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(54) **COLORED BLUE BLOCKERS**

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(58) **Field of Classification Search**

None

See application file for complete search history.

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ABSTRACT

Methods and devices are described that relate to spectral filters and associated eyewear that are specifically designed to block emissions of circadian-active blue light to reach the observer. An example wearable device that includes one or more windows, and a spectral filter that comprises a coating positioned on one or more sections of the one or more windows. The spectral filter includes a multi-layer stack of dielectric material with alternate high and low indices of refraction. The number of the layers and a thickness of each layer are selected to provide designed transmission and blocking characteristics to block circadian-active spectra

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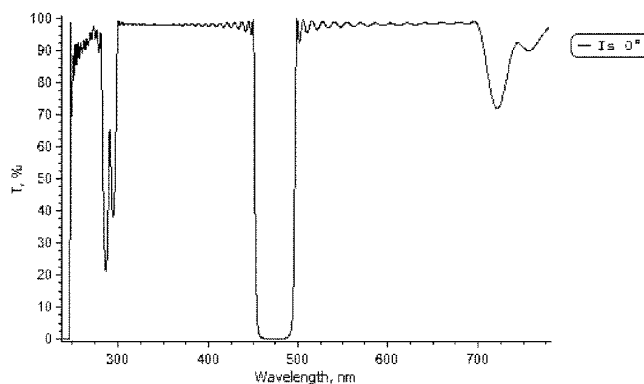
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while allowing spectral content outside of the circadian-active spectra to pass through the spectral filter. The spectral filter further includes an additional layer to effectuate a particular color such as the color pink.

22 Claims, 11 Drawing Sheets

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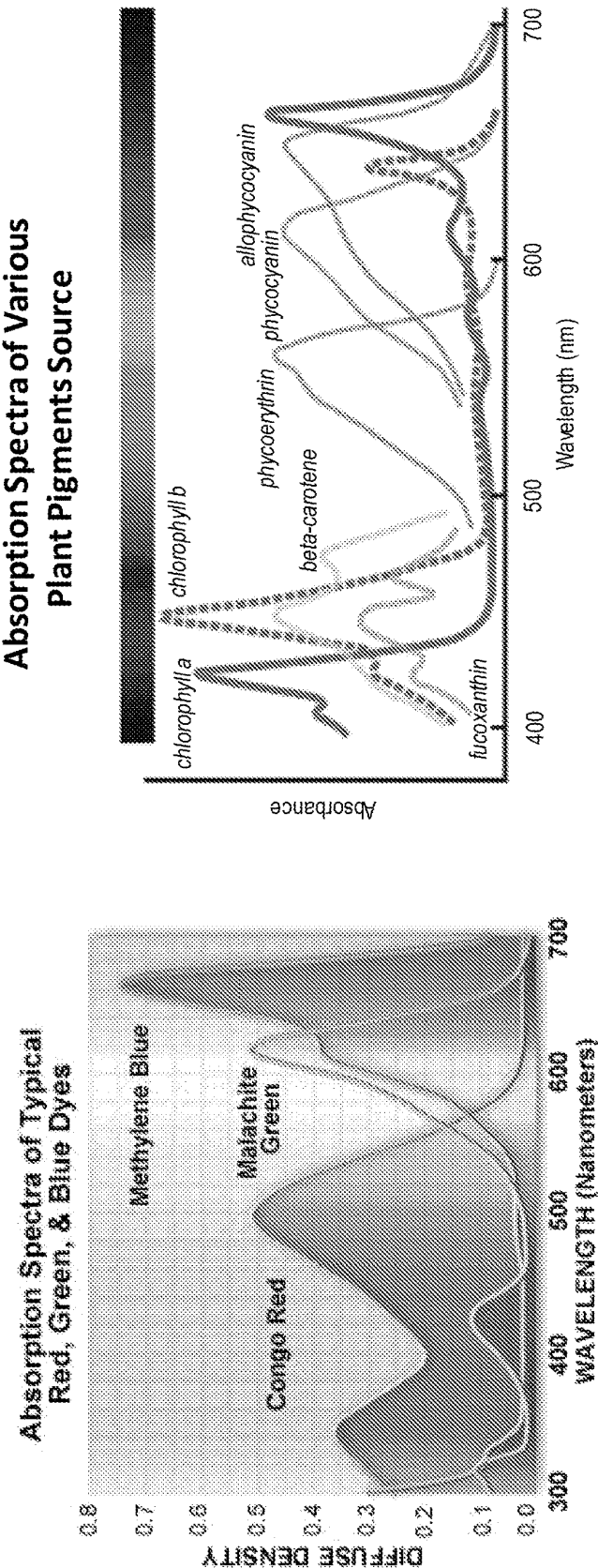


