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(54) **STRUCTURALLY-COLORED ARTICLES AND METHODS FOR MAKING AND USING STRUCTURALLY-COLORED ARTICLES**

(52) **U.S. Cl.**  
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(57) **ABSTRACT**

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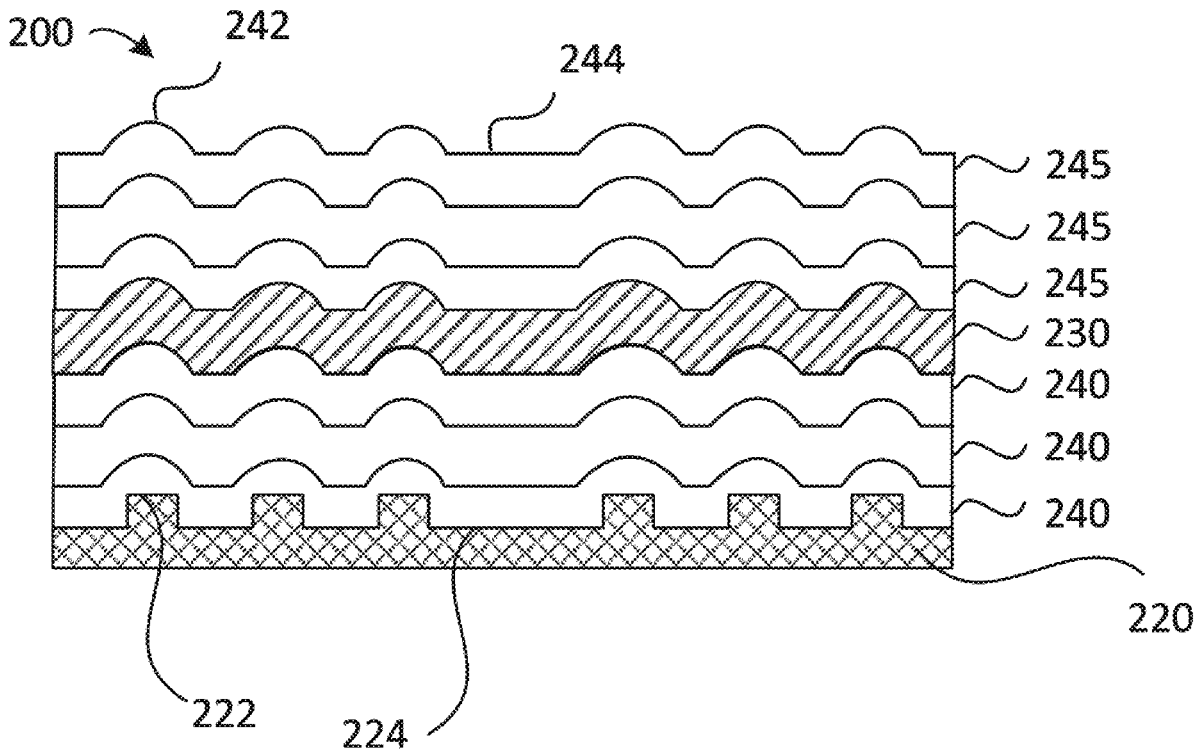
**Related U.S. Application Data**

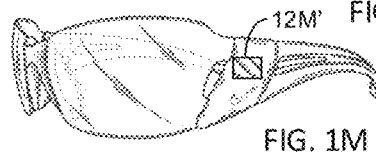
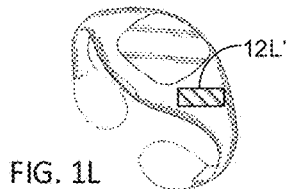
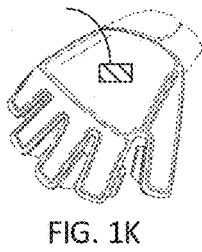
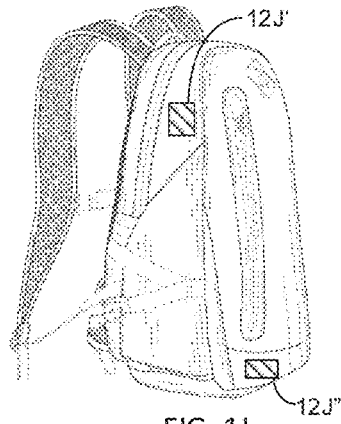
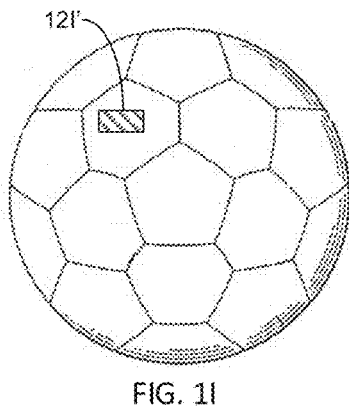
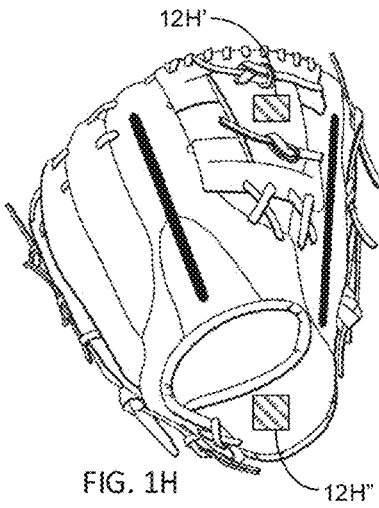
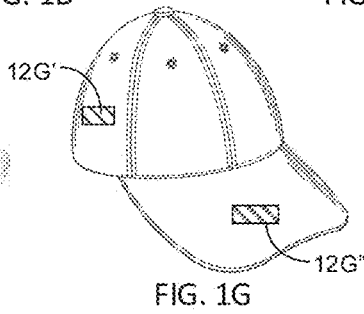
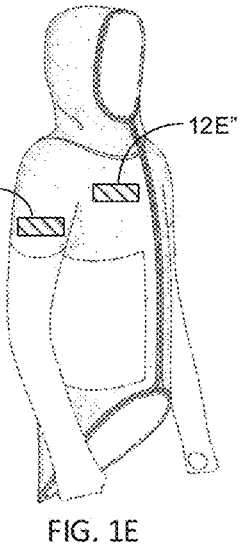
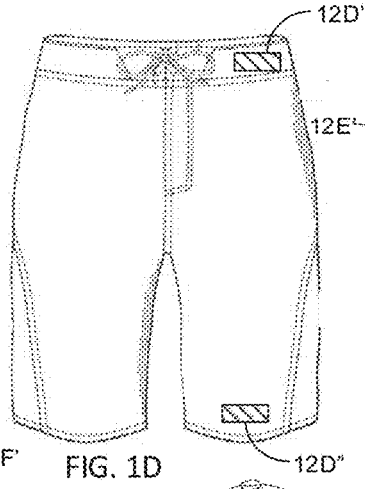
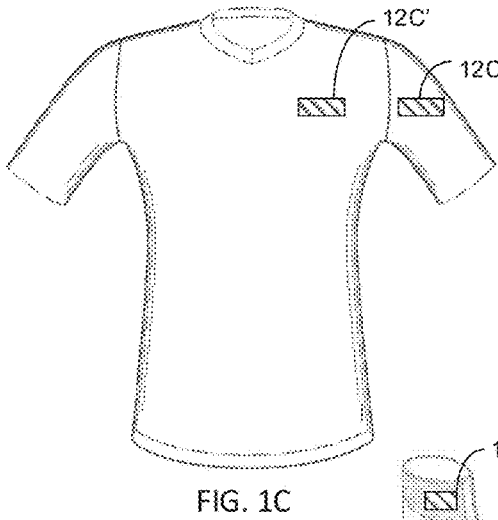
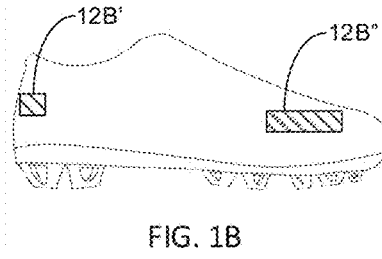
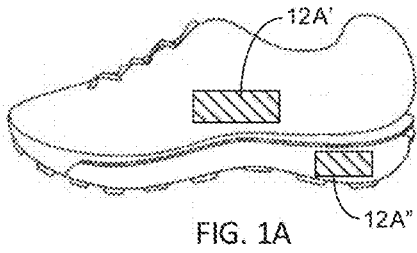
(60) Provisional application No. 62/878,956, filed on Jul. 26, 2019, provisional application No. 62/916,289, filed on Oct. 17, 2019.

As described above, one or more aspects of the present disclosure provide articles having structural color, and methods of making articles having structural color. The present disclosure provides for articles that exhibit structural colors through the use of an optical element, where structural colors are visible colors produced, at least in part, through optical effects. The optical element (e.g., a single layer reflector, a single layer filter, a multilayer reflector or a multilayer filter) can include the reflective layer(s), constituent layers, and an optional textured surface. The optical element has a minimum percent reflectance in a wavelength range within the wavelength range of about 380 to 625 nanometers. The optical element imparts a structural color that corresponds substantially to the range of wavelength range.

**Publication Classification**

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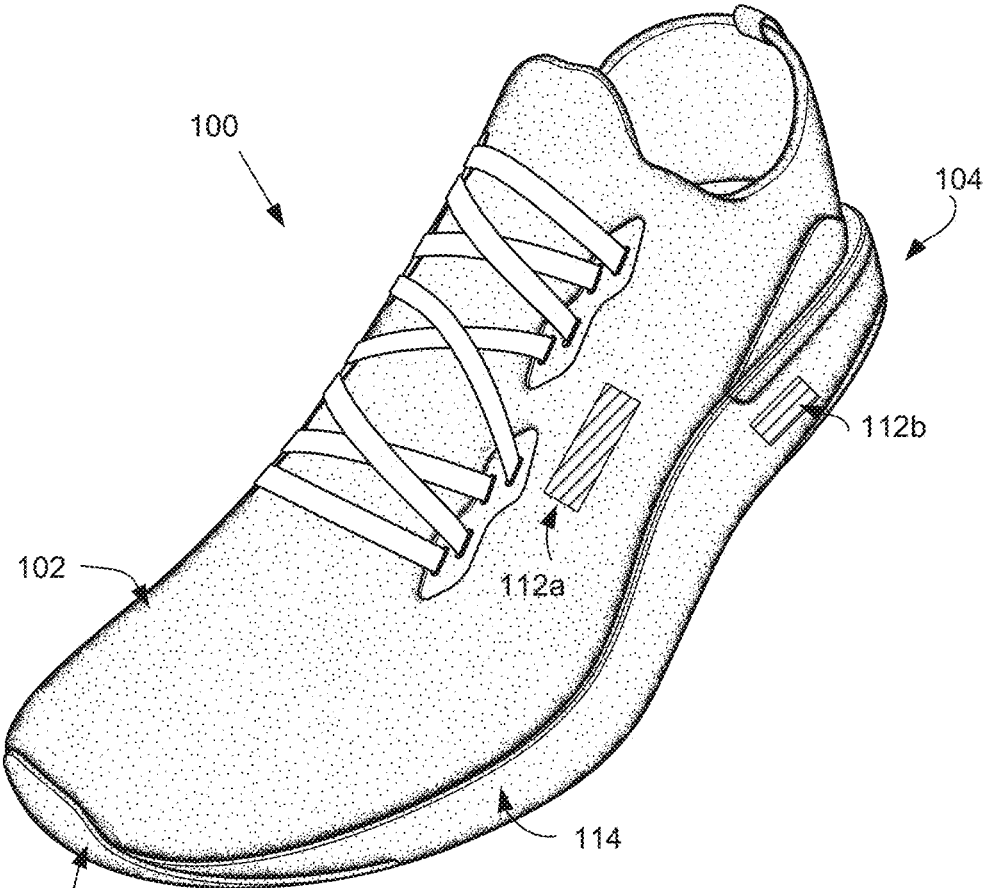


Fig. 1N(a)

