contain the colorant, creating thin film-specific reflectance spectra by selecting at plurality of materials each having their on respective refractive index, selecting the number of layers in the thin film, creating each film layer, and constructing an optical device including the created one or more layers containing the colorant and the created film layers.

[0009a] According to one aspect, there is provided a transmissive optical device for enhancing human color vision, said device comprising: a substrate; one or more colorant layers applied at least one of onto and into the substrate, the one or more colorant layers including at least one colorant, the colorant created based on colorant-specific absorption spectra as defined by selected concentrations; and one or more thin film layers provided on the combined substrate and one or more colorant layers, the one or more thin film layers including materials creating thin film-specific reflectance spectra based on selected pluralities of materials each having their own respective refractive index. The colorant-specific absorption, the thin film-specific reflectance and substrate cooperate to produce a static transmission spectrum of the optical device. At least one of the one or more thin film layers and the one or more colorant layers cause the optical device to exhibit metamerism control such that the cosmetic tint of the static transmission spectrum of the optical device has a white point shift within 0.35 under every illuminant from the set of two or more illuminants and has a difference in lightness of less than 30 when the illuminant changes from one to another, wherein illuminants are selected from the pool of CIE, D55, D65, D75, F2, F7, F11 and L-series LED illuminants.

[0009b] According to another aspect, there is provided a method for creating an optical device to enhance human color vision, said method comprising: creating colorant-specific absorption spectra by selecting colorants, creating concentrations of the selected colorants, and creating one or more layers to contain the colorant; creating thin film-specific reflectance spectra by selecting a plurality of materials each having their own respective refractive index, selecting the number of layers in the thin film, creating each film layer; and constructing an optical device including the created one or

more layers containing the colorant and the created film layers. The colorant-specific absorption and the thin film-specific reflectance cooperate to produce a static transmission spectrum of the optical device. The optical device exhibits metamerism control such that the cosmetic tint has a white point shift within 0.35 under every illuminant from the set of two or more illuminants and has a difference in lightness of less than 30 when the illuminant changes from one to another, wherein illuminants are selected from the pool of CIE, D55, D65, D75, F2, F7, F11 and L-series LED illuminants.

[0009c] According to yet another aspect, there is provided a transmissive optical device for enhancing human color vision, said device comprising: a substrate; and one or more colorant layers applied at least one of onto and into the substrate, the one or more colorant layers including at least one colorant, the colorant created based on colorant-specific absorption spectra as defined by selected concentrations. The colorant-specific absorption and substrate cooperate to produce a static transmission spectrum of the optical device. The one or more colorant layers cause the optical device to exhibit metamerism control such that the cosmetic tint has a white point shift within 0.35 under every illuminant from the set of two or more illuminants and has a difference in lightness of less than 30 when the illuminant changes from one to another, wherein illuminants are selected from the pool of CIE, D55, D65, D75, F2, F7, F11 and L-series LED illuminants.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] A more detailed understanding may be had from the following description, given by way of example in conjunction with the accompanying drawings wherein:

[0011] Figure 1 illustrates a cross-sectional illustration of an optical device for enhancing human vision;

[0012] Figure 2 is a method of constructing the optical device of Figure 1 to achieve the desired transmission spectrum by using colorants and/or thin films;

[0013] Figure 3 illustrates a method for designing the transmission spectra of the optical device of Figure 1 to satisfy minimum transmission constraints and achieve CPI targets;

[0014] Figure 4 illustrates a plot of three gamuts using CIE D65 illuminant for noon daylight lighting conditions;

[0015] Figure 5 illustrates a plot of three gamuts using CIE F2 illuminant for the optical device used in Figure 4;

[0016] Figure 6 illustrates an additional sample target transmission spectra for Red-Green CVD correction;

[0017] Figure 7 illustrates a plot of transmission spectrum versus wavelength for a configuration of the device of Figure 1;

[0018] Figure 8 illustrates the manufacturing process for the device illustrated by the transmission plot of Figure 7;

[0019] Figurer 9 illustrates a plot of transmission spectrum versus wavelength for a configuration of the device of Figure 1;

[0020] Figure 10 illustrates the manufacturing process for the device illustrated by the transmission plot of Figure 9;

CLAIMS

1. A transmissive optical device for enhancing human color vision, said device comprising:

a substrate;

one or more colorant layers applied at least one of onto and into the substrate, the one or more colorant layers including at least one colorant, the colorant created based on colorant-specific absorption spectra as defined by selected concentrations; and

one or more thin film layers provided on the combined substrate and one or more colorant layers, the one or more thin film layers including materials creating thin film-specific reflectance spectra based on selected pluralities of materials each having their own respective refractive index,

wherein the colorant-specific absorption, the thin film-specific reflectance and substrate cooperate to produce a static transmission spectrum of the optical device, wherein at least one of the one or more thin film layers and the one or more colorant layers cause the optical device to exhibit metamerism control such that the cosmetic tint of the static transmission spectrum of the optical device has a white point shift within 0.35 under every illuminant from the set of two or more illuminants and has a difference in lightness of less than 30 when the illuminant changes from one to another, wherein illuminants are selected from the pool of CIE, D55, D65, D75, F2, F7, F11 and L-series LED illuminants.