FIG. 1

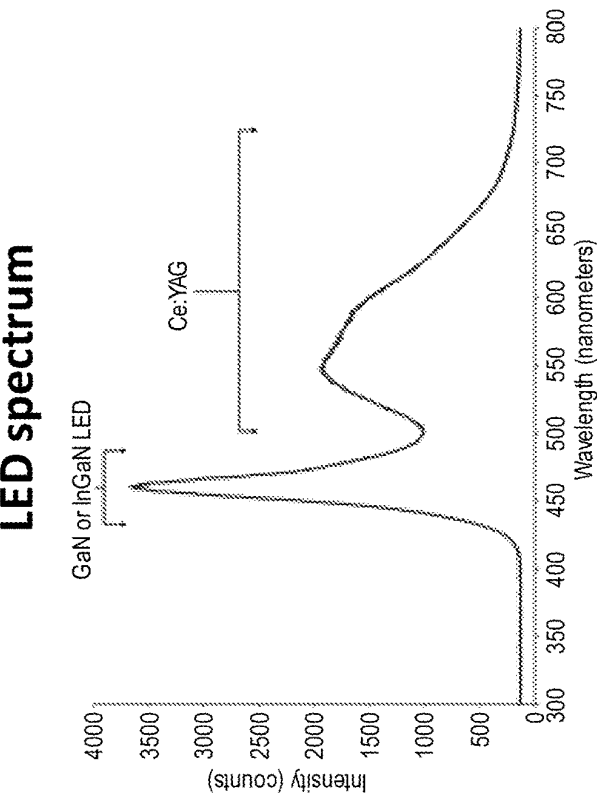


FIG. 2B

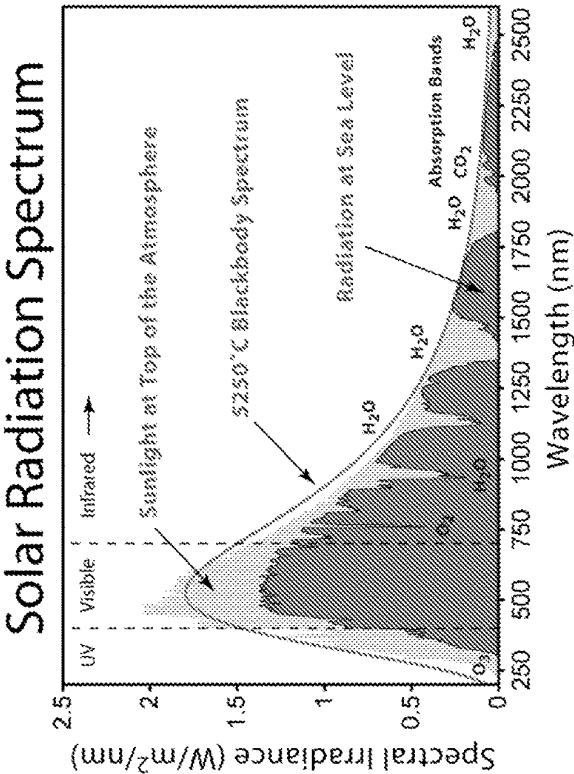
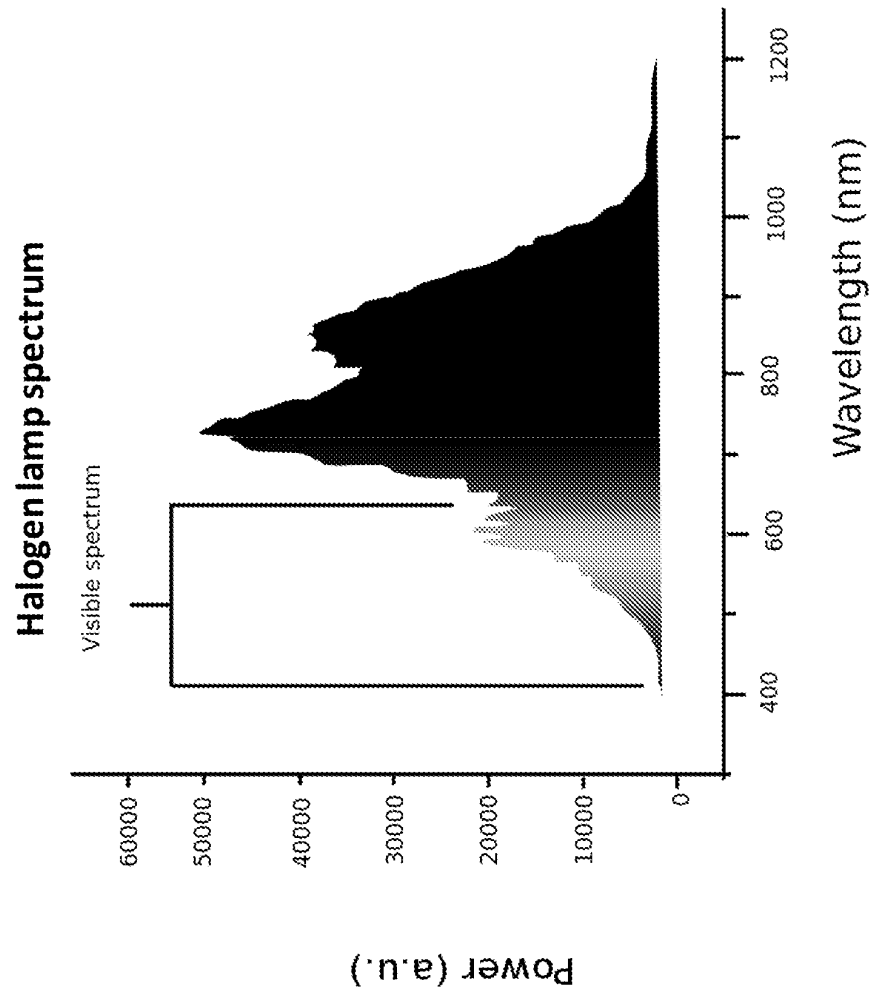