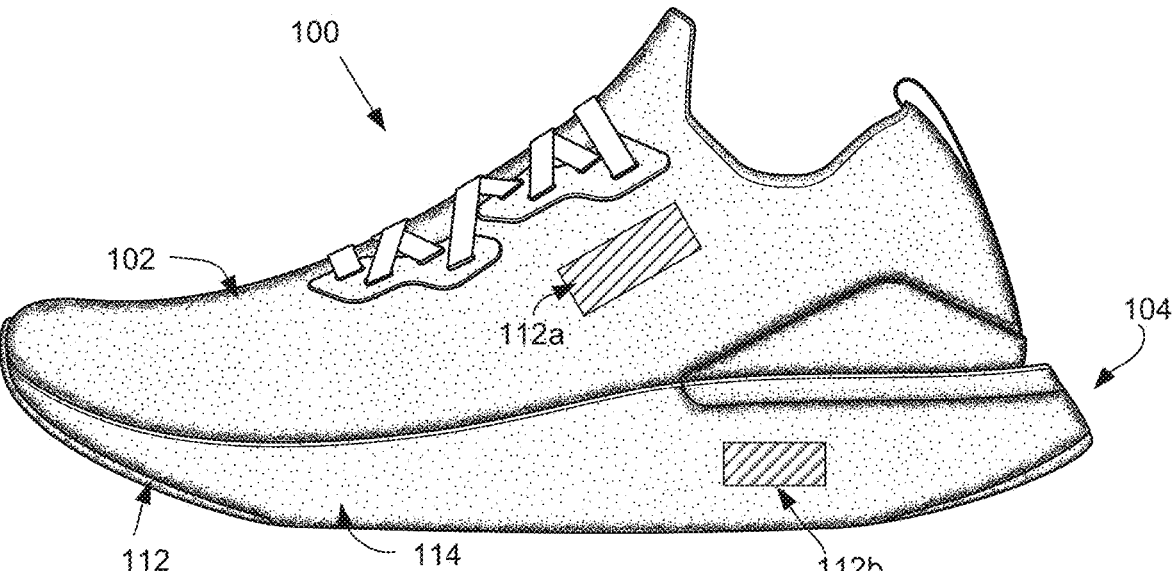


Fig. 1N(b)

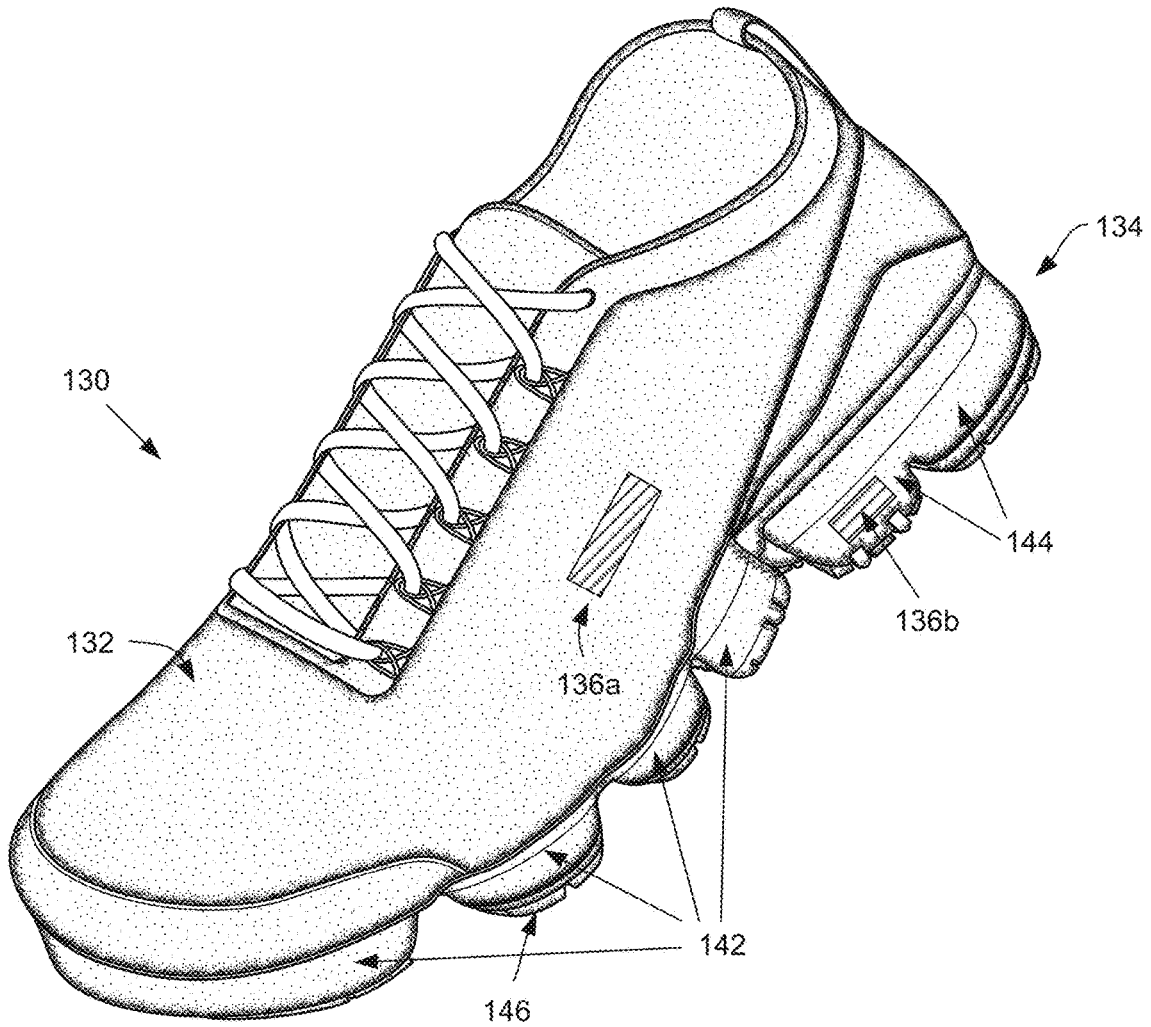


Fig. 10(a)

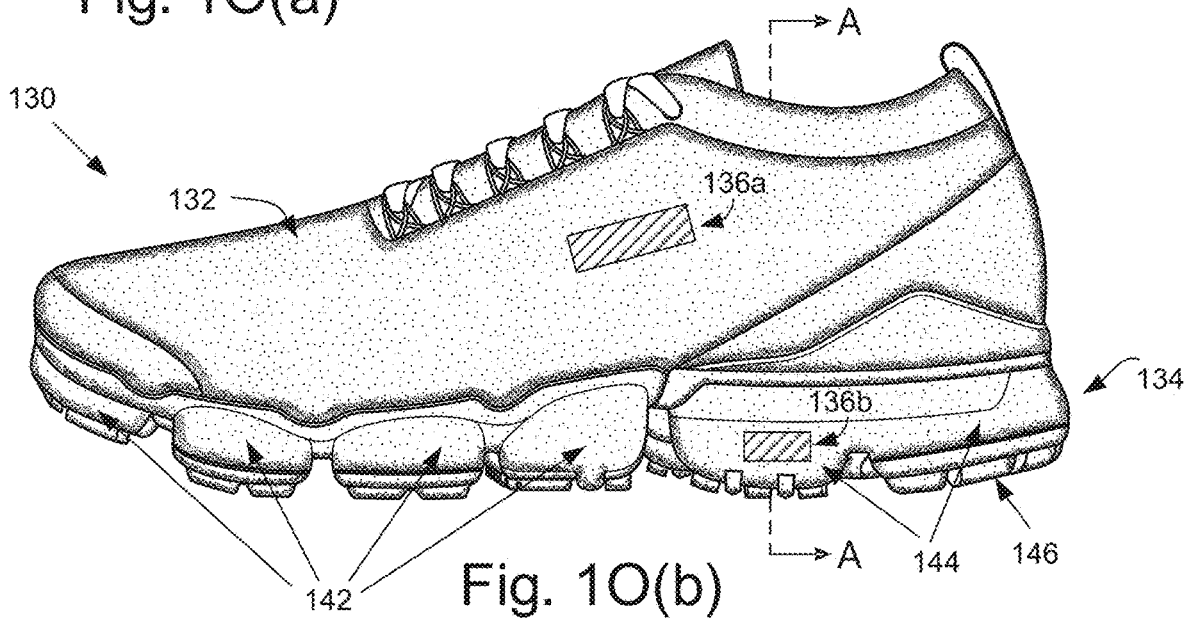


Fig. 10(b)

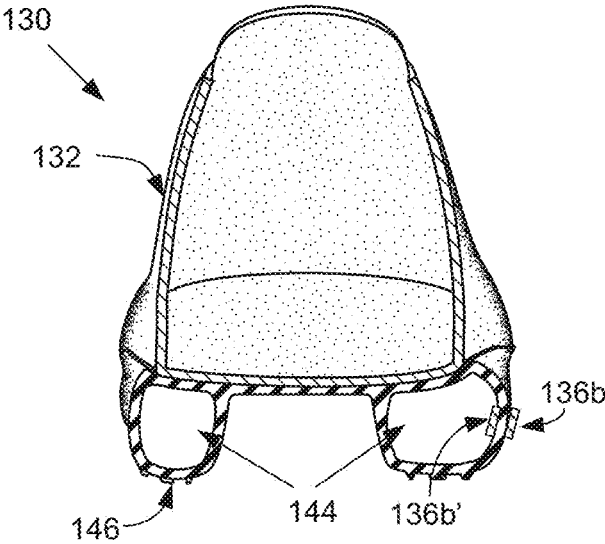
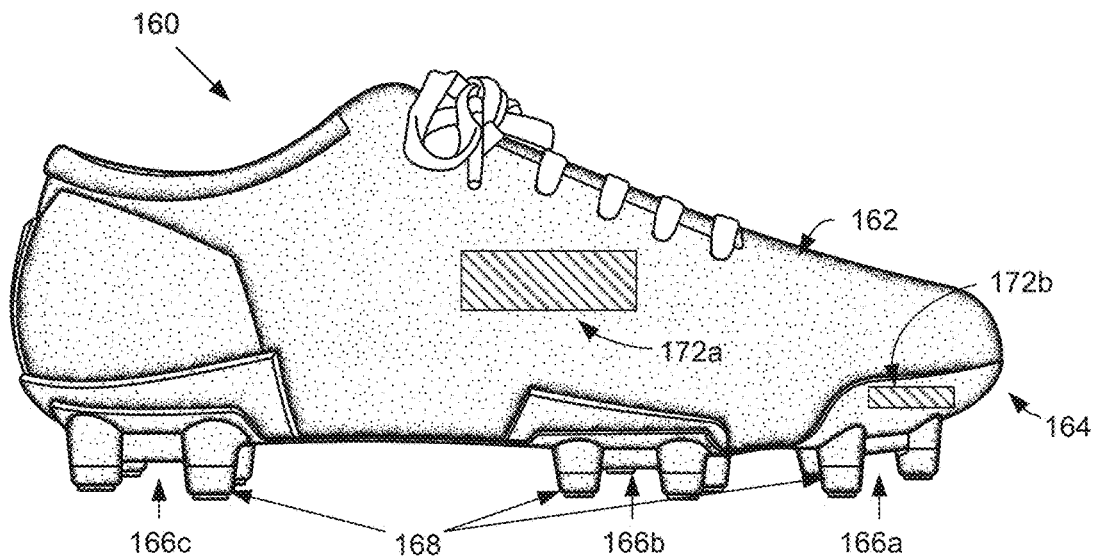
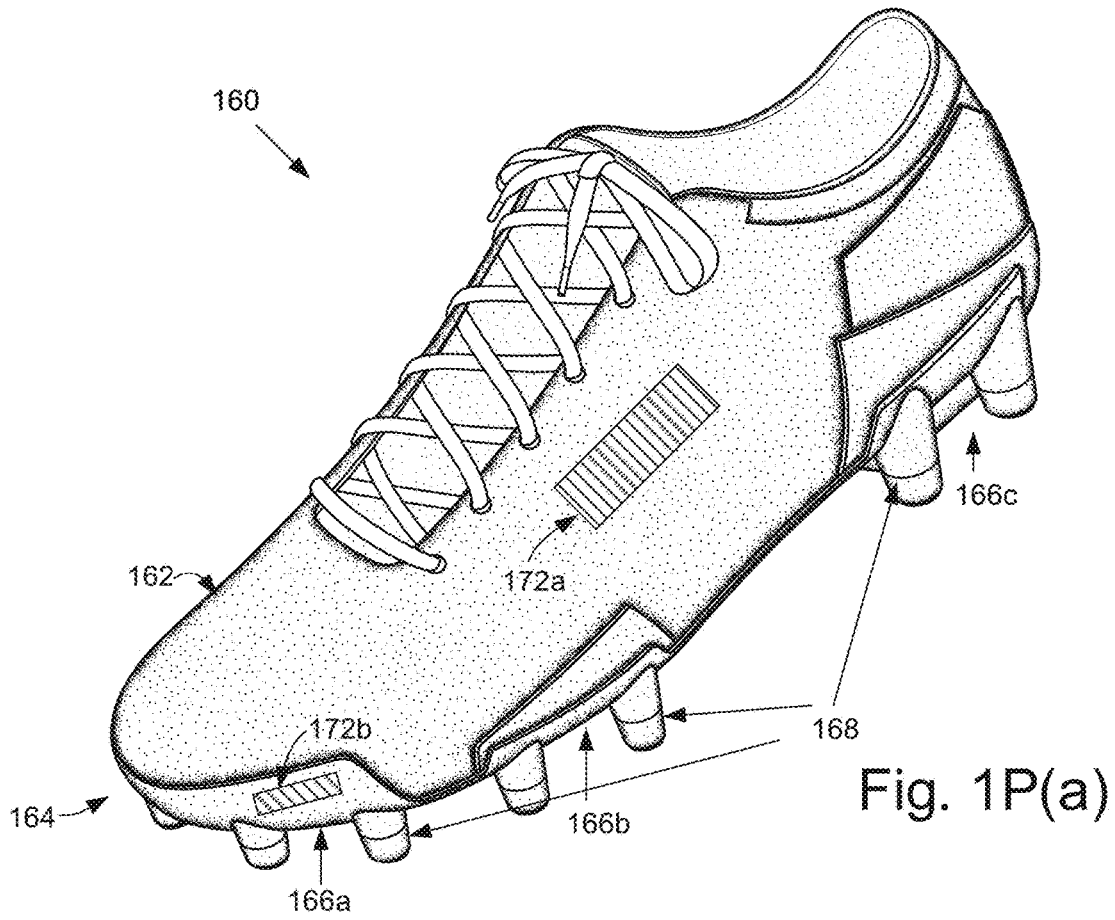