2. The optical device of claim 1, wherein the red color set maintain a warm-color hue of yellow, orange, red, pink or purple, when viewed through the device, and at least one color in the green color set maintains a cool-colored hue of green, cyan, blue, purple when viewed through the device.

3. The optical device of claim 1 wherein red-green color separation is evaluated using any one or more colors in the red color set, including one or more of the Munsell Colors: 2.5YR 5/4, 7.5R 5/4, 2.5R 5/4, 5RP 5/4, 10P 5/4, 10YR 5/4, 10R 5/4, 10RP 5/4, and any one or more colors in the green color set, including

one or more of the Munsell Colors: 5BG 5/4, 10G 5/4, 5G 5/4, 10GY 5/4, 5GY 5/4, 10BG 5/4, and blue-yellow color separation is evaluated using any one or more colors in the blue color set, including one or more of the Munsell Colors: 5B 5/4, 10BG 5/4, 5BG 5/4, 5P 5/4, 10B 5/4, 10P 5/4, 10PB 5/4, and any one or more colors in the yellow color set, including one or more of the Munsell Colors: 10GY 5/4, 5GY 5/4, 5Y 5/4, 10YR 5/4, 2.5YR 5/4, 10Y 5/4, 10YR 5/4.

4. The optical device of claim 1, wherein the minimum transmission is 0.5% from 575 nm to 585 nm.

5. The optical device of claim 1, wherein there is at least one stop band substantially centered between 550 nm and 605 nm.

6. The optical device of claim 1 including a stop band substantially centered between 450 nm and 505 nm.

7. The optical device of claim 1 including a stop band substantially centered between 400 nm and 449 nm.

8. The optical device of claim 1 exhibiting a lightness under 65, the optical device is capable of providing red-green color separation of at least 7% more than that of unassisted color vision.

9. The optical device of claim 1 exhibiting a lightness under 65.

10. The optical device of claim 1 exhibiting a lightness above 65, the optical device is capable of providing red-green color separation of at least 4% more than that of unassisted color vision.

11. The optical device of claim 1, the optical device is capable of providing a blue-yellow color separation of at least 2% more than that of unassisted color vision.

12. The optical device of claim 1, wherein the white point shift of yellow color vision is reduced by 0.01.

13. The optical device of claim 1, wherein the plurality of thin film layers provided on the substrate include a radially-variable filter wherein the optical thickness of at least one layer of the radially-variable filter increases radially from a viewing center to the periphery of the optical device.

14. The optical device of claim 13, wherein at angles of incidence between 0 and 75 degree, the white point shift of the cosmetic tint is within 0.2 from the corresponding white point at 0 degrees angle of incidence.

15. The optical device of claim 1, wherein, for deuteranomaly, the colorimetric performance indices are evaluated with peak sensitivity of Y (M-cone) color matching function shifted to a longer wavelength by at least 1 nm from the CIE 1931 2° standard observer, and for protanomaly, the colorimetric performance indices are evaluated with peak sensitivity of X (L-cone) color matching function shifted to a shorter wavelength by at least 1 nm from the CIE 1931 2° standard observer, for tritanomaly, the colormetric performance indices are evaluated with peak sensitivity of Z (S-cone) color matching function shifted by at least 1 nm from CIE 1931 2° standard observer.

16. The optical device of claim 1 wherein at angles of incidence between 0 and 60 degrees, stop bands of the transmission spectrum of the optical device shift less than 40 nm from corresponding stop bands at 0 degrees angle of incidence.

17. A method for creating an optical device to enhance human color vision, said method comprising:

creating colorant-specific absorption spectra by selecting colorants, creating concentrations of the selected colorants, and creating one or more layers to contain the colorant;

creating thin film-specific reflectance spectra by selecting a plurality of materials each having their own respective refractive index, selecting the number of layers in the thin film, creating each film layer; and

constructing an optical device including the created one or more layers containing the colorant and the created film layers,

wherein the colorant-specific absorption and the thin film-specific reflectance cooperate to produce a static transmission spectrum of the optical device, wherein the optical device exhibits metamerism control such that the cosmetic tint has a white point shift within 0.35 under every illuminant from the set of two or more illuminants and has a difference in lightness of less than 30 when the illuminant changes from one to another, wherein illuminants are selected from the pool of CIE, D55, D65, D75, F2, F7, F11 and L-series LED illuminants.

18. The method for creating an optical device of claim 17, further comprise the selected colorants are at least one of infused into a substrate of the optical device, laminated onto the substrate and coated onto the substrate.

19. The optical device of claim 1 wherein the plurality of thin film layers provides at least one of an anti-reflection coating, anti-scratch coting and hydrophobic coating.

20. A transmissive optical device for enhancing human color vision, said device comprising:

a substrate; and

one or more colorant layers applied at least one of onto and into the substrate, the one or more colorant layers including at least one colorant, the colorant created based on colorant-specific absorption spectra as defined by selected concentrations;

wherein the colorant-specific absorption and substrate cooperate to produce a static transmission spectrum of the optical device, wherein the one or more colorant layers cause the optical device to exhibit metamerism control such that the cosmetic tint has a white point shift within 0.35 under every illuminant

from the set of two or more illuminants and has a difference in lightness of less than 30 when the illuminant changes from one to another, wherein illuminants are selected from the pool of CIE, D55, D65, D75, F2, F7, F11 and L-series LED illuminants.