FIG. 2A

**FIG. 2C**

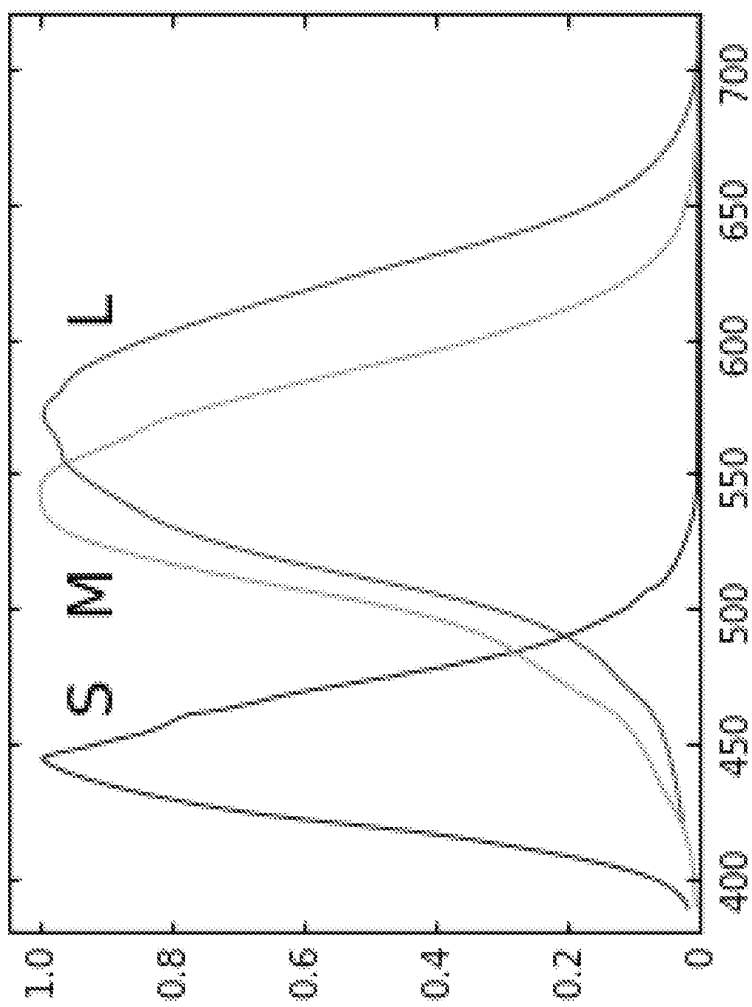


FIG. 3

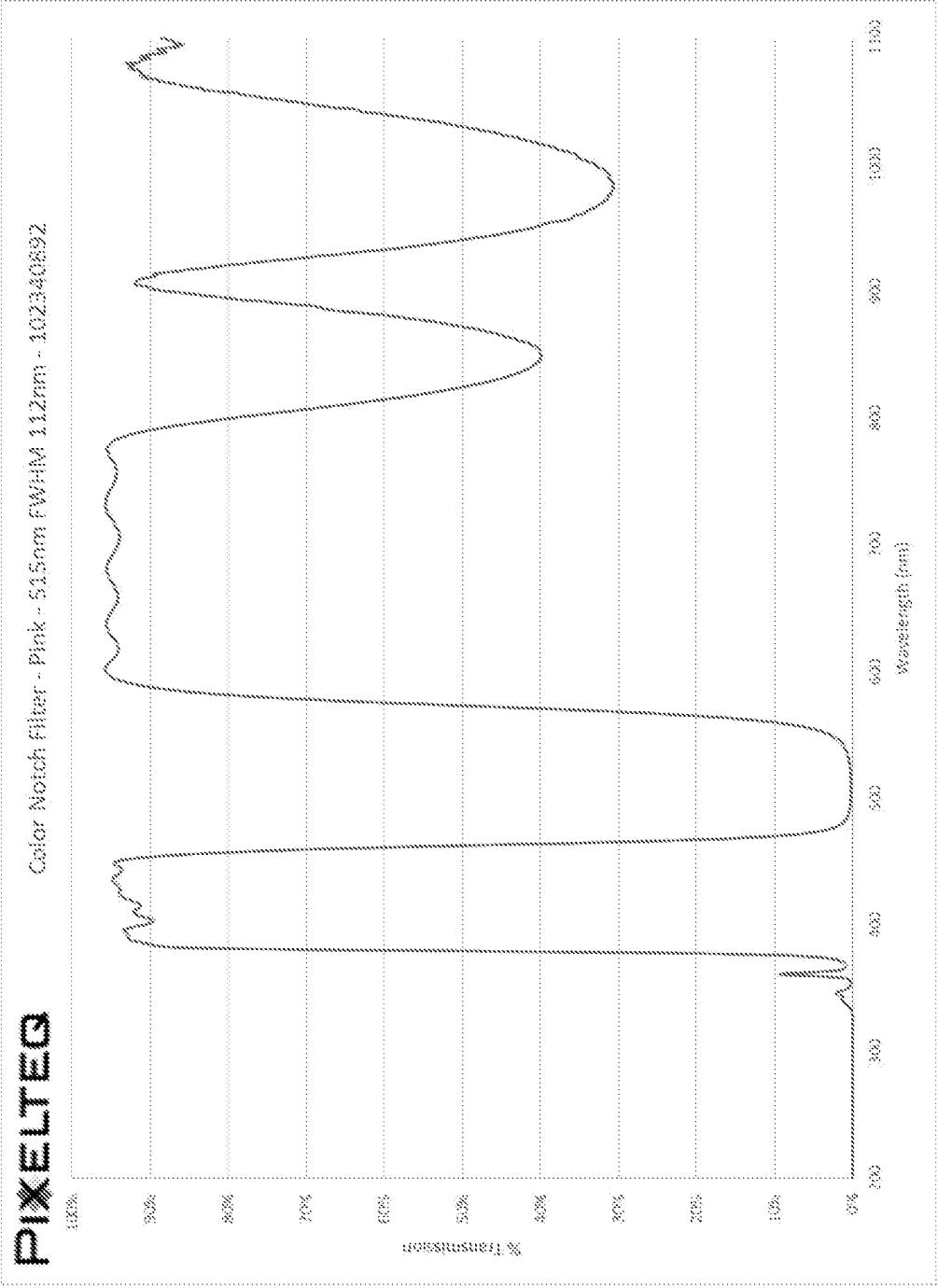


FIG. 4

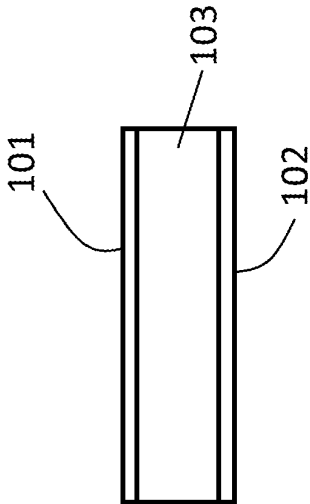


FIG. 5B

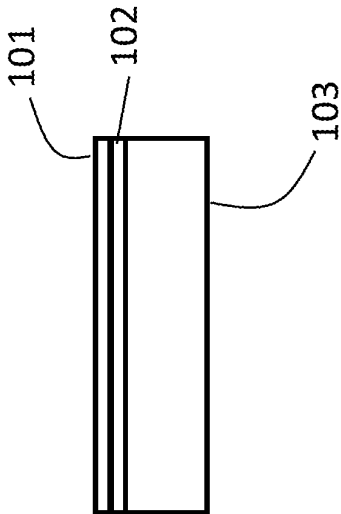


FIG. 5A

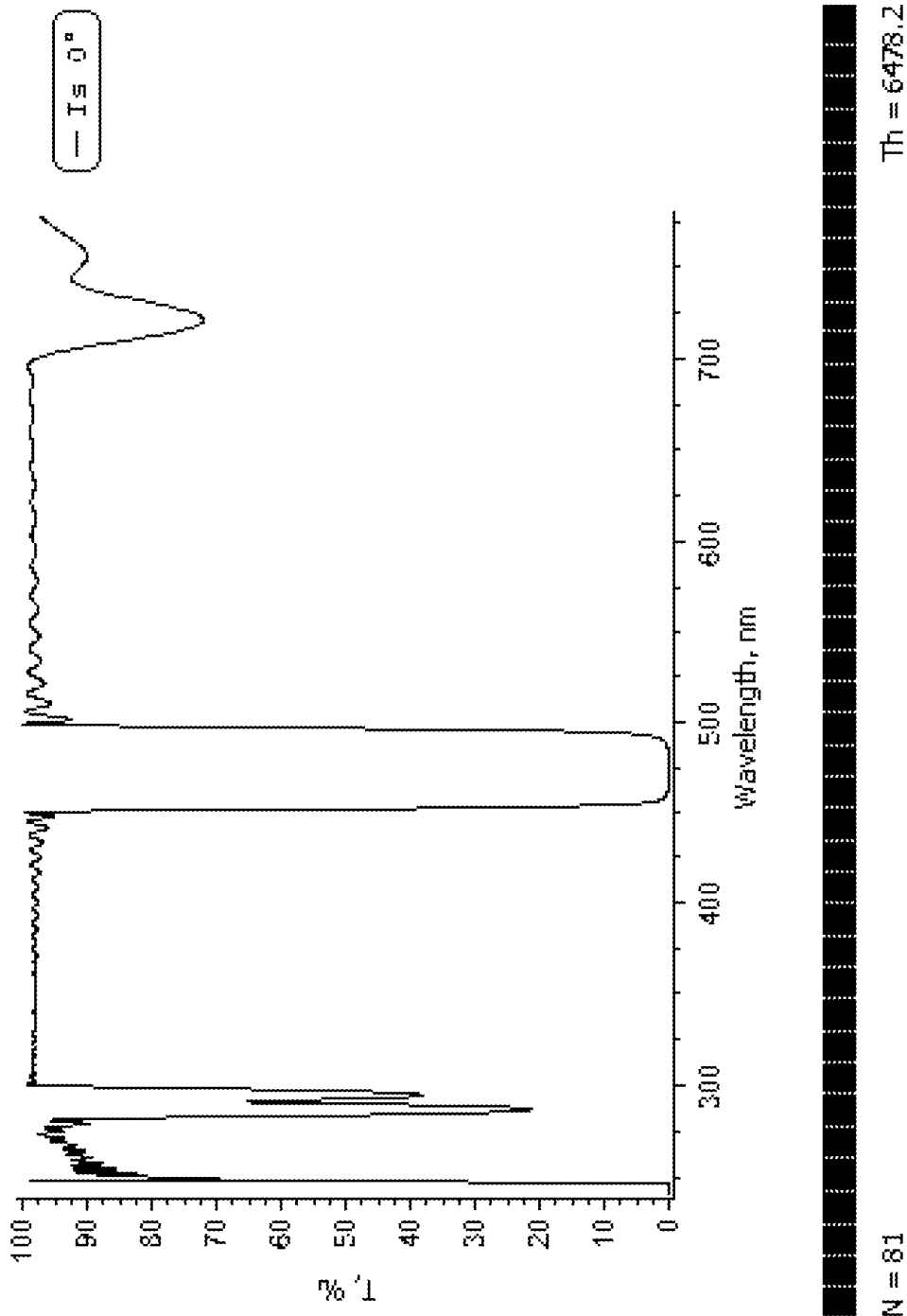
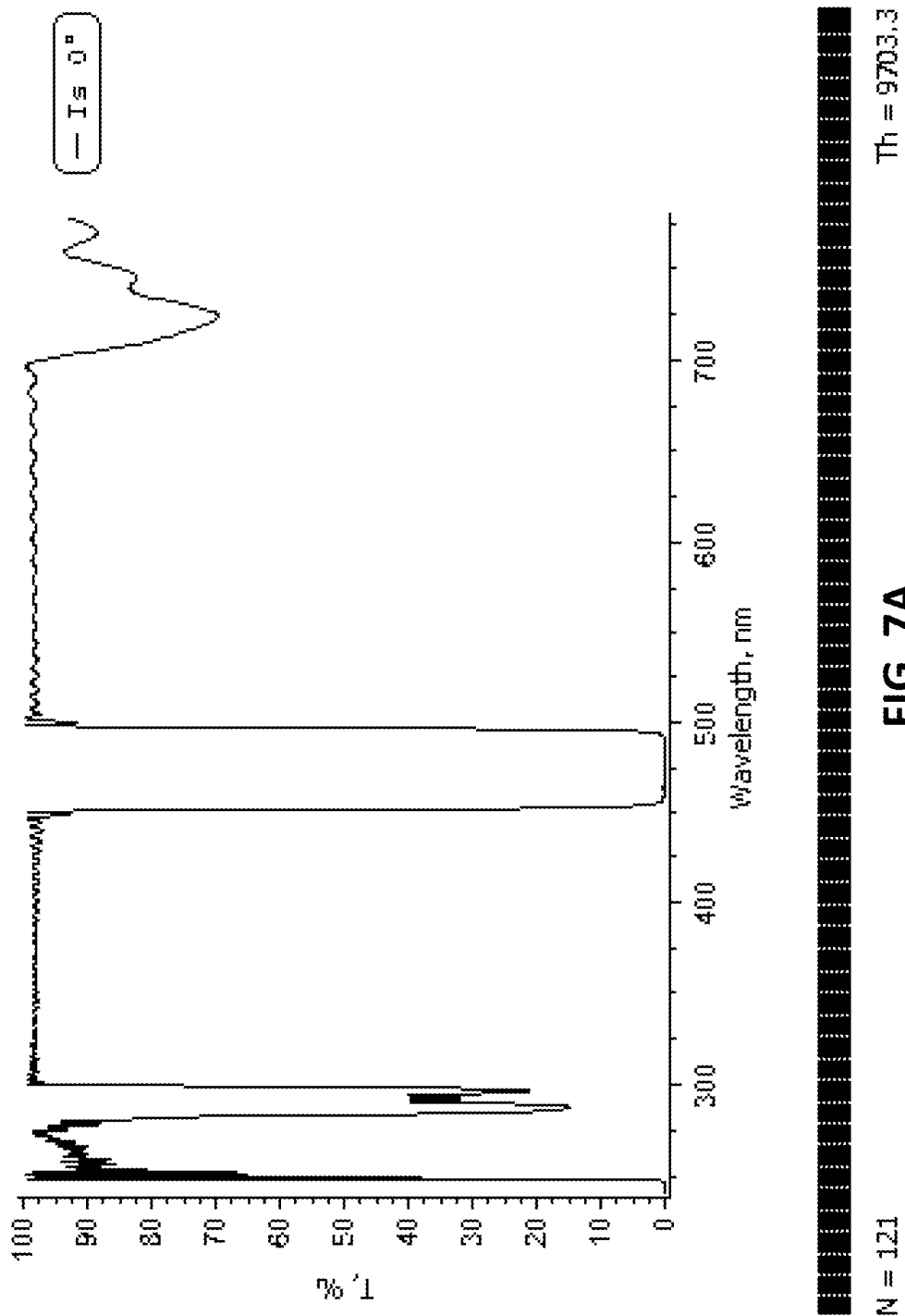