Fig. 10(c)



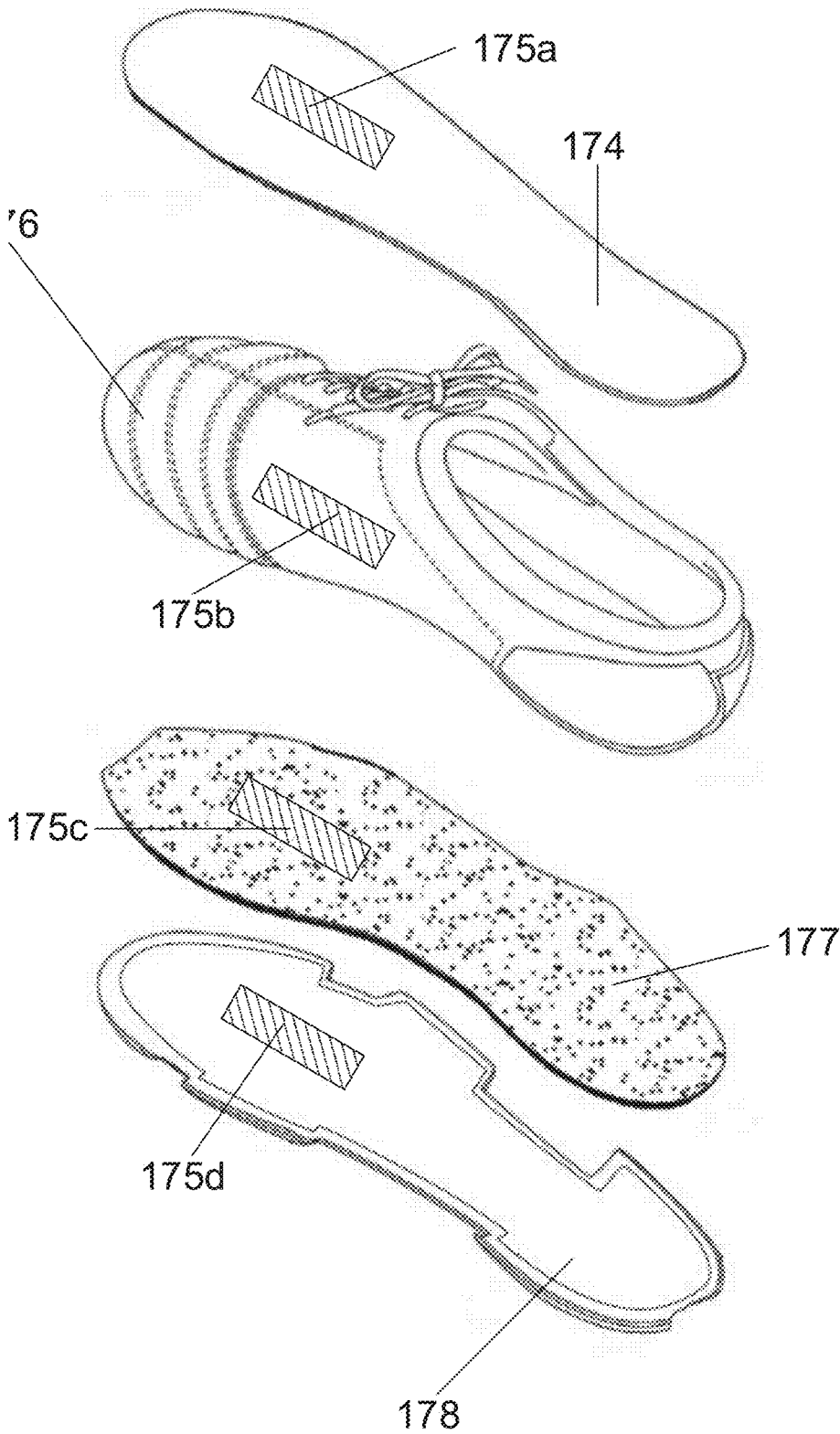


FIG. 1Q(a)

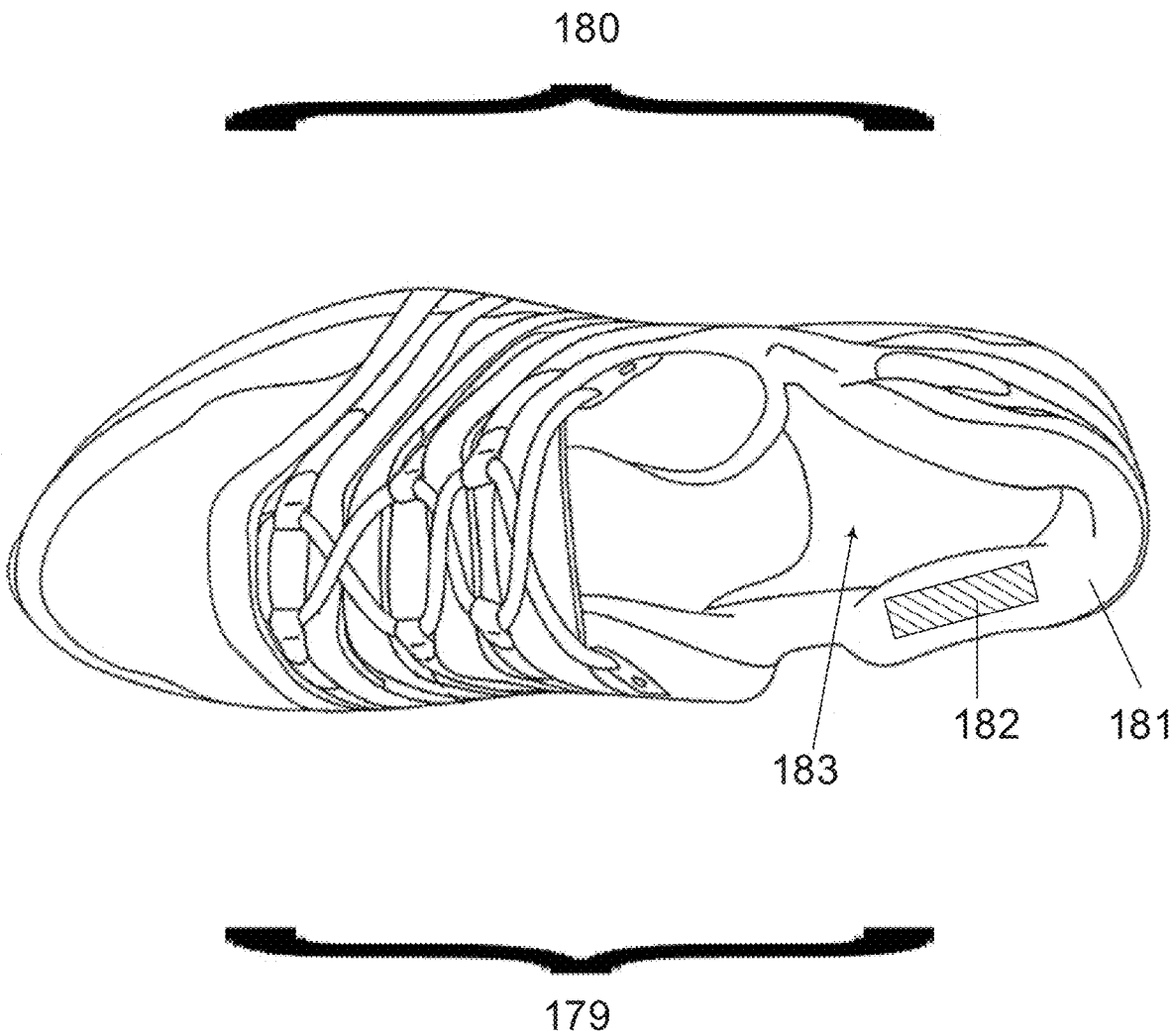


FIG. 1Q(b)



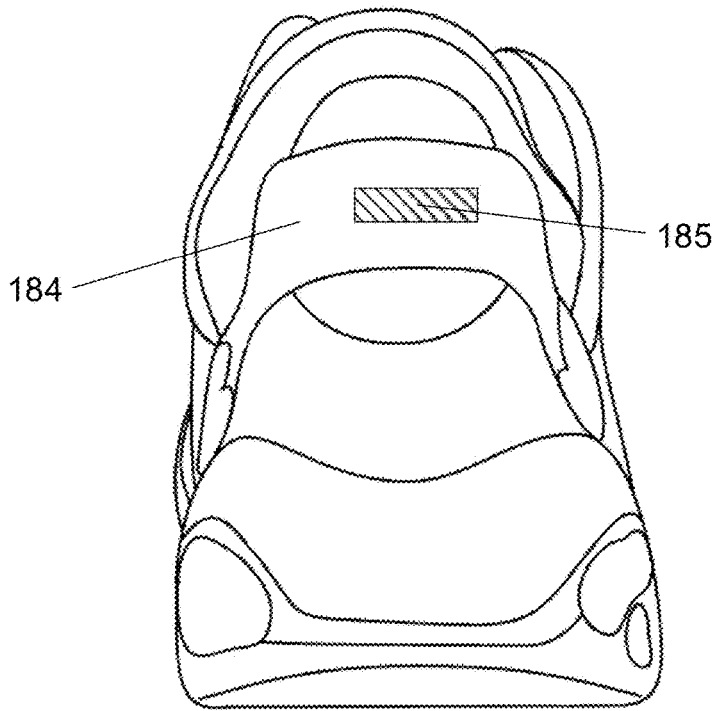


FIG. 1Q(c)

