength (nm)
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
350
370
390
410
430
450
470
490
510
530
550
570
590
610
630
650
670
690
710
730
750
770
790
810
830
850
870
890

FIG. 8C

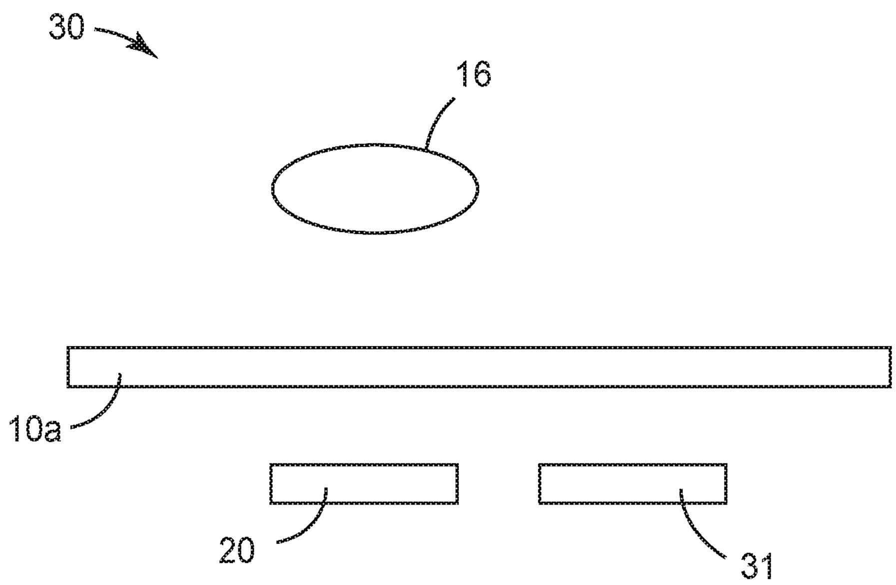


FIG. 9

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2017/057191

A. CLASSIFICATION OF SUBJECT MATTER

G02B 5/20 (2006.01) *G02C 7/10 (2006.01)* *G02B 5/28 (2006.01)* *G01J 1/06 (2006.01)*

According to International Patent Classification (IPC)

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

G02B, G02C, G01J

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)

EPODOC/DWPI/FAMPAT/Google Scholar/CNKI: optical filter, angle, blocking, limiting, selective, incident, prism, Fresnel, recess, louver, interference filter, MOF, multilayer optical film, reflection band, wavelength, 光滤波器, 光学滤波器, 滤光片, 干涉滤光片, 干扰滤波器, 角度, 限制, 阻滞, 阻断, 选择, and other relevant terms

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	US 2013/0135750 A1 (WALKER JR. C. B. ET AL.) 30 May 2013 Whole document, especially Paragraphs [0021]-[0022], [0038] and [0107]; Figures 2 and 3	1, 4-12, 14-16, 28-33 13
X A	US 2015/0002809 A1 (COHEN-TANNOUDJI D. ET AL.) 1 January 2015 Whole document, especially Paragraphs [0009]-[0010], [0101], [0149]-[0152] and [0182]; Figure 3	1-6, 14-20, 28-33 13
A	US 2012/0236313 A1 (NAKAMURA N.) 20 September 2012 Whole document, especially Paragraphs [0038]-[0063]; Figure 2	

☒ 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

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
15/01/2018 *(day/month/year)*	29/01/2018 *(day/month/year)*

Name and mailing address of the ISA/SG

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Singapore 189554

Email: pct@ipos.gov.sg

Authorized officer

Wang Jiayi (Dr)

IPOS Customer Service Tel. No.: (+65) 6339 8616

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2017/057191

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2008/0291541 A1 (PADIYATH R. ET AL.) 27 November 2008 Whole document, especially Paragraphs [0022] and [0024]; Figure 1	
A	US 2009/0080075 A1 (HO Y.-L. ET AL.) 26 March 2009 Whole document, especially Paragraph [0017]; Figures 2 and 4-5	
A	CN 1054319 A (UNIVERSITY TOMSKY) 4 September 1991 Whole document, especially Figures 5-6 of the original non-English language document (a machine translation is enclosed **only** for your reference)	
A	JP 2011-221376 A (DAI NIPPON PRINTING) 4 November 2011 Whole document, especially Abstract; Figures 2-3 of the machine translation	

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2017/057191

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
   because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
   because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
   because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

Please refer to Supplemental Box (Continuation of Box No. III).

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:
   1-20 and 28-33

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2017/057191

Supplemental Box
(Continuation of Box No. III)

This International Searching Authority found multiple inventions in this international application, as follows:

Group 1: Claims 1-20 (in full) and claims 28-33 (in part) relate to an optical filter comprising a major surface having a normal axis, an angle blocking layer having a first angular light blocking range relative to the normal axis, and an interference filter adjacent the angle blocking layer having a second angular light blocking range relative to the normal axis, wherein the optical filer has a predetermined light transmission zone and a predetermined angular light blocking zone, and a system comprising the optical filter thereof;

Group 2: Claims 21-27 (in full) and claims 28-33 (in part) relate to an optical filter comprising an interference filter having an incidence angle-dependent reflection band, and an absorbing layer having an absorption band, wherein the incidence angle-dependent reflection band and the absorption band overlap at at least one wavelength at at least one angle of incidence, and a system comprising the optical filter thereof.

Please refer to **Box No. IV** of Written Opinion of The International Searching Authority (Form PCT/ISA/237) for detailed explanation.

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/US2017/057191

Note: This Annex lists known patent family members relating to the patent documents cited in this International Search Report. This Authority is in no way liable for these particulars which are merely given for the purpose of information.

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