FIG. 6A

$\lambda_0=580\text{nm}$, 81 layers (bottom to top layers) glass substrate ($n=1.52$), TiO_2 (H , $n=2.35$), SiO_2 (L , $n=1.45$)
1.349560L 0.028668H 1.512985L 0.041271H 1.608583L 0.064332H 1.593296L 0.067141H 1.526096L 0.071896H
1.546255L 0.095840H 1.556345L 0.099822H 1.499656L 0.093959H 1.509435L 0.125315H 1.539214L 0.121542H
1.461539L 0.107563H 1.501363L 0.151621H 1.524701L 0.126945H 1.428969L 0.122958H 1.509952L 0.166405H
1.499674L 0.124171H 1.428197L 0.140889H 1.508788L 0.163955H 1.472750L 0.129484H 1.451755L 0.147971H
1.488396L 0.155941H 1.475261L 0.143863H 1.459095L 0.136241H 1.467875L 0.162160H 1.504930L 0.148110H
1.427090L 0.120350H 1.486239L 0.180843H 1.528930L 0.129698H 1.376479L 0.122505H 1.535028L 0.188392H
1.528392L 0.098481H 1.371031L 0.138032H 1.571188L 0.168913H 1.487031L 0.074569H 1.439979L 0.142092H
1.591707L 0.127810H 1.447825L 0.068508H 1.528525L 0.114215H 1.586401L 0.086688H 1.534449L 0.068064H
1.975467L

FIG. 6B



$\lambda_0=580\text{nm}$, 121 layers (bottom to top layers) glass substrate ($n=1.52$), TiO_2 (H , $n=2.35$), SiO_2 (L , $n=1.45$) 1.330763L
0.016607H 1.508918L 0.029100H 1.605007L 0.042579H 1.608162L 0.048616H 1.564965L 0.052669H 1.565974L
0.068108H 1.578153L 0.070477H 1.537573L 0.075404H 1.564034L 0.085403H 1.547952L 0.081168H 1.539358L
0.090588H 1.565908L 0.085063H 1.534168L 0.083015H 1.575261L 0.089134H 1.578085L 0.070811H 1.556622L
0.076271H 1.632505L 0.077031H 1.606912L 0.059673H 1.583861L 0.072740H 1.648657L 0.081810H 1.583524L
0.071398H 1.555738L 0.092632H 1.582556L 0.102521H 1.529586L 0.099728H 1.524401L 0.117209H 1.520406L
0.119841H 1.504295L 0.130506H 1.503003L 0.124282H 1.473167L 0.140072H 1.513313L 0.147865H 1.461721L
0.121496H 1.472626L 0.164610H 1.513805L 0.144019H 1.422811L 0.129352H 1.494737L 0.177106H 1.494568L
0.133754H 1.421644L 0.145674H 1.499933L 0.170246H 1.468525L 0.137350H 1.450323L 0.150736H 1.476671L
0.159164H 1.476338L 0.154628H 1.457656L 0.133209H 1.452456L 0.169274H 1.513473L 0.158991H 1.411374L
0.113005H 1.482001L 0.195548H 1.541925L 0.135025H 1.339466L 0.119329H 1.544518L 0.206000H 1.544875L
0.096410H 1.330282L 0.142127H 1.580833L 0.182598H 1.488887L 0.067121H 1.422164L 0.150768H 1.600870L
0.133406H 1.422217L 0.063714H 1.539112L 0.121610H 1.594765L 0.086015H 1.514099L 0.066710H 1.983568L

FIG. 7B

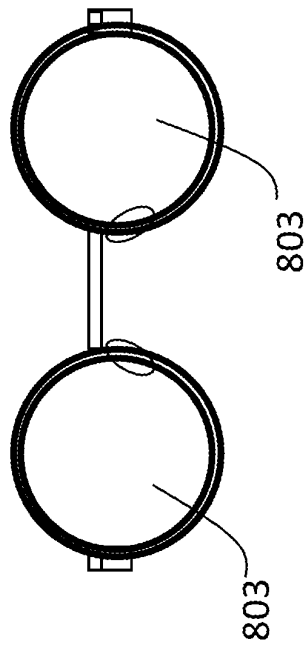


FIG. 8

COLORED BLUE BLOCKERS**CROSS-REFERENCE TO RELATED APPLICATION(S)**

This patent document is a 371 National Stage Application of International Patent Application No. PCT/US2022/038220, filed Jul. 26, 2022, which claims priority to the provisional application with Ser. No. 63/225,785 titled “PINK BLUE BLOCKERS,” filed Jul. 26, 2021. The entire contents of the above noted applications are incorporated by reference as part of the disclosure of this document.

TECHNICAL FIELD

The disclosed embodiments relate to eyewear and spectral filters.

SUMMARY

Methods and devices are described that, among providing other features and benefits, relate to spectral filters and associated eyewear that are specifically designed to block emissions of circadian-active blue light to reach the observer. The filters can further include additional materials or layers that causes the filter to have a particular color, such as pink.

An example wearable device includes one or more windows positioned to allow light from a light source to propagate toward a position of a wearer's eyes, and a spectral filter that comprises a coating positioned on one or more sections of the one or more windows. The spectral filter includes a multi-layer stack of dielectric material with alternate high and low indices of refraction such that a layer having a high index of refraction is positioned above or below a layer having a low index of refraction, and a layer having a high index of refraction is positioned above or below a layer having a low index of refraction. The number of the layers and a thickness of each layer are selected to provide designed transmission and blocking characteristics to block circadian-active spectra while allowing spectral content outside of the circadian-active spectra to pass through the spectral filter. The designed transmission and blocking characteristics include a contiguous blocking region within 455-495 nm band of wavelengths to within at least ± 5 nm, and two contiguous transmission regions, a first one of the contiguous regions extending below 455 nm and a second one of the contiguous transmission regions extending above 495 nm. The spectral filter is configured to block 98-100% of the spectral content the blocking region and transmit 80%-100% of the spectral content in the contiguous transmission regions. The spectral filter further includes an additional layer to effectuate a particular color.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates example spectral characteristics of dye-based (left) and pigment-based (right) filters.

FIG. 2A illustrates the solar radiation spectrum.

FIG. 2B illustrates the radiation spectrum of an example light emitting diode (LED).

FIG. 2C illustrates the spectrum of an example halogen lamp.

FIG. 3 illustrates a typical spectral sensitivity of the human eye.

FIG. 4 illustrates transmission spectra of an example filter with pink color.

FIG. 5A illustrates a configuration for implementing a colored optical filter in accordance with an example embodiment.

FIG. 5B illustrates another configuration for implementing a colored optical filter in accordance with an example embodiment.

FIG. 6A illustrates a plot of the transmission spectra for a filter specifically designed to block certain circadian-active wavelengths that is suitable for including a pink layer in accordance with an example embodiment.

FIG. 6B illustrates a set of parameters associated with the filter of FIG. 6A.