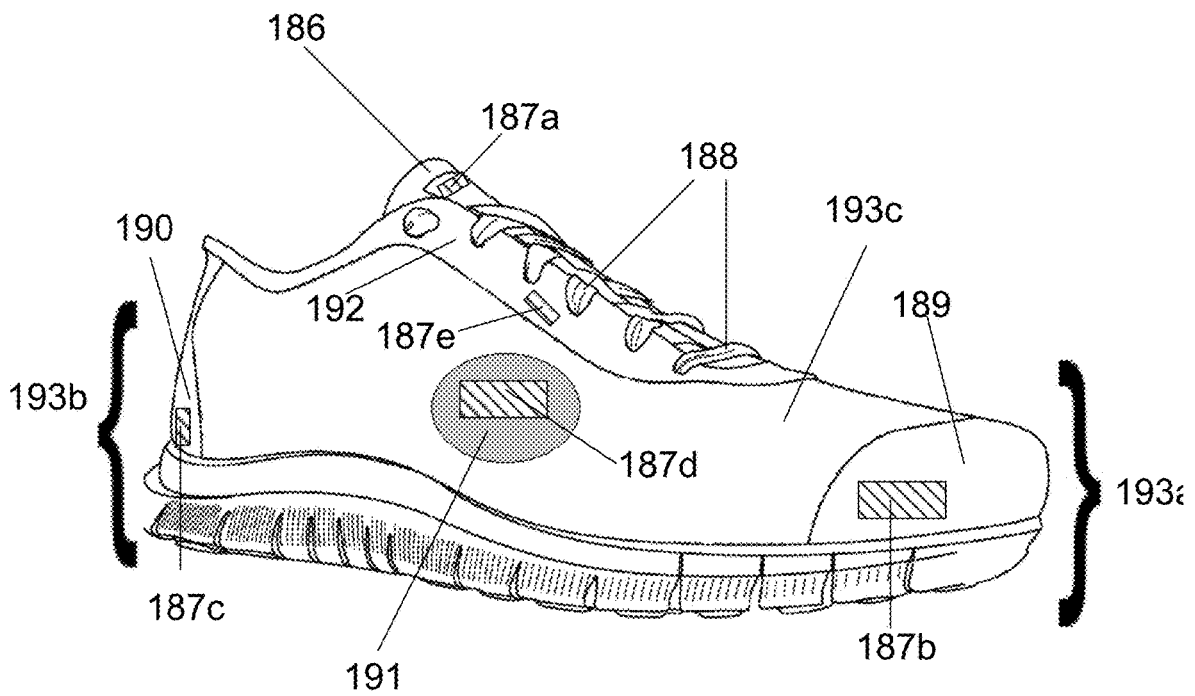


FIG. 1Q(d)

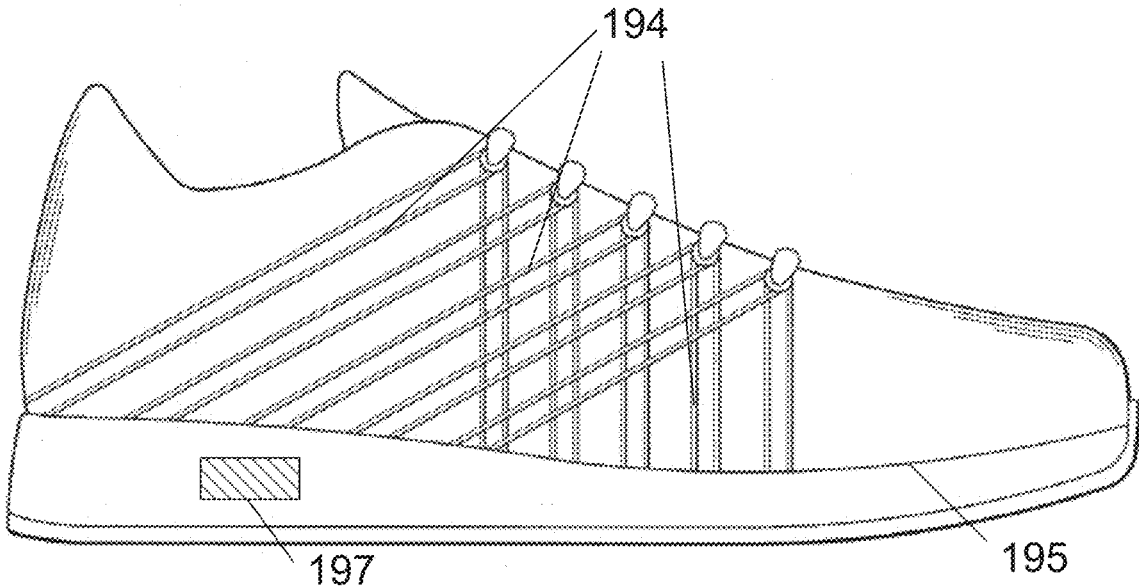
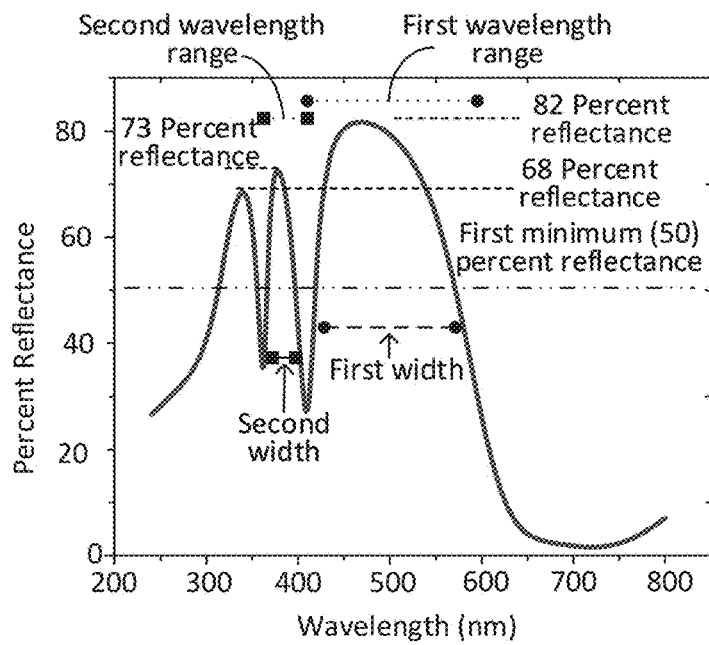
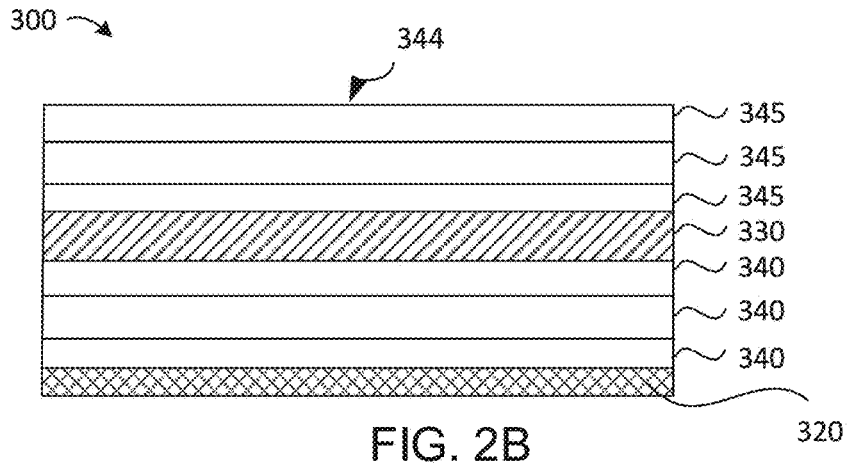
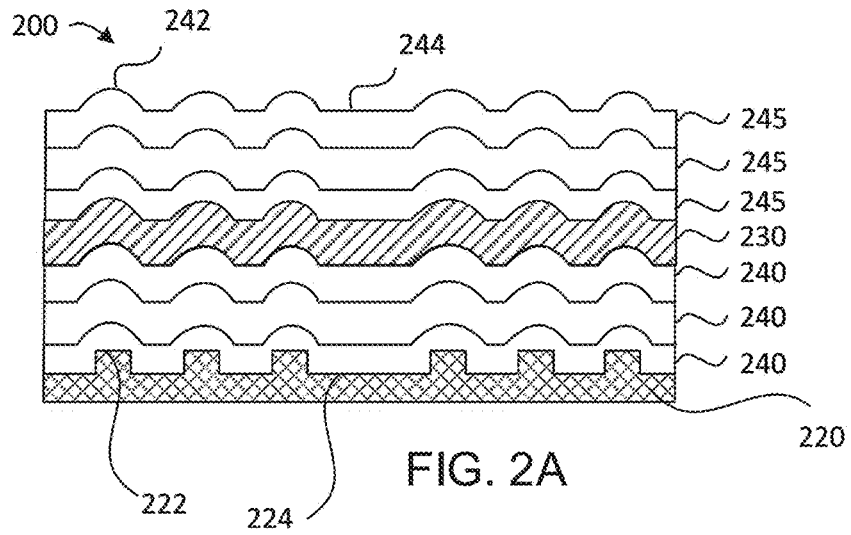


FIG. 1Q(e)



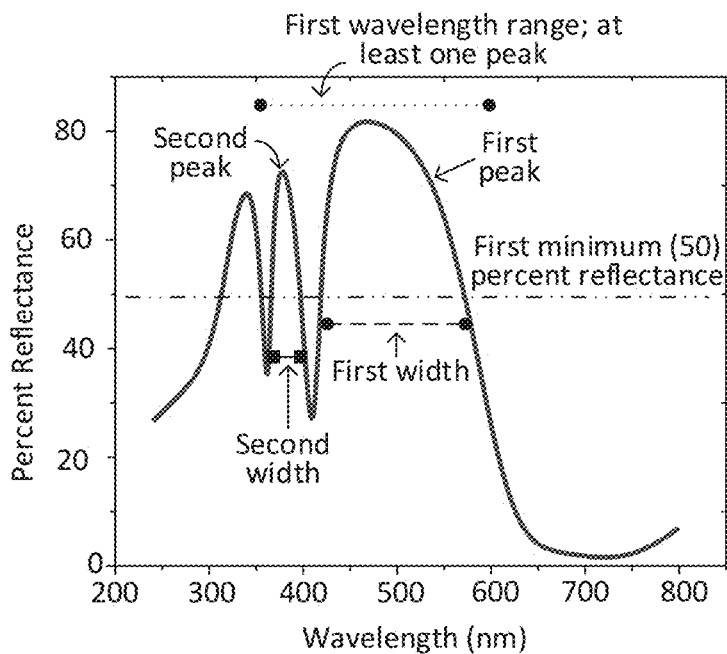


FIG. 3B

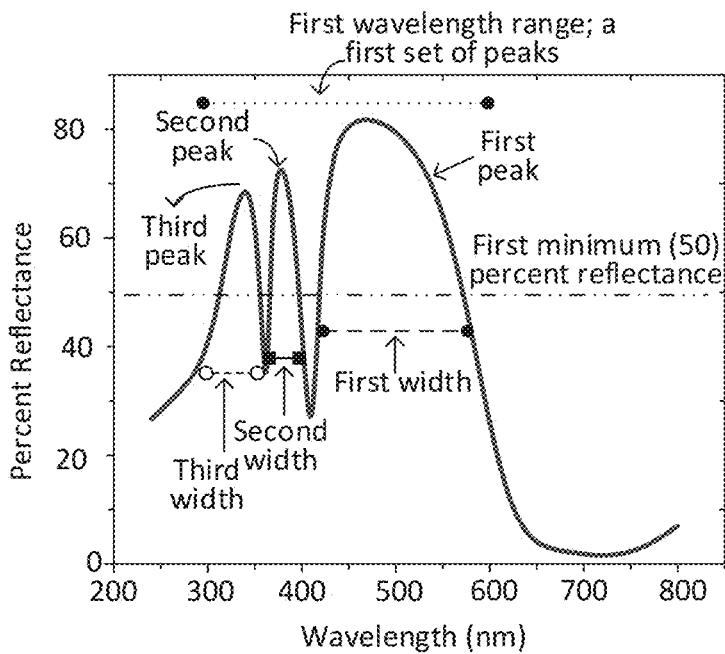


FIG. 3C

## STRUCTURALLY-COLORED ARTICLES AND METHODS FOR MAKING AND USING STRUCTURALLY-COLORED ARTICLES

### CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to, co-pending U.S. patent application entitled “STRUCTURALLY-COLORED ARTICLES AND METHODS FOR MAKING AND USING STRUCTURALLY-COLORED ARTICLES,” filed on Jul. 26, 2019, and assigned application No. 62/878,956; and claims priority to, co-pending U.S. patent application entitled “STRUCTURALLY-COLORED ARTICLES AND METHODS FOR MAKING AND USING STRUCTURALLY-COLORED ARTICLES,” filed on Oct. 17, 2019, and assigned application No. 62/916,289, both of which are incorporated herein by reference in their entireties.