FIG. 7A illustrates a plot of the transmission spectra for another filter specifically designed to block certain circadian-active wavelengths that is suitable for including a pink layer in accordance with an example embodiment.

FIG. 7B illustrates a set of parameters associated with the filter of FIG. 7A.

FIG. 8 illustrates an example eyewear that incorporates the circadian rhythm restoring filters of the disclosed technology.

DETAILED DESCRIPTION

The timing of the brain's circadian clock is set by schedules of natural sunlight exposure. All physiological processes in the body are synchronized to the signals sent from the brain's clock as it interprets these environmental light patterns. As such, the clock's estimation of whether it is daytime (presence of light) or nighttime (near absence of light) has widespread impacts on the timing and organization of the sleep-wake cycle. Electric room lighting can interfere with the circadian clock's estimation of day versus night because the photoreceptors in the eye that send information to the clock are activated by both natural sunlight and electric room lighting. Electric lighting can thus interfere with sleep because humans are most biologically prepared to sleep at night not during the day. If the clock interprets a daytime signal when sensing electric light, it will delay the timing of sleep and will have more difficulty communicating with the rest of the body so that a consolidated period of rest is coordinated at night.

The photoreceptors that transmit light information to the brain's clock are most sensitive to certain parts of the light spectrum. One photoreceptor, melanopsin, is expressed by a subpopulation of cells in the eye called intrinsically photosensitive retinal ganglion cells (ipRGCs). They are most activated by light occurring between 455-495 nm, which is perceived as “blue light.” A second important photoreceptor that relays information to the clock is expressed by cone cells in the retina that are sensitive to mid-wavelength light occurring between 500-560 nm, which is perceived as “green light.” Though blue and green light are only partial pieces of the overall visible spectrum (400-800 nm), they have outsized effects on how the brain's clock measures light exposure and interprets for itself and for the rest of the body the timing and length of the day versus the timing and length of the night.

The circuitry that comprises the brain's clock is different from the circuitry that comprises the image-forming visual system (i.e., the system that allows us to see). Current lens technologies that seek to limit the sleep-disrupting effects of electric lighting at night, take advantage of this segregation by filtering out all incident light below approximately 560 nm and allowing the rest through to enable visibility. This approach blocks about 50% of circadian-active light, while maintaining approximately 80% visibility.

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The disclosed embodiments, among other features and benefits, rely on interference filter designs that are implemented in a wearable device (e.g., glasses, goggles, etc.) or used as a covering for a luminaire (e.g., a light source from a house lamp) that provide a precise and granular spectral behavior by precisely specifying what light is blocked versus that which is allowed to go through within that part of the range that is normally completely blocked up to 560 nm with current lens technologies. The filters are further augmented with additional materials or layers to be perceived as having a particular color, such as pink. The disclosed technology can be implemented by designing a lens that maintains high visibility, while blocking the most circadian-active blue light occurring between 455-495 nm (i.e., that which activates melanopsin). The result of this more precise targeting of circadian-active light is that about 75% the spectrum that is blocked by current lens technology between 400-560 nm would be freed up to maximize perceived visibility.

A large number of the existing systems rely on dye- or pigment-based filters that block or transmit a contiguous band of wavelengths but without a capability to selectively transmit or block narrower subbands within the larger contiguous band. Dye and pigment filters operate based on absorption of light by color dye and pigment embedded in a material such as polymer or sol-gel. The transmission spectrum of this type of filter has broad peaks shaped like a Gaussian function with linewidth equal to the inhomogeneous broadening of the materials. FIG. 1 illustrates example spectral characteristics of dye-based (left) and pigment-based (right) filters that exhibit this type of behavior. As also evident from FIG. 1, each spectrum includes a prominent peak with gradual fall off characteristics on both sides thereof. Thus, the usefulness of these filters can be limited to applications where the desired spectral range happens to coincide with the spectral peak of the filter. But even then, the gradual falloff of the spectra can cause part of the desired spectrum to be filtered while allowing part of the undesired spectral content to seep through. In addition, the materials can be bleached under high light intensity, high temperature and/or corrosive environment.

Other types of filters include doped glass, semiconductor, metal, and metamaterial optical filters. Doped glass filters are made of a glass doped with a trace of impurity such as a metal and semiconductor nanocrystal, silver halides and cuprous ions. Semiconductor optical filters are made of semiconductor material with a transmission edge determined by the bandgap. Metal optical filters are made by depositing several layers of metal or metallic alloy made of rhodium, palladium, tungsten, nickel and chromium on a transparent substrate and are used extensively as neutral density filters. Metamaterial optical filters are made of micro- and nano-fabricated structures with dimensions of the order of or smaller than the operating wavelength. Another class of optical filters are tunable optical filters with transmission spectra that can be changed by temperature, electric and/or magnetic field. Examples of tunable optical filters are liquid crystal, Fabry-Perot and MEMS filters. These types of filters are generally bulky and have a lower transmission than non-tunable filters.

The disclosed embodiments rely on multi-layer dielectric interference filter configurations to enable the precise spectral shaping that is required for precise channeling of circadian-active green light. Multi-layer dielectric or dichroic filters operate by optical interference instead of absorption. These filters are made by depositing multiple layers of dielectric coating such as magnesium fluoride, zinc sulfide,

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cerium dioxide, titanium dioxide, silicon oxide, zirconium dioxide to name a few. Interference filters can be designed to transmit light of different wavelength band with sharp transmission edge, in contrast to the broad band spectrum of the dye and pigment filter. The transmission spectrum of this type of filter is generally dependent on the angle of the incident light, although designs can be made to minimize the angular variation.

Several types of interference filters are described that relate to the features of the disclosed embodiments: long-wave pass, short-wave pass, notch (minus, bandstop), and band pass interference filter. A long-wave pass interference filter can include a multilayer structure and can be described using the following shorthand notation:

$$\left[\frac{H}{2} L \frac{H}{2} \right]^s.$$

In the above expression, H denotes a quarter-wave high-index layer having a thickness $\lambda_0/4n_H$ and H/2 denotes half of a quarter-wave high-index layer, i.e., one-eighth of a wave $\lambda_0/8n_H$. L denotes a quarter-wave low-index layer having a thickness $\lambda_0/4n_L$; s is an integer that denotes the number of basic periods (i.e., how many times the basis structure of high-low-high is repeated), λ_0 is the reference wavelength (i.e., the center wavelength used to design the filter), and $n_{H,L}$ represents the high or the low refractive index, depending on whether the H or L subscript is used. A short-wave pass interference filter can include a multilayer structure and can be described by the following notation that follows a similar convention as described above:

$$\left[\frac{L}{2} H \frac{L}{2} \right]^s.$$

A bandpass filter is a combination of long-wave pass and short-wave pass filters, and allows only a particular spectral band (i.e., the passband) to be transmitted. A notch filter blocks a particular band of wavelengths (i.e., the notch) but allows the remaining spectral content to pass therethrough. A notch filter can be implemented by using a multilayer structure, represented by the following notation:

$$[\alpha L \beta H]^s \alpha L.$$

In the above expression, α and β are numbers chosen for the location and width of the notch filter. For example, a notch filter with a reference wavelength at 550 nm and bandwidth of about 100 nm can be implemented using the multilayer structure represented by:

$$[1.68L0.30H]^{59}1.68L.$$

In the above example, $\alpha=1.68$ and $\beta=0.30$.

One key advantage of the disclosed embodiments is the selective transmission and blocking of different wavelengths of light to match the photo receptor sensitivity of the human retina with high efficiency that maintains a high visibility. To this end, the coating on the lens that is part of the eyewear is specifically designed to elicit a particular biological

response. To meet these requirements, the optical lens with the coating must satisfy two efficiency conditions: transmission efficiency and illumination efficiency. The transmission efficiency of a color filter can be described as:

$$\eta_T = \frac{\int_{\lambda_1}^{\lambda_2} d\lambda T(\lambda)}{\int_{\lambda_3}^{\lambda_4} d\lambda T(\lambda)}.$$

In the above expression, η_T is the transmission efficiency; λ_1 and λ_2 are the lower and upper wavelengths, respectively, of the transmission band; λ_3 and λ_4 are the lower and upper wavelengths, respectively, of the incident illumination; and $T(\lambda)$ is the filter transmission spectrum. Interference filters with sharp transition edge and low transmission ripple are used to achieve high η_T .