### BACKGROUND

[0002] Structural color is caused by the physical interaction of light with the micro- or nano-features of a surface and the bulk material as compared to color derived from the presence of dyes or pigments that absorb or reflect specific wavelengths of light based on the chemical properties of the dyes or pigments. Color from dyes and pigments can be problematic in a number of ways. For example, dyes and pigments and their associated chemistries for fabrication and incorporation into finished goods may not be environmentally friendly.

### BRIEF DESCRIPTION OF THE DRAWINGS

[0003] Further embodiments of the present disclosure will be more readily appreciated upon review of the detailed description of its various embodiments, described below, when taken in conjunction with the accompanying drawings.

[0004] FIGS. 1A-1M shows various articles of footwear, apparel, athletic equipment, container, electronic equipment, and vision wear that include the primer layer in accordance with the present disclosure, while FIGS. 1N(a)-1Q(e) illustrate additional details regarding different types of footwear.

[0005] FIG. 2A illustrates a side view of exemplary optical element of the present disclosure. FIG. 2B illustrates a side view of exemplary optical element of the present disclosure.

[0006] FIGS. 3A to 3C illustrate graphs of wavelength as a function of percent reflectance, where each graph is illustrative of measurement of various parameters.

[0007] The drawings described herein are for illustration purposes only and are not intended to limit the scope of the present disclosure in any way.

### DESCRIPTION

[0008] The present disclosure provides for articles that exhibit structural colors using an optical element, where structural colors are visible colors produced, at least in part, through optical effects (e.g., through scattering, refraction, reflection, interference, and/or diffraction of visible wavelengths of light). The optical element (e.g., a single layer reflector, a single layer filter; a multilayer reflector or a multilayer filter; inorganic and/or organic material) can include a reflective layer(s) and/or a constituent layer(s), as well as an optional textured surface. The optical element has a minimum percent reflectance in a wavelength range within the wavelength range of about 380 to 625 nanometers. For

example, the structural color imparted to the article can be a color such as cyan, blue, green, purple, yellow and combinations thereof (e.g., purple-blue, blue-green) as well as other colors within the wavelength range. The optical element imparts a structural color that corresponds substantially to the range of wavelength range. The wavelength range can have a first width (e.g., spectral width) of about 10 to 245 nanometers (e.g., 10 to 120 nanometers and the like), while the minimum percent reflectance is about 50 percent or more (e.g., optionally about 70 percent, 80 percent, or 90 percent or more).

[0009] Due to the high level of reflectance of the optical elements disclosed herein, a large percentage of the light hitting the optical element is reflected back in the form of visible light. To a viewer, the visible light reflected back by the optical element imparts a structural color to the optical element, and thus to the article on which the optical element is disposed. The visible light reflected back has a maximum peak within the range of about 380 to 625 nanometers or about 380 to 565 nanometers or about 450 to 500 nanometers (or subranges therein), and the maximum peak has a first width of about 10 to 245 nanometers or about 10 to 185 nanometers or about 10 to 50 nanometers (or subranges therein), which determine the structural color imparted by the optical element when viewed at a particular angle of illumination or observation. Optical elements that reflect back fewer peaks and/or narrower peaks at a single angle of illumination or observation impart structural colors which appear purer, as compared to optical elements that reflect more peaks and/or wider peaks at the same single angle of illumination or observation.

[0010] The use of optical elements with a minimum percent reflectance of about 50 percent or more offers several advantages over using only pigments or dyes to impart color, and over using optical elements with lower levels of reflectance. While pigments and dyes use molecules that absorb light over the particular wavelength ranges that correspond to the color imparted by the molecules, highly reflective optical elements absorb little light within the particular wavelength range of the imparted color, but instead reflect the light back to a viewer. This makes the colors imparted by highly reflective optical elements appear brighter and more luminous than the colors imparted by pigments, dyes, as well as optical elements with lower levels of reflectivity. Imparting brighter, more luminous colors offers significant advantages as it allows a high level of relatively pure color to be imparted to an article while requiring low levels of raw materials to be used to impart the color. Colors imparted by highly reflective optical elements are also more visibility in low levels of light as compared to the colors imparted by pigments, dyes, and optical elements with lower levels of reflectivity. This offers significant advantages as the use of highly-reflective optical elements can be used to increase visibility to improve safety or detectability (e.g., by making an article more visible at night).

[0011] The first wavelength range can include at least one peak (e.g., two or more peaks, a set of peaks, or the like) within the wavelength range of 380 to 625 nanometers. The optical element imparts the structural color that corresponds substantially to the at least one peak (e.g., two or more peaks, a set of peaks, or the like). Each peak, if more than one is present, can have a spectral width of about 10 to 245 nanometers (e.g., about 10 to 120 nanometers and the like), each of which is measured according to the full width at half

maximum approach (e.g., take the total peak height and multiple by 50 percent and then measure the peak width at that amount) for each peak. At least one peak has a minimum percent reflectance of about 50 percent. When more than one peak is present, the peaks overlap one another by less than 20 percent (e.g., at the 5 percent reflectance level).

**[0012]** The optical element has a characteristic that upon exposure to white light imparts the structural color that comprises one of: wavelength range, at least one peak, and/or the first peak, the first set of peaks, as a function of wavelength and percent reflectance.

**[0013]** The structural color that corresponds substantially to the range of the wavelength range can be determined when measured according to the CIE 1976 color space under a given illumination condition at a single observation angle of about  $-15$  to  $180$  degrees or about  $-15$  and  $60$  degrees. A first color measurement at a first angle of observation having coordinates  $L_1^*$  and  $a_1^*$  and  $b_1^*$  over the wavelength range of  $380$  to  $625$  nanometers can be obtained. A second color measurement at the first angle of observation having coordinates  $L_2^*$  and  $a_2^*$  and  $b_2^*$  over the first wavelength value can be obtained. The difference between the first and second color measurement can be determined using:  $\Delta E_{ab}^* = [(L_1^* - L_2^*)^2 + (a_1^* - a_2^*)^2 + (b_1^* - b_2^*)^2]^{1/2}$ . When  $\Delta E_{ab}^*$  between the first color measurement and the second color measurement is less than or equal to  $3$  or optionally less than or equal to  $2.2$ , the first color associated with the first color measurement and the second color associated with the second color measurement are the same or not perceptibly different to an average observer (e.g., an observer having  $20/20$  visual acuity and normal color vision from a distance of about  $1$  meter from the object being viewed at about  $30$  lux of sunlight). In other words, the structural color corresponds substantially to the range of the wavelength range. When  $\Delta E_{ab}^*$  between the first color measurement and the second color measurement is greater than  $3$  or optionally greater than about  $4$  or  $5$ , the first color associated with the first color measurement and the second color associated with the second color measurement are different or perceptibly different to an average observer. In other words, the structural color does not correspond substantially to the range of the wavelength range.

**[0014]** In an alternative approach, when the percent difference between one or more of values  $L_1^*$  and  $L_2^*$ ,  $a_1^*$  and  $a_2^*$ , and  $b_1^*$  and  $b_2^*$  is less than  $20$  percent (e.g., less than  $15$  percent, less than  $10$  percent, less than  $5$  percent), the first color associated with the first color measurement and the second color associated with the second color measurement are the same or not perceptibly different to an average observer (e.g., the structural color corresponds substantially to the range of the wavelength range). When the percent difference between one or more of values  $L_1^*$  and  $L_2^*$ ,  $a_1^*$  and  $a_2^*$ , and  $b_1^*$  and  $b_2^*$  is greater than  $20$  percent, the first color associated with the first color measurement and the second color associated with the second color measurement are different or perceptibly different to an average observer (e.g., the structural color does not correspond substantially to the range of the wavelength range).

**[0015]** The minimum percent of reflectance can be independent of the angle of incident light upon the optical element or is independent of the observation angle of the optical element. Alternatively, the minimum percent of reflectance of the optical element is dependent of the angle

of incident light upon the optical element or is dependent upon observation angle of the optical element.

**[0016]** The dependence upon the angle of incident light or the observation angle can be evaluated using the CIE 1976 color space under a given illumination condition at two observation angles of about  $-15$  to  $180$  degrees or about  $-15$  degrees and  $+60$  degrees and which are at least  $15$  degrees apart from each other. For example, at a first observation angle the structural color is a first structural color and at a second observation angle the structural color is a second structural color.

**[0017]** A first color measurement at the first observation angle can be obtained and has coordinates  $L_i^*$  and  $a_i^*$  and  $b_i^*$ , while a second color measurement at the second observation angle can be obtained and has coordinates  $L_2^*$  and  $a_2^*$  and  $b_2^*$  can be obtained. When  $\Delta E_{ab}^*$  between the first color measurement and the second color measurement is less than or equal to  $2.2$  or is less than or equal to  $3$ , the first structural color associated with the first color measurement and the second structural color associated with the second color measurement are the same or not perceptibly different to an average observer. In other words, the minimum percent of reflectance is independent of the angle of incident light upon the optical element or is independent upon observation angle of the optical element.

**[0018]** When  $\Delta E_{ab}^*$  between the first color measurement and the second color measurement is greater than  $3$  or optionally greater than about  $4$  or  $5$ , the first structural color associated with the first color measurement and the second structural color associated with the second color measurement are different or perceptibly different to an average observer (e.g., the minimum percent of reflectance is dependent of the angle of incident light upon the optical element or is dependent upon observation angle of the optical element).

**[0019]** In an alternative approach, when the percent difference between one or more of values  $L_1^*$  and  $L_2^*$ ,  $a_1^*$  and  $a_2^*$ , and  $b_1^*$  and  $b_2^*$  is less than  $20$  percent, the first color associated with the first color measurement and the second color associated with the second color measurement are the same or not perceptibly different to an average observer (e.g., the minimum percent of reflectance is independent of the angle of incident light upon the optical element or is independent upon observation angle of the optical element). When the percent difference between one or more of values  $L_1^*$  and  $L_2^*$ ,  $a_1^*$  and  $a_2^*$ , and  $b_1^*$  and  $b_2^*$  is greater than  $20$  percent, the first structural color associated with the first color measurement and the second structural color associated with the second color measurement are different or perceptibly different to an average observer (e.g., the minimum percent of reflectance is dependent of the angle of incident light upon the optical element or is dependent upon observation angle of the optical element).

**[0020]** In addition to the wavelength range (e.g., also referred to as the "first wavelength range"), a second wavelength range may be present within the wavelength range of  $380$  to  $625$  nanometers. The minimum percent reflectance in the first wavelength range is greater than (e.g., about  $60$  percent or more) a reflectance in the second wavelength range, where the second wavelength range does not overlap the first wavelength range. The structural color corresponds substantially to the first wavelength range. Similarly, the second wavelength range can include at least one peak or a set of peaks that have a reflectance in the second wavelength

range that is less than (e.g., about 60 percent or more) the minimum percent reflectance of at least one peak or a set of peaks in the first wavelength range. The structural color corresponds substantially to the at least one peak or a set of peaks in the first wavelength range.

**[0021]** The article includes the optical element including the reflective layer(s) and/or constituent layers as well as an optional textured surface. The optical element can be disposed on a surface of the article with the optional textured surface between the optical element and the surface or the textured surface is part of the optical element, depending upon the design. The combination of the optical element and the optional textured surface imparts structural color (e.g., single color, multicolor, iridescent corresponding the wavelength range), to the article, where the structural color can be designed to be different than the color of the components of the optical element or the underlying material, optionally with or without the application of pigments or dyes to the article. In this way, the structural color imparts an aesthetically appealing color to the article without requiring the use of inks or pigments and the environmental impact associated with their use.

**[0022]** The article can be a finished article such as, for example, an article of footwear, apparel or sporting equipment. The article can be a component of an article of footwear, apparel or sporting equipment, such as, for example, an upper or a sole for an article of footwear, a waistband or arm or hood of an article of apparel, a brim of a hat, a portion of a backpack, or a panel of a soccer ball, and the like. For example, the optical element can be disposed (e.g., affixed, attached, adhered, bonded, joined) on a surface of one or more components of the footwear, such as on the shoe upper and/or the sole. The optical element can be incorporated into the sole by incorporating it into a cushioning element such as a bladder or a foam. The sole and/or upper can be designed so that one or more portions of the structurally colored component are visible in the finished article, by including an opening, or a transparent component covering the structurally colored component, and the like.