In addition, the illumination efficiency of a color filter can be described as:

$$\eta_i = \frac{\int_{\lambda_1}^{\lambda_2} d\lambda S(\lambda) T(\lambda) \rho(\lambda)}{\int_{\lambda_3}^{\lambda_4} d\lambda S(\lambda) \rho(\lambda)}.$$

In the above expression, η_i is the illumination efficiency; λ_1 and λ_2 are the lower and upper wavelengths, respectively, of the transmission band; λ_3 and λ_4 are the lower and upper wavelengths, respectively, of the incident illumination; $S(\lambda)$ is the illumination spectrum; $T(\lambda)$ is the filter transmission spectrum; and $\rho(\lambda)$ is the human eye sensitivity. $S(\lambda)$ can be the spectrum of the sun, a light emitting diode (LED), a halogen lamp, a fluorescent lamp, or another source of illumination. Example spectra of some of the above sources are presented in FIGS. 2A to 2C. In particular, FIG. 2A illustrates the solar radiation spectrum; FIG. 2B illustrates the radiation spectrum of an example LED; and FIG. 2C illustrates the spectrum of an example halogen lamp. FIG. 3 illustrates a typical spectral sensitivity of the human eye, and in particular, the normalized responsivity spectra for S-, M- and L-cone cells. The illumination efficiency of the lens must be high so that light visibility is not critically reduced during day and night.

In some applications, it may be desirable to provide optical filters, which in addition to having the above noted spectral characteristics, also have a certain color. The specific color of the filters may be for medical or other reasons. The perceived color of a filter is governed by the incident illumination and spectral characteristics of the filter, which may not produce the desired color. For example, the transmission of a filter with pink color, as shown in the example of FIG. 4, does not match the transmission of a blue-blocker (see one example in FIG. 6A). By energy conservation, $R+T+A=1$, where R is the reflection, T is the transmission and A is the absorption for the filter. For most interference filters, A is close to or equal to zero. But modifying A provides another degree of freedom to change the color of the optical filter. This can be accomplished by (1) using a substrate with some absorption, (2) doping the materials of the interference filter layers and/or (3) adding an absorbing layer to create the desirable color.

Color is a nonobjective human response to light of different spectrum. A common standard is the tristimulus

values, denoted by X, Y and Z, developed by the International Commission on Illumination (abbreviated as CIE in French) based on the photopic response curves of the human eye. The tristimulus values of a coating can be calculated using standard illuminants, which define a relative spectral power distribution of a theoretical source of light. Thus, the color of a coating depends on the illuminants or source of light. Coatings of different spectrum can have the same color, when the light spectrum creates the same response in the three-color receptors in the human eye. This is the concept of metamerism, and the coatings with the same color are metameric. In the disclosed embodiments, an absorbing material with a specific absorption spectrum is chosen such that the combination of the interference filter and the absorbing coating, such as those shown in FIGS. 6A and 7A, has the desired tristimulus values for the color pink. As there is a range of the color pink, there is also a range of tristimulus value.

FIGS. 5A and 5B illustrates two configurations for implementing a colored optical filter in accordance with some example embodiments. In both configurations of FIGS. 5A and 5B, an interference filter 101 (e.g., the multi-layer dielectric stack) is positioned on a substrate 103; an additional (or color) layer 102 may be placed on one side of the substrate 103 to effectuate the desired color. In FIG. 5A, the color layer 102 and the interference filter 101 are on the same side of the substrate 103, while in FIG. 5B, the color layer 102 and the interference filter 101 are on opposite sides of the substrate 103. The disclosed configurations can operate with the light that is incident from either the top or the bottom. The configuration in FIG. 5B may be easier to manufacture because the interference filter 101 can be deposited using a vacuum chamber and the color layer 102 can be deposited by spraying. The additional layer 102 can be a semitransparent color coating, an organic or inorganic pigment or dye layer. One example of the additional layer 102 is a layer that includes inorganic pink pigment, such as E-5300 Ultramarine Pink and E-5302 Ultramarine Pink sold by Color Techniques, Inc., or PV15 Ultramarine Pink sold by Ferro. The material can include sodium aluminum sulfosilicate with chemical formula $\text{Na}_8\text{-x}[(\text{Al},\text{Si})_{12}\text{O}_{24}(\text{Sy})_2]$. In some embodiments, two or more additional layers (e.g., on both sides of the substrate) can be used to effectuate the desired color.

As an example, a thin layer of absorbing material can include PV15 Ultramarine pink in a polymer matrix. The thickness of the absorbing layer and the layers of the interference filter can be varied to give the desired tristimulus value without changing the filter transmission band. This task can be accomplished using thin film design software, such as Essential Macleod or OptiLayer.

When designing the disclosed melanopsin-blocker filters, the inclusion of the above noted additional layers must be taken into account in order to provide the desired spectral characteristics. For example, FIG. 6A illustrates a plot of the transmission spectra for a filter specifically designed to block certain circadian-active wavelengths that is suitable for including a pink layer in accordance with an example embodiment. The plot shows the spectra for the filter without the pink layer. In particular, the filter in FIG. 6A includes a high transmission region (in some embodiments, with close to 100% transmission capability) in bands 300-455 nm and 495-700 nm (± 5 nm), while blocking (i.e., with nearly 0% transmission) the spectral contents in the range 455-495 nm (± 2 nm). The filter has 81 dielectric layers (designed with a reference wavelength $\lambda_0=580$) stacked on top of a glass substrate with thicknesses that are listed in FIG. 6B.

FIG. 7A illustrates a plot of the transmission spectra for another filter specifically designed to block certain circadian-active wavelengths that is suitable for including a pink layer in accordance with an example embodiment. In particular, the filter in FIG. 7A includes a high transmission region (in some embodiments, with close to 100% transmission capability) in bands 300-455 nm and 495-700 nm (± 5 nm), while blocking (i.e., with nearly 0% transmission) the spectral contents in the range 455-495 nm (± 2 nm). The filter has 121 dielectric layers (designed with a reference wavelength $\lambda_0=580$) stacked on top of a glass substrate with thicknesses that are listed in FIG. 7B. Compared to the FIG. 6A filter, the filter in FIG. 7B has smaller ripple and sharper band edge transitions. This is achieved by using larger number of dielectric layers.

The disclosed filters can be implemented as part of specialized glasses or goggles (e.g., virtual reality goggles). FIG. 8 illustrates a pair of example glasses that includes a pair of lenses 803 that can be coated with the disclosed filters. In some implementations, the glasses can include opaque side shields or blocks (not shown) to prevent side illumination to reach the eye. In some implementations, the side shields can be transparent and include filters with similar transmission and blocking characteristic as those on the lenses 803, and further include the color layer to impart a particular color. The disclosed filters can be implemented as a coating provided on other types of eyewear, such as goggles. For instance, the wearable device can include a unitary transparent window that can be coated uniformly, or at particular locations thereon, with the disclosed filters having transmission and blockage characteristics at precisely tailored bands of the spectrum. For example, the particular locations of coatings can be selected to affect light that reaches the user's eyes at approximately normal angles. In another example, the coatings' locations and areal extent can be chosen to filter the light that reaches the user's eyes at both normal and inclined angles. In yet another example, the filters can be made detachable to existing eye wear, for example by small magnets or by screw-in adapter.

One aspect of the disclosed embodiments relates to a wearable device that includes one or more windows positioned to allow light from a light source to propagate toward a position of a wearer's eyes, and a spectral filter that comprises a coating positioned on one or more sections of the one or more windows. The spectral filter includes a multi-layer stack of dielectric material with alternate high and low indices of refraction such that a layer having a high index of refraction is positioned above or below a layer having a low index of refraction, and a layer having a high index of refraction is positioned above or below a layer having a low index of refraction. The number of the layers and a thickness of each layer are selected to provide designed transmission and blocking characteristics to block circadian-active spectra while allowing spectral content outside of the circadian-active spectra to pass through the spectral filter. The designed transmission and blocking characteristics include a contiguous blocking region within 455-495 nm band of wavelengths to within at least ± 5 nm, and two contiguous transmission regions, a first one of the contiguous regions extending below 455 nm and a second one of the contiguous transmission regions extending above 495 nm. The spectral filter is configured to block 98-100% of the spectral content the blocking region and transmit 80%-100% of the spectral content in the contiguous transmission regions. The spectral filter further includes an additional layer to effectuate a particular color.