**[0023]** The present disclosure provides for an article comprising: an optical element on a surface of the article, wherein the optical element has a first minimum percent reflectance in a first wavelength range within the wavelength range of about 380 to 625 nanometers, wherein the first wavelength range has a first width of about 10 to 245 nanometers (optionally about 10 to 200 nanometers, about 10 to 150 nanometers, about 10 to 120 nanometers, about 10 to 100 nanometers, about 10 to 70 nanometers, about 10 to 65 nanometers, about 10 to 50 nanometers, about 10 to 35 nanometers, about 10 to 25 nanometers, about 10 to 15 nanometers), wherein the first minimum percent reflectance is about 50 percent or more (optionally about 60 percent or more, about 70 percent or more, about 80 percent or more, about 90 percent or more, or about 95 percent or more), wherein the optical element imparts a structural color that corresponds substantially to the range of first wavelength range.

**[0024]** The present disclosure will be better understood upon reading the following numbered aspects, which should not be confused with the claims. Any of the numbered aspects below can, in some instances, be combined with aspects described elsewhere in this disclosure and such combinations are intended to form part of the disclosure.

Article 1. An article comprising:

**[0025]** an optical element on a surface of the article, wherein the optical element has a first minimum percent reflectance in a first wavelength range within the wavelength range of about 380 to 625 nanometers, wherein the first wavelength range has a first width of about 10 to 245 nanometers, wherein the first minimum percent reflectance is about 50 percent or more, wherein the optical element imparts a structural color that corresponds substantially to the range of first wavelength range.

Article 2. The article of article 1, wherein the first wavelength range has a first width of about 10 to 200 nanometers, about 10 to 150 nanometers, about 10 to 120 nanometers, about 10 to 100 nanometers, about 10 to 70 nanometers, about 10 to 65 nanometers, about 10 to 35 nanometers, about 10 to 25 nanometers, or about 10 to 15 nanometers,

Article 3. The article of any preceding article, wherein the first minimum percent reflectance is about 60 percent or more, about 70 percent or more, about 80 percent or more, about 90 percent or more, or about 95 percent or more.

Article 4. The article of any preceding article, wherein the optical element, as disposed onto the article, imparts the structural color that corresponds substantially to the range of the first wavelength range, is determined when measured according to the CIE 1976 color space under a given illumination condition at a single observation angle of about  $-15$  to  $180$  degrees or about  $-15$  and  $60$  degrees, where a first color measurement at a first angle of observation having coordinates  $L_1^*$  and  $a_1^*$  and  $b_1^*$  over the wavelength range of 380 to 625 nanometers and a second color measurement at the first angle of observation having coordinates  $L_2^*$  and  $a_2^*$  and  $b_2^*$  over the first wavelength value is obtained, wherein the  $L_1^*$  and  $L_2^*$  values are the same or different, wherein the  $a_1^*$  and  $a_2^*$  coordinate values are the same or different, wherein the  $b_1^*$  and  $b_2^*$  coordinate values are the same or different, where  $\Delta E_{ab}^* = [(L_1^* - L_2^*)^2 + (a_1^* - a_2^*)^2 + (b_1^* - b_2^*)^2]^{1/2}$ , and wherein the  $\Delta E_{ab}^*$  between the first color measurement and the second color measurement is less than or equal to about 3, or optionally wherein the  $\Delta E_{ab}^*$  between the first color measurement and the second color measurement is less than or equal to about 2.2, wherein the structural color at the first observation angle and the second observation angle are the same.

Article 5. The article of any preceding article, wherein the optical element, as disposed onto to the article, imparts the structural color that corresponds substantially to the range of first wavelength range, is determined when measured according to the CIE 1976 color space under a given illumination condition at a single observation angle of about  $-15$  to  $180$  degrees or about  $-15$  and  $60$  degrees, where a first color measurement at a first angle of observation having coordinates  $L_1^*$  and  $a_1^*$  and  $b_1^*$  over the wavelength range of 380 to 625 nanometers and a second color measurement at the first angle of observation having coordinates  $L_2^*$  and  $a_2^*$  and  $b_2^*$  over the first wavelength value are obtained, wherein the  $L_1^*$  and  $L_2^*$  values are the same or different, wherein the  $a_1^*$  and  $a_2^*$  coordinate values are the same or different, wherein the  $b_1^*$  and  $b_2^*$  coordinate values are the same or different, and, wherein the percent difference between one or more of values  $L_1^*$  and  $L_2^*$ ,  $a_1^*$  and  $a_2^*$ , and  $b_1^*$  and  $b_2^*$  is less than 5 percent (optionally, less than 10 percent, less than 15 percent, less than 20 percent), wherein the structural color at the first observation angle and the second observation angle are the same.

Article 6. The article of any preceding article, wherein the optical element has a second minimum percent reflectance in a second wavelength range within the wavelength range of about 380 to 625 nanometers, wherein the second wavelength range has a second width of about 10 to 245 nanometers (optionally about 10 to 200 nanometers, about 10 to 150 nanometers, about 10 to 120 nanometers, about 10 to 100 nanometers, about 10 to 70 nanometers, about 10 to 65 nanometers, about 10 to 35 nanometers, about 10 to 25 nanometers, about 10 to 15 nanometers), wherein the second minimum percent reflectance is about 50 percent or more (optionally about 60 percent or more, about 70 percent or more, about 80 percent or more, about 90 percent or more, about 95 percent or more), wherein the optical element imparts the structural color that corresponds substantially to the range of the first wavelength value, the second wavelength value, or a combination of both.

Article 7. The article of any preceding article, wherein the first wavelength and the second wavelength having the first minimum percent reflectance and the second minimum percent reflectance, respectively, are observed at different viewing angles, wherein the different viewing angles are at least 15 degrees apart.

Article 8. The article of any preceding article, wherein the structural color corresponds substantially to the hue corresponding to the hue of the first wavelength value, or optionally the hue of the second wavelength value, or optionally to the hue of the combination of both.

Article 9. The article of any preceding article, wherein the first wavelength range and the second wavelength range overlap by less than 20 percent (optionally less than 15 percent, less than 10 percent) or overlap by less than 20 nanometers (optionally less than 15 nanometers, less than 10 nanometers).

Article 10. The article of any preceding article, wherein the first wavelength range comprises a minimum percent reflectance of about 50 percent for at least a one peak (as a function of wavelength and percent reflectance) within the wavelength range of 380 to 625 nanometers, optionally, wherein the at least one peak has a first width of about 10 to 245 nanometers, wherein the optical element imparts the structural color that corresponds substantially to the at least one peak.

Article 11. The article of any preceding article, wherein the at least one peak comprises a first peak, wherein the first peak has a first width of about 10 to 245 nanometers (optionally about 10 to 200 nanometers, about 10 to 150 nanometers, about 10 to 120 nanometers, about 10 to 100 nanometers, about 10 to 70 nanometers, about 10 to 65 nanometers, about 10 to 35 nanometers, about 10 to 25 nanometers, about 10 to 15 nanometers), wherein the first peak has a minimum percent reflectance of about 50 percent, wherein the optical element imparts the structural color that corresponds substantially to the first peak.

Article 12. The article of article 7, wherein the at least one peak comprises a second peak, wherein the second peak has a first width of about 10 to 245 nanometers (optionally about 10 to 200 nanometers, about 10 to 150 nanometers, about 10 to 120 nanometers, about 10 to 100 nanometers, about 10 to 70 nanometers, about 10 to 65 nanometers, about 10 to 35 nanometers, about 10 to 25 nanometers, about 10 to 15 nanometers), wherein the second peak has a minimum percent reflectance of about 50 percent, wherein the optical

element imparts the structural color that corresponds substantially to the first peak, the second peak, or a combination thereof.

Article 13. The article of article 8, wherein the first peak and the second peak overlap by less than 20 percent (optionally less than 15 percent, less than 10 percent) or overlap by less than 20 nanometers (optionally less than 15 nanometers, less than 10 nanometers).

Article 14. The article of any preceding article, wherein the at least one peak comprises a first set of peaks, wherein each peak of the first set of peaks has a first width of about 10 to 245 nanometers (optionally about 10 to 200 nanometers, about 10 to 150 nanometers, about 10 to 120 nanometers, about 10 to 100 nanometers, about 10 to 70 nanometers, about 10 to 65 nanometers, about 10 to 35 nanometers, about 10 to 25 nanometers, or about 10 to 15 nanometers), wherein at least one of the peaks of the first set of peaks has a minimum percent reflectance of about 50 percent, wherein the optical element imparts the structural color that corresponds substantially to the first set of peaks.

Article 15. The article of any preceding article, wherein the first set of peaks (as a function of wavelength and percent reflectance) comprises at least three peaks, where one or more of the three peaks has a minimum percent reflectance of about 50 percent or more (optionally about 60 percent or more, about 70 percent or more, about 80 percent or more, about 90 percent or more, or about 95 percent or more) within the wavelength range of about 380 to 625 nanometers, wherein the each peak independently has a width of about 10 to 245 nanometers (optionally about 10 to 200 nanometers, about 10 to 150 nanometers, about 10 to 120 nanometers, about 10 to 100 nanometers, about 10 to 70 nanometers, about 10 to 65 nanometers, about 10 to 35 nanometers, about 10 to 25 nanometers, or about 10 to 15 nanometers), wherein the optical element imparts the structural color that corresponds substantially to the first set of peaks.

Article 16. The article of article 15, wherein the each peak overlaps another peak by less than 20 percent (optionally less than 15 percent, less than 10 percent) or overlap by less than 20 nanometers (optionally less than 15 nanometers, less than 10 nanometers).

Article 17. The article of any preceding article, wherein the optical element has a characteristic that upon exposure to white light imparts the structural color that comprises one of: at least one peak, the first peak, and the first set of peaks, as a function of wavelength and percent reflectance.

Article 18. The article of any preceding article, wherein the minimum percent of reflectance is independent of the angle of incident light upon the optical element

Article 19. The article of articles 1 to 18, wherein the minimum percent of reflectance of the optical element is dependent of the angle of incident light upon the optical element.

Article 20. The article of any preceding article, wherein the structural color is independent of observation angle.

Article 21. The article of articles 1 to 20, wherein the structural color is dependent upon observation angle.

Article 22. The article of any preceding article, wherein at a first observation angle the structural color is a first structural color and at a second observation angle the structural color is a second structural color, optionally, wherein the first structural color and the second structural color are the same



hue or wherein the first structural color and the second structural color are different hues.

Article 23. The article of any preceding article, wherein the optical element, as disposed onto the article, when measured according to the CIE 1976 color space under a given illumination condition at two observation angles of about  $-15$  to  $180$  degrees or about  $-15$  degrees and  $+60$  degrees and which are at least  $15$  degrees apart from each other, wherein a first color measurement at the first observation angle having coordinates  $L_1^*$  and  $a_1^*$  and  $b_1^*$ , and a second color measurement at the second observation angle having coordinates  $L_2^*$  and  $a_2^*$  and  $b_2^*$  is obtained, wherein the  $L_1^*$  and  $L_2^*$  values may be the same or different, wherein the  $a_1^*$  and  $a_2^*$  coordinate values may be the same or different, wherein the  $b_1^*$  and  $b_2^*$  coordinate values may be the same or different, and wherein  $\Delta E_{ab}^* = [(L_1^* - L_2^*)^2 + (a_1^* - a_2^*)^2 + (b_1^* - b_2^*)^2]^{1/2}$ , and wherein the  $\Delta E_{ab}^*$  between the first color measurement and the second color measurement is less than or equal to about  $2.2$ , or optionally wherein the  $\Delta E_{ab}^*$  between the first color measurement and the second color measurement is less than or equal to about  $3$ , wherein the structural color is independent of observation angle.

Article 24. The article of any preceding article, wherein the optical element, as disposed onto the article, when measured according to the CIE 1976 color space under a given illumination condition at two observation angles of about  $-15$  to  $180$  degrees or about  $-15$  degrees and  $+60$  degrees and which are at least  $15$  degrees apart from each other, wherein a first color measurement at the first observation angle having coordinates  $L_1^*$  and  $a_1^*$  and  $b_1^*$ , and a second color measurement at the second observation angle having coordinates  $L_2^*$  and  $a_2^*$  and  $b_2^*$  is obtained, wherein the  $L_1^*$  and  $L_2^*$  values may be the same or different, wherein the  $a_1^*$  and  $a_2^*$  coordinate values may be the same or different, wherein the  $b_1^*$  and  $b_2^*$  coordinate values may be the same or different, and wherein  $\Delta E_{ab}^* = [(L_1^* - L_2^*)^2 + (a_1^* - a_2^*)^2 + (b_1^* - b_2^*)^2]^{1/2}$ , and wherein the  $\Delta E_{ab}^*$  between the first color measurement and the second color measurement is greater than  $3$ , or optionally wherein the  $\Delta E_{ab}^*$  between the first color measurement and the second color measurement is more than or equal to about  $4$  or  $5$ , or  $10$ , wherein the structural color is dependent upon observation angle.

Article 25. The article of any preceding article, wherein the first wavelength range or at least the one peak have a wavelength spectral width of about  $15$  nanometers, about  $25$  nanometers, about  $35$  nanometers, about  $65$  nanometers, or about  $70$  nanometers, within the wavelength range of  $380$  to  $625$  nanometers

Article 26. The article of any preceding article, wherein the first wavelength range or at least the one peak have a wavelength spectral width of about  $50$  nanometers, about  $60$  nanometers, about  $80$  nanometers, about  $90$  nanometers, or about  $105$  nanometers, within the wavelength range of  $380$  to  $625$  nanometers.

Article 27. The article of any preceding article, wherein the first wavelength range or at least the one peak have a wavelength spectral width of about  $105$  nanometers, about  $115$  nanometers, about  $125$  nanometers, or about  $120$  nanometers, within the wavelength range of  $380$  to  $625$  nanometers

Article 28. The article of any preceding article, wherein the first wavelength range or at least the one peak have a

wavelength of about  $380$  to about  $450$  nanometers, about  $450$  to about  $485$  nanometers, about  $485$  to about  $500$  nanometers, about  $500$  to about  $565$  nanometers, about  $565$  to about  $590$  nanometers, or about  $590$  to about  $625$  nanometers.

Article 29. The article of any preceding article, wherein the first wavelength range or at least the one peak have a wavelength of about  $380$  to about  $485$  nanometers, about  $450$  to about  $500$  nanometers, about  $485$  to about  $565$  nanometers, about  $500$  to about  $590$  nanometers, or about  $590$  to about  $625$  nanometers.

Article 30. The article of any preceding article, wherein the first wavelength range or at least the one peak have a wavelength of about  $380$  to about  $500$  nanometers, about  $450$  to about  $565$  nanometers, about  $485$  to about  $590$  nanometers, or about  $590$  to about  $625$  nanometers.

Article 31. The article of any preceding article, wherein the minimum percent reflectance in the first wavelength range is greater than a reflectance in a second wavelength range (optionally by about  $60$  percent or more, about  $70$  percent or more, about  $80$  percent or more, about  $90$  percent or more, about  $95$  percent or more, or about  $99$  percent or more greater than the minimum reflectance of the second wavelength range), wherein the second wavelength range does not overlap the first wavelength range, and wherein the structural color corresponds substantially to the first wavelength range.

Article 32. The article of any preceding article, wherein the minimum percent reflectance of a first peak in the first wavelength range is greater than a reflectance of a second peak in a second wavelength range (optionally by about  $60$  percent or more, about  $70$  percent or more, about  $80$  percent or more, about  $90$  percent or more, about  $95$  percent or more, or about  $99$  percent or more greater than the minimum reflectance of the second wavelength range), wherein the second wavelength range does not overlap the first wavelength range, and wherein the structural color corresponds substantially to the first peak.

Article 33. The article of any preceding article, wherein the minimum percent reflectance of a first set of peaks in the first wavelength range is greater than a reflectance of a second set of peaks in a second wavelength range (optionally by about  $60$  percent or more, about  $70$  percent or more, about  $80$  percent or more, about  $90$  percent or more, about  $95$  percent or more, or about  $99$  percent or more greater than the minimum reflectance of the second wavelength range), wherein the second wavelength range does not overlap the first wavelength range, and wherein the structural color corresponds substantially to the first set of peaks.

Article 34. A method, comprising:

[0026] disposing or positioning an optical element on a surface of an article according to any one of articles 1 to 33.

Article 35. The method of article 34, wherein disposing the optical element comprises forming the optical element on the surface of the article.

Article 36. The method of any one of the preceding articles, wherein disposing the optical element comprises forming the optical element on a surface of a component, and then disposing the component with the optical element on a surface of the article; optionally wherein the component is a film, or a textile, or a molded component.

Article 37. The method of any one of the preceding articles, wherein forming the optical element comprises using: physical vapor deposition, electron beam deposition, atomic layer

deposition, molecular beam epitaxy, cathodic arc deposition, pulsed laser deposition, sputtering, chemical vapor deposition, plasma-enhanced chemical vapor deposition, low pressure chemical vapor deposition, wet chemistry techniques, or a combination thereof.

Article 38. The method of any one of the preceding clauses, wherein disposing the optical element comprises depositing the at least one reflective layer and the at least two constituent layers of the optical element using a deposition process, wherein the method optionally includes depositing a first reflective layer comprising a metal, depositing a first constituent layer comprising a metal oxide on the first reflective layer, and depositing a second constituent layer comprising a metal oxide on the first reflective layer.

Article 39. An article comprising: a product of the method of any one of the preceding method articles.

Article 40. The methods and/or articles of any one of the preceding articles, wherein the article comprises a polymeric material.

Article 41. The methods and/or articles of any one of the preceding articles, wherein the optical element is disposed on the polymeric material.

Article 42. The methods and/or articles of any one of the preceding articles, wherein the optical element is a single layer reflector, a single layer filter, a multilayer reflector or a multilayer filter.

Article 43. The methods and/or articles of any one of the preceding articles, wherein the multilayer reflector has at least two constituent layers and the at least one reflector layer.

Article 44. The methods and/or articles of any one of the preceding articles, wherein the at least two constituent layers adjacent to the base reflective layer have different refractive indices, optionally wherein each constituent layer of the multilayer reflector has a thickness of about one quarter of the wavelength of the wavelength to be reflected.

Article 45. The methods and/or articles of any one of the preceding articles, wherein the at least one reflective layer comprises a material selected from a metal or a metal oxide.

Article 46. The methods and/or articles of any one of the articles, wherein the at least one reflective layer comprises a metal.

Article 47. The methods and/or articles of any one of the preceding articles, wherein adjacent constituent layers have different refractive indices, optionally wherein the different reflective indices differ by about 5 percent or more, or about 10 percent or more.

Article 48. The methods and/or articles of any one of the preceding articles, wherein the each constituent layer of the multilayer reflector has a thickness of about one quarter of the wavelength of the wavelength of light to be reflected.

Article 49. The methods and/or articles of any of the preceding articles, wherein the optical element has a total thickness of about 100 to about 700 nanometers, or of about 200 to about 500 nanometers.

Article 50. The methods and/or articles of any one of the preceding articles, wherein the at least one reflector layer comprises a material selected from metal or metal oxide or alloy.

Article 51. The methods and/or articles of any one of the preceding articles, wherein the metal is selected from the group consisting of: titanium, aluminum, silver, zirconium, chromium, magnesium, silicon, gold, platinum, or alloy and a combination thereof.

Article 52. The methods and/or articles of any one of the preceding articles, the base reflective layer has a thickness of at least 10 nanometers (optionally at least 30 nanometers, optionally at least 40 nanometers, optionally at least 50 nanometers, optionally at least 60 nanometers, optionally a thickness of from about 10 nanometers to about 100 nanometers, or of from about 30 nanometers to about 80 nanometers, or from about 40 nanometers to about 60 nanometers).

Article 53. The methods and/or articles of any one of the preceding articles, wherein the constituent layer comprises a material selected from the group consisting of: silicon dioxide, titanium dioxide, zinc sulphide, magnesium fluoride, tantalum pentoxide, and a combination thereof.

Article 54. The methods and/or articles of any one of the preceding articles, wherein the at least one reflective layer comprises a titanium layer, wherein the first constituent layer comprises a titanium dioxide layer, or a silicon layer, and wherein the second constituent layer comprises a titanium dioxide layer or a silicon dioxide layer.

Article 55. The methods and/or articles of any one of the preceding articles, wherein a layer of the optical element further comprises a textured surface, and the textured surface and the optical element impart the structural color.

Article 56. The methods and/or articles of any one of the preceding articles, wherein the surface of the article is a textured surface, wherein the optical element is on the textured surface, and the textured surface of the substrate and the optical element impart the structural color.

Article 57. The methods and/or articles of any one of the preceding articles, wherein the textured surface includes a plurality of profile features and flat planar areas, wherein the profile features extend above the flat areas of the textured surface, optionally wherein the dimensions of the profile features, a shape of the profile features, a spacing among the plurality of the profile features, in combination with the optical element create the structural color, optionally wherein the profile features are in random positions relative to one another for a specific area, optionally wherein the spacing among the profile features is set to reduce distortion effects of the profile features from interfering with one another in regard to the structural color of the article, optionally wherein the profile features and the flat areas result in at least one layer of the optical element having an undulating topography across the textured surface, wherein there is a planar region between neighboring profile features that is planar with the flat planar areas of the textured surface, wherein the planar region has dimensions relative to the profile features to impart the structural color, optionally wherein the profile features and the flat areas result in each layer of the optical element having an undulating topography across the textured surface.

Article 58. The methods and/or articles of any one of the preceding articles, wherein the structural color exhibits a single hue or multiple different hues.

Article 59. The methods and/or articles of any one of the preceding articles, wherein the methods and/or articles is a fiber.

Article 60. The methods and/or articles of any one of the preceding articles, wherein the article is a yarn.

Clause 61. The methods and/or articles of any one of the preceding clauses, wherein the article is a monofilament yarn.

Article 62. The methods and/or articles of any one of the preceding articles, wherein the article is a textile, optionally a knit textile, a non-woven textile, a woven textile, a crocheted textile, or a braided textile.

Article 63. The methods and/or articles of any one of the preceding articles, wherein the article is a knit textile.

Article 64. The methods and/or articles of any one of the preceding articles, wherein the article is a non-woven textile.

Article 65. The methods and/or articles of any one of the preceding articles, wherein the article is a non-woven synthetic leather, optionally wherein the structural color is visible on a side of the non-woven synthetic leather intended to be externally-facing during use.

Article 66. The methods and/or articles of any one of the preceding articles, wherein the article is a film.

Article 67. The methods and/or articles of any one of the preceding articles, wherein the article is an article of footwear, a component of footwear, an article of apparel, a component of apparel, an article of sporting equipment, or a component of sporting equipment.

Article 68. The methods and/or articles of any one of the preceding articles, wherein the article is an article of footwear.

Article 69. The methods and/or articles of any one of the preceding articles, wherein the article is a sole component of an article of footwear.

Article 70. The methods and/or articles of any one of the preceding articles, wherein the article is an upper component of an article of footwear.

Article 71. The methods and/or articles of any one of the preceding articles, wherein the article is a knit upper component of an article of footwear.

Article 72. The methods and/or articles of any one of the preceding articles, wherein the article is a non-woven synthetic leather upper for an article of footwear.

Article 73. The methods and/or articles of any one of the preceding articles, wherein the article is a bladder including a volume of a fluid, wherein the bladder has a first bladder wall having a first bladder wall thickness, wherein the first bladder wall has a gas transmission rate of  $15 \text{ cm}^3/\text{m}^2 \cdot \text{atm} \cdot \text{day}$  or less for nitrogen for an average wall thickness of 20 mils.

Article 74. The methods and/or articles of any one of the preceding articles, wherein the article is a bladder, and the optical element is optionally on an inside surface of the bladder or optionally the optical element is on an outside surface of the bladder.

Article 75. The methods and/or articles of any preceding article, wherein the structural color is visible to an observer having 20/20 visual acuity and normal color vision from a distance of about 1 meter from the bladder.

Article 76. The methods and/or articles of any preceding article, wherein the structural color has a single hue.

Article 77. The methods and/or articles of any preceding article, wherein the structural color includes two or more hues.

Article 78. The methods and/or articles of any preceding article, wherein the structural color is iridescent.

Article 79. The methods and/or articles of any preceding article, wherein the structural color has limited iridescence.