In one example embodiment, the additional layer comprises an absorbing material with a specific absorption spectrum that in combination with the designed transmission and blocking characteristics of the spectral filter produce tristimulus values that correspond to the particular color. In another example embodiment, the tristimulus values correspond to the color pink. In yet another example embodiment, the additional layer includes an inorganic pink pigment or sodium aluminum sulfosilicate with chemical formula $\text{Na}_8\text{x}[(\text{Al},\text{Si})_{12}\text{O}_{24}(\text{Sy})_2]$ in a polymer matrix.

In one example embodiment, the blocking region extends from 455 nm to 495 nm, the first contiguous transmission region extends from 300 nm to 455 nm, and the second contiguous transmission region extends from 495 nm to at least 700 nm, all with a ± 5 nm tolerance. In another example embodiment, each layer with the high index of refraction includes titanium dioxide (TiO_2) and has a 2.35 index of refraction, each layer with the low index of refraction includes silicon dioxide (SiO_2) and has a 1.45 index of refraction, and the multi-layer stack includes 81 layers. In yet another example embodiment, the contiguous blocking region extends from 455 nm to 495 nm, the first contiguous transmission region extends from 300 nm to 455 nm, and the second contiguous transmission region extends from 495 nm to at least 700 nm, all with a ± 2 nm tolerance. In still another example embodiment, each layer with the high index of refraction includes titanium dioxide (TiO_2) and has a 2.35 index of refraction, each layer with the low index of refraction includes silicon dioxide (SiO_2) and has a 1.45 index of refraction, and the multi-layer stack includes 121 layers.

According to another example embodiment, the additional layer is positioned on a first side of a substrate that is opposite to a second side of the substrate where the multi-layer stack is positioned. In one example embodiment, the additional layer is positioned on a first side of a substrate below or above the multi-layer stack.

In another example embodiment, the wearable device is a pair of goggles, the one or more windows form a unitary window, and the spectral filter is formed as the coating on the unitary window. In still another example embodiment, the wearable device is a pair of goggles, the one or more windows form a unitary window, and the spectral filter is formed as the coating on two or more sections of the unitary window. In yet another example embodiment, the one or more windows are made of glass or plastic. In one example embodiment, the spectral filter is removably attached to the one or more windows.

Another aspect of the disclosed embodiments relates to a spectral filter for use in an eyewear for restoring circadian rhythm that includes a multi-layer stack coating on a substrate, the multi-layer stack including a plurality of layers of dielectric material with alternate high and low indices of refraction such that a layer having a high index of refraction is positioned above or below a layer having a low index of refraction, and a layer having a high index of refraction is positioned above or below a layer having a low index of refraction. The number of the layers and a thickness of each layer are selected to provide designed transmission and blocking characteristics to block circadian-active spectra to be transmitted through the spectral filter. The designed transmission and blocking characteristics include a contiguous blocking region within 455-495 nm band of wavelengths to within at least ± 5 nm, and two contiguous transmission regions, a first one of the contiguous regions extending below 455 nm and a second one of the contiguous transmission regions extending above 495 nm. The spectral filter is configured to block 98-100% of the spectral content the

contiguous blocking region, and transmit 80%-100% of the spectral content in the contiguous transmission regions. The spectral filter includes an additional layer to effectuate a particular color.

In one example embodiment of the spectral filter, the additional layer comprises an absorbing material with a specific absorption spectrum that in combination with the designed transmission and blocking characteristics of the spectral filter produce tristimulus values that correspond to the particular color. In another example embodiment, the tristimulus values correspond to the color pink. In yet another example embodiment, the additional layer includes an inorganic pink pigment or sodium aluminum sulfosilicate with chemical formula $\text{Na}_8\text{-x}[(\text{Al}, \text{Si})_{12}]\text{O}_{24}(\text{Sy})_2$ in a polymer matrix.

According to another example embodiment of the spectral filter, the contiguous blocking region extends from 455 nm to 495 nm, the first contiguous transmission region extends from 300 nm to 455 nm, and the second contiguous transmission region extends from 495 nm to at least 700 nm, all with a ± 5 nm tolerance, and each layer with the high index of refraction includes titanium dioxide (TiO_2) and has a 2.35 index of refraction, each layer with the low index of refraction includes silicon dioxide (SiO_2) and has a 1.45 index of refraction, and the multi-layer stack includes 81 layers. In yet another example embodiment of the spectral filter, the contiguous blocking region extends from 455 nm to 495 nm, the first contiguous transmission region extends from 300 nm to 455 nm, and the second contiguous transmission region extends from 495 nm to at least 700 nm, all with a ± 2 nm tolerance, and each layer with the high index of refraction includes titanium dioxide (TiO_2) and has a 2.35 index of refraction, each layer with the low index of refraction includes silicon dioxide (SiO_2) and has a 1.45 index of refraction, and the multi-layer stack includes 121 layers.

In still another example embodiment of the spectral filter, the additional layer is positioned on a first side of a substrate that is opposite to a second side of the substrate where the multi-layer stack is positioned. In one example embodiment, the additional layer is positioned on a first side of a substrate below or above the multi-layer stack. In another example embodiment, the spectral filter is configured to receive input illumination from one or more light sources including an atmospheric light source, a light emitting diode (LED), a halogen lamp, or a fluorescent lamp.

The foregoing description of embodiments has been presented for purposes of illustration and description. The foregoing description is not intended to be exhaustive or to limit embodiments of the present invention to the precise form disclosed, and modifications and variations are possible in light of the above teachings or may be acquired from practice of various embodiments. The embodiments discussed herein were chosen and described in order to explain the principles and the nature of various embodiments and its practical application to enable one skilled in the art to utilize the present invention in various embodiments and with various modifications as are suited to the particular use contemplated. While operations are depicted in the drawings in a particular order, this should not be understood as requiring that such operations be performed in the particular order shown or in sequential order, or that all illustrated operations be performed, to achieve desirable results. The features of the embodiments described herein may be combined in all possible combinations of methods, apparatus, modules, and systems.

Only a few implementations and examples are described, and other implementations, enhancements and variations can be made based on what is described and illustrated in this patent document.

We claim:

1. A wearable device, comprising:

one or more windows positioned to allow light from a light source to propagate toward a position of a wearer's eyes; and

a spectral filter that comprises a coating positioned on one or more sections of the one or more windows,

wherein the spectral filter includes a multi-layer stack of dielectric material with alternate high and low indices of refraction such that a layer having a high index of refraction is positioned above or below a layer having a low index of refraction,

wherein a number of the layers and a thickness of each layer are selected to provide designed transmission and blocking characteristics to block circadian-active spectra while allowing spectral content outside of the circadian-active spectra to pass through the spectral filter,

wherein the designed transmission and blocking characteristics include a contiguous blocking region within 455-495 nm band of wavelengths to within at least ± 5 nm, and two contiguous transmission regions, a first one of the contiguous transmission regions extending below 455 nm and a second one of the contiguous transmission regions extending above 495 nm,

wherein the spectral filter is configured to block 98-100% of the spectral content in the contiguous blocking region, and transmit 80%-100% of the spectral content in the contiguous transmission regions,

wherein the spectral filter further includes an additional layer to effectuate a particular color,

wherein the additional layer comprises an absorbing material with a specific absorption spectrum that in combination with the designed transmission and blocking characteristics of the spectral filter produce tristimulus values that correspond to the particular color, wherein the tristimulus values correspond to a pink color, and

wherein additional layer includes an inorganic pink pigment or sodium aluminum sulfosilicate with chemical formula $\text{Na}_8\text{-x}[(\text{Al}, \text{Si})_{12}]\text{O}_{24}(\text{Sy})_2$ in a polymer matrix.

2. The wearable device of claim 1, wherein the blocking region extends from 455 nm to 495 nm, the first contiguous transmission region extends from 300 nm to 455 nm, and the second contiguous transmission region extends from 495 nm to at least 700 nm, all with a ± 5 nm tolerance.

3. The wearable device of claim 2, wherein each layer with the high index of refraction includes titanium dioxide (TiO_2) and has a 2.35 index of refraction, each layer with the low index of refraction includes silicon dioxide (SiO_2) and has a 1.45 index of refraction, and the multi-layer stack includes 81 layers.

4. The wearable device of claim 1, wherein the contiguous blocking region extends from 455 nm to 495 nm, the first contiguous transmission region extends from 300 nm to 455 nm, and the second contiguous transmission region extends from 495 nm to at least 700 nm, all with a ± 2 nm tolerance.

5. The wearable device of claim 4, wherein each layer with the high index of refraction includes titanium dioxide (TiO_2) and has a 2.35 index of refraction, each layer with the low index of refraction includes silicon dioxide (SiO_2) and has a 1.45 index of refraction, and the multi-layer stack includes 121 layers.

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6. The wearable device of claim 1, wherein the additional layer is positioned on a first side of a substrate that is opposite to a second side of the substrate where the multi-layer stack is positioned.

7. The wearable device of claim 1, wherein the additional layer is positioned on a first side of a substrate below or above the multi-layer stack.

8. The wearable device of claim 1, wherein the one or more windows include two lenses, and the spectral filter is formed as the coating on each of the lenses.

9. The wearable device of claim 1, wherein the wearable device is a pair of goggles, the one or more windows form a unitary window, and the spectral filter is formed as the coating on the unitary window.

10. The wearable device of claim 1, wherein the wearable device is a pair of goggles, the one or more windows form a unitary window, and the spectral filter is formed as the coating on two or more sections of the unitary window.

11. The wearable device of claim 1, wherein the one or more windows are made of glass or plastic.

12. The wearable device of claim 1, wherein the spectral filter is removably attached to the one or more windows.

13. A spectral filter for use in an eyewear for restoring circadian rhythm, comprising:

a multi-layer stack coating on a substrate, the multi-layer stack including a plurality of layers of dielectric material with alternate high and low indices of refraction such that a layer having a high index of refraction is positioned above or below a layer having a low index of refraction,

wherein a number of the layers and a thickness of each layer are selected to provide designed transmission and blocking characteristics to block circadian-active spectra to be transmitted through the spectral filter,

wherein the designed transmission and blocking characteristics include a contiguous blocking region within 455-495 nm band of wavelengths to within at least ± 5 nm, and two contiguous transmission regions, a first one of the contiguous regions extending below 455 nm and a second one of the contiguous transmission regions extending above 495 nm,

wherein the spectral filter is configured to block 98-100% of the spectral content in the contiguous blocking region, and transmit 80%-100% of the spectral content in the contiguous transmission regions,

wherein the spectral filter includes an additional layer to effectuate a particular color,

wherein the additional layer comprises an absorbing material with a specific absorption spectrum that in combination with the designed transmission and blocking characteristics of the spectral filter produces tristimulus values that correspond to the particular color, wherein the tristimulus values correspond to a pink color, and

wherein the additional layer includes an inorganic pink pigment or sodium aluminum sulfosilicate with chemical formula $\text{Na}_8\text{-x}[(\text{Al},\text{Si})_{12}\text{O}_{24}(\text{Sy})_2]$ in a polymer matrix.

14. The spectral filter of claim 13, wherein:

the contiguous blocking region extends from 455 nm to 495 nm, the first contiguous transmission region extends from 300 nm to 455 nm, and the second contiguous transmission region extends from 495 nm to at least 700 nm, all with a ± 5 nm tolerance, and

each layer with the high index of refraction includes titanium dioxide (TiO_2) and has a 2.35 index of refraction, each layer with the low index of refraction

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includes silicon dioxide (SiO_2) and has a 1.45 index of refraction, and the multi-layer stack includes 81 layers.

15. The spectral filter of claim 13, wherein:

the contiguous blocking region extends from 455 nm to 495 nm, the first contiguous transmission region extends from 300 nm to 455 nm, and the second contiguous transmission region extends from 495 nm to at least 700 nm, all with a ± 2 nm tolerance, and

each layer with the high index of refraction includes titanium dioxide (TiO_2) and has a 2.35 index of refraction, each layer with the low index of refraction includes silicon dioxide (SiO_2) and has a 1.45 index of refraction, and the multi-layer stack includes 121 layers.

16. The spectral filter of claim 13, wherein the additional layer is positioned on a first side of a substrate that is opposite to a second side of the substrate where the multi-layer stack is positioned.

17. The spectral filter of claim 13, wherein the additional layer is positioned on a first side of a substrate below or above the multi-layer stack.

18. The spectral filter of claim 13, configured to receive input illumination from one or more light sources including an atmospheric light source, a light emitting diode (LED), a halogen lamp, or a fluorescent lamp.

19. A spectral filter for use in an eyewear for restoring circadian rhythm, comprising:

a multi-layer stack coating on a substrate, the multi-layer stack coating including a plurality of layers of dielectric material with alternate high and low indices of refraction such that a layer having a high index of refraction is positioned above or below a layer having a low index of refraction,

wherein a number of the layers and a thickness of each layer are selected to provide designed transmission and blocking characteristics to block circadian-active spectra to be transmitted through the spectral filter,

wherein the designed transmission and blocking characteristics include a contiguous blocking region within 455-495 nm band of wavelengths to within at least ± 5 nm, and two contiguous transmission regions, a first one of the contiguous transmission regions extending below 455 nm and a second one of the contiguous transmission regions extending above 495 nm,

wherein the spectral filter is configured to block 98-100% of spectral content in the contiguous blocking region, and transmit 80%-100% of the spectral content in the contiguous transmission regions,

wherein the spectral filter includes an additional layer to effectuate a particular color,

wherein the contiguous blocking region extends from 455 nm to 495 nm, the first contiguous transmission region extends from 300 nm to 455 nm, and the second contiguous transmission region extends from 495 nm to at least 700 nm, all with a ± 5 nm tolerance, and

wherein each layer with the high index of refraction includes titanium dioxide (TiO_2) and has a 2.35 index of refraction, each layer with the low index of refraction includes silicon dioxide (SiO_2) and has a 1.45 index of refraction, and the multi-layer stack includes 81 layers.

20. The spectral filter of claim 19, wherein the additional layer comprises an absorbing material with a specific absorption spectrum that in combination with the designed transmission and blocking characteristics of the spectral

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filter produce tristimulus values that correspond to the particular color, and the tristimulus values correspond to a pink color.

21. A spectral filter for use in an eyewear for restoring circadian rhythm, comprising:

a multi-layer stack coating on a substrate, the multi-layer stack including a plurality of layers of dielectric material with alternate high and low indices of refraction such that a layer having a high index of refraction is positioned above or below a layer having a low index of refraction,

wherein a number of the layers and a thickness of each layer are selected to provide designed transmission and blocking characteristics to block circadian-active spectra to be transmitted through the spectral filter,

wherein the designed transmission and blocking characteristics include a contiguous blocking region within 455-495 nm band of wavelengths to within at least ± 5 nm, and two contiguous transmission regions, a first one of the contiguous transmission regions extending below 455 nm and a second one of the contiguous transmission regions extending above 495 nm,

wherein the spectral filter is configured to block 98-100% of spectral content in the contiguous blocking region,

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and transmit 80%-100% of the spectral content in the contiguous transmission regions,

wherein the spectral filter includes an additional layer to effectuate a particular color,

wherein the contiguous blocking region extends from 455 nm to 495 nm, the first contiguous transmission region extends from 300 nm to 455 nm, and the second contiguous transmission region extends from 495 nm to at least 700 nm, all with a ± 2 nm tolerance, and

wherein each layer with the high index of refraction includes titanium dioxide (TiO_2) and has a 2.35 index of refraction, each layer with the low index of refraction includes silicon dioxide (SiO_2) and has a 1.45 index of refraction, and the multi-layer stack includes 121 layers.

22. The spectral filter of claim **21**, wherein the additional layer comprises an absorbing material with a specific absorption spectrum that in combination with the designed transmission and blocking characteristics of the spectral filter produce tristimulus values that correspond to the particular color, and the tristimulus values correspond to a pink color.

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