Article 80. The methods and/or articles of the preceding article, wherein the structural color has limited iridescence such that, when each color visible at each possible angle of observation is assigned to a single hue selected from the

group consisting of the primary, secondary and tertiary colors on the yellow and blue (RYB) color wheel, all of the assigned hues fall into a single hue group, wherein the single hue group is one of a) green-yellow, yellow, and yellow-orange; b) yellow, yellow-orange and orange; c) yellow-orange and orange; d) purple; e) purple and purple-blue; f) purple, purple-blue, and blue; g) purple-blue, blue, and blue-green; h) blue, blue-green and green; and i) blue-green, green, and green-yellow, (optionally the structural color does not include a single hue of red, optionally the structural color does not include a multihued that includes red).

Article 81. The article and/or method of any of the preceding articles, wherein the profile feature has at least one dimension greater than 500 micrometers and optionally greater than about 600 micrometers.

Article 82. The article and/or method of any of the preceding articles, wherein at least one of the length and width of the profile feature is greater than 500 micrometers or optionally both the length and the width of the profile feature is greater than 500 micrometers.

Article 83. The article and/or method of any of the preceding articles, wherein the height of the profile features can be greater than 50 micrometers or optionally greater than about 60 micrometers.

Article 84. The article and/or method of any of the preceding articles, wherein at least one of the length and width of the profile feature is less than 500 micrometers or both the length and the width of the profile feature is less than 500 micrometers, while the height is greater than 50 micrometers.

Article 85. The article and/or method of any of the preceding articles, wherein at least one of the length and width of the profile feature is greater than 500 micrometers or both the length and the width of the profile feature is greater than 500 micrometers, while the height is greater than 50 micrometers.

Article 86. The article and/or method of any of the preceding articles, wherein at least one of the dimensions of the profile feature is in the nanometer range, while at least one other dimension is in the micrometer range.

Article 87. The article and/or method of any of the preceding articles, wherein the nanometer range is about 10 nanometers to about 1000 nanometers, while the micrometer range is about 5 micrometers to 500 micrometers.

Article 88. The article and/or method of any of the preceding articles, wherein at least one of the length and width of the profile feature is in the nanometer range, while the other of the length and the width of the profile feature is in the micrometer range.

Article 89. The article and/or method of any of the preceding articles, wherein height of the profile features is greater than 250 nanometers.

Article 90. The article and/or method of any of the preceding articles, wherein at least one of the length and width of the profile feature is in the nanometer range and the other in the micrometer range, where the height is greater than 250 nanometers.

Article 91. The article and/or method of any of the preceding articles, wherein spatial orientation of the profile features is periodic.

Article 92. The article and/or method of any of the preceding articles, wherein spatial orientation of the profile features is a semi-random pattern or a set pattern.

Article 93. The article and/or method of any of the preceding articles, wherein the surface of the layers of the optical element are a substantially three dimensional flat planar surface or a three dimensional flat planar surface.

Article 94. The article and/or method of any one of the preceding articles, wherein the optical element is an inorganic optical element, an organic optical element, or a mixed inorganic/organic optical element.

Article 95. The article and/or method of any one of the preceding articles, wherein the organic optical element has at least one layer that is made of an organic material, optionally wherein the at least one layer is made of a non-metal or non-metal oxide material, optionally, wherein at least one layer is made of a polymeric material (optionally a synthetic polymeric material), optionally wherein the at least one layer is made an organic material that does not include a metal or metal oxide, optionally wherein the at least one layer is made of a polymeric (optionally a synthetic polymeric material) that does not include a metal or metal oxide.

Article 96. The article and/or method of any one of the preceding articles, wherein the structural color does not include a single hue of red or the structural color does not include a multihued including red, or wherein the limited iridescence structural color does not include a red hue or multihued including red.

Article 97. An article of footwear comprising:

**[0027]** an optical element on a surface of the article of footwear, wherein the optical element has a first minimum percent reflectance in a first wavelength range within the wavelength range of about 450 to 500 nanometers, wherein the first wavelength range has a first width of about 10 to 50 nanometers, wherein the first minimum percent reflectance is about 50 percent or more, wherein the optical element imparts a structural color that corresponds substantially to a blue and/or cyan hue.

Article 98 The article of article 97, wherein the article is an upper component of an article of footwear optionally, wherein the upper component is a synthetic leather upper.

Article 99. The article of article 97, wherein the article is a sole component of an article of footwear.

Article 100. An article comprising:

**[0028]** an optical element on a surface of the article, wherein the optical element has a first minimum percent reflectance in a first wavelength range within the wavelength range of about 380 to 565 nanometers, wherein the first wavelength range has at least one peak, wherein the at least one peak has a first width of about 10 to 185 nanometers, wherein the first minimum percent reflectance is about 50 percent or more, wherein the optical element imparts a structural color that corresponds substantially to the at least one peak.

Article 101. The article of article 100, wherein the at least one peak has a first width of about 10 to 100 nanometers.

Article 102. The article of article 100, wherein the at least one peak has a first width of about 10 to 120 nanometers.

Article 103. The article of article 100, wherein the first wavelength range is about 450 to 485 nanometers.

Article 104. The article of article 100, wherein the first wavelength range is about 380 to 500 nanometers.

Article 105. The article of article 100, wherein the first wavelength range is about 450 to 500 nanometers.

Article 106. The article of article 100, wherein the structural color is a hue of blue, a hue of cyan, a hue of purple-blue, a hue of blue-green or a combination thereof.

Article 107. The article of article 100, wherein first minimum percent reflectance is about 70 percent or more.

Article 108. The article of article 100, wherein at a first observation angle the structural color is a first structural color and at a second observation angle the structural color is a second structural color, wherein the first structural color and the second structural color are selected from the group consisting of: a hue of blue, a hue of cyan, a hue of purple-blue, and a hue of blue-green.

Article 109. The article of article 100, wherein the structural color has limited iridescence, wherein the limited iridescence is based on hues of selected from: blue, cyan, purple-blue, or blue-green.

Article 110. The article of article 100, wherein the optical element is an inorganic optical element, an organic optical element, or a mixed inorganic/organic optical element.

Article 111. The article of article 110, wherein each layer of the inorganic optical element comprises a material selected from metal or metal oxide.

Article 112. The article of article 111, wherein the metal is selected from the group consisting of: titanium, aluminum, silver, zirconium, chromium, magnesium, silicon, gold, platinum, and a combination thereof.

Article 113. The article of claim 100, wherein the article is a sole component of an article of footwear.

Article 114. The article of claim 113, wherein the article is an upper component of an article of footwear.

Article 115. The article of claim 114, wherein the upper component is a synthetic leather upper.

**[0029]** Now having described embodiments of the present disclosure generally, additional discussion regarding embodiments will be described in greater details.

**[0030]** This disclosure is not limited to particular embodiments described, and as such may, of course, vary. The terminology used herein serves the purpose of describing particular embodiments only, and is not intended to be limiting, since the scope of the present disclosure will be limited only by the appended claims.

**[0031]** Where a range of values is provided, each intervening value, to the tenth of the unit of the lower limit unless the context clearly dictates otherwise, between the upper and lower limit of that range and any other stated or intervening value in that stated range, is encompassed within the disclosure. The upper and lower limits of these smaller ranges may independently be included in the smaller ranges and are also encompassed within the disclosure, subject to any specifically excluded limit in the stated range. Where the stated range includes one or both of the limits, ranges excluding either or both of those included limits are also included in the disclosure.

**[0032]** As will be apparent to those of skill in the art upon reading this disclosure, each of the individual embodiments described and illustrated herein has discrete components and features which may be readily separated from or combined with the features of any of the other several embodiments without departing from the scope or spirit of the present disclosure. Any recited method may be carried out in the order of events recited or in any other order that is logically possible.

**[0033]** Embodiments of the present disclosure will employ, unless otherwise indicated, techniques of material

science, chemistry, textiles, polymer chemistry, and the like, which are within the skill of the art. Such techniques are explained fully in the literature.

**[0034]** Unless otherwise defined, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art of material science, chemistry, textiles, polymer chemistry, and the like. Although methods and materials similar or equivalent to those described herein can be used in the practice or testing of the present disclosure, suitable methods and materials are described herein.

**[0035]** As used in the specification and the appended claims, the singular forms “a,” “an,” and “the” may include plural referents unless the context clearly dictates otherwise. Thus, for example, reference to “a support” includes a plurality of supports. In this specification and in the claims that follow, reference will be made to a number of terms that shall be defined to have the following meanings unless a contrary intention is apparent.

**[0036]** The present disclosure provides for articles that exhibit structural color. The structural color can be imparted by the optical element having the one or more layers, such as reflective layer(s) and/or constituent layer(s), incorporated onto one or more components of the article, for example, when the article is an article of footwear, on an upper or sole of an article of footwear. In one or more embodiments of the present disclosure the surface of the article includes the optical element (e.g., a single layer reflector, a single layer filter, a multilayer reflector or a multilayer filter), and is optionally a textured surface, where the optical element and optionally the textured surface impart structural color (e.g., single color, multicolor, iridescent). The optional textured surface can be disposed between the optical element and the surface or be part of the optical element, depending upon the design.

**[0037]** The optical element can be disposed on or is an integral part of a surface of the article and imparts a structural color to the article. The optical element has a minimum percent reflectance (e.g., a first minimum percent reflectance) in a wavelength range (e.g., a first wavelength range) in the visible region of the spectrum (e.g., about 380 to 625 nanometers). The optical element imparts the structural color that corresponds substantially to the range of first wavelength value.

**[0038]** The minimum percent reflectance can be about 50 percent or more (e.g., up to about 70 percent, about 80 percent, about 90 percent, about 95 percent, about 99 percent, or 100 percent) or optionally about 60 percent or more, about 70 percent or more, about 80 percent or more, about 90 percent or more, or about 95 percent or more. The wavelength range can have a first width (e.g., spectral width) of about 10 to 245 nanometers (optionally about 10 to 200 nanometers, about 10 to 150 nanometers, about 10 to 120 nanometers, about 10 to 100 nanometers, about 10 to 70 nanometers, about 10 to 65 nanometers, about 10 to 35 nanometers, about 10 to 25 nanometers, about 10 to 15 nanometers, as measured at 10 percent reflectance (for the wavelength range for the first width). In general, the spectral width is measured according to the full width at half maximum approach (e.g., take the total peak height and multiply by 50 percent and then measure the peak width at that amount).

**[0039]** In addition to the optical element having the wavelength range (first wavelength range), the optical element

can have a second minimum percent reflectance in a second wavelength range in the visible wavelength range (e.g., about 380 to 625 nanometers). The optical element can impart the structural color that corresponds substantially to the range of the first wavelength value, the second wavelength value, or a combination of both. The second wavelength range can have a second width (e.g., spectral width) of about 10 to 245 nanometers (optionally about 10 to 200 nanometers, about 10 to 150 nanometers, about 10 to 120 nanometers, about 10 to 100 nanometers, about 10 to 70 nanometers, about 10 to 65 nanometers, about 10 to 35 nanometers, about 10 to 25 nanometers, about 10 to 15 nanometers). The second minimum percent reflectance can be about 50 percent or more or optionally about 60 percent or more, about 70 percent or more, about 80 percent or more, about 90 percent or more, or about 95 percent or more. FIG. 3A illustrates a graph showing the first wavelength range, second wavelength range, first width, second width, first minimum percent reflectance (at 50 percent), as well as the peak heights of three peaks.

**[0040]** The first wavelength range and the second wavelength range can overlap one another to a certain degree. The first wavelength range and the second wavelength range can overlap by less than 20 percent or optionally less than 15 percent, or less than 10 percent as measured at 10 percent reflectance (for the wavelength range for the first width). In addition or alternatively, the first wavelength range and the second wavelength range can overlap by less than 20 nanometers or optionally less than 15 nanometers, or less than 10 nanometers as measured at 5 percent reflectance (wavelength as a function of reflectance). The measurement for overlap can be performed at 5 percent reflectance as a function of wavelength.

**[0041]** Alternatively, the minimum percent reflectance in the first wavelength range can be greater than a reflectance in the second wavelength range (e.g., in the visible wavelength range), where the structural color corresponds substantially or totally to the first wavelength range and not the second wavelength range. The reflectance of the first wavelength range can be greater than the second wavelength range by at least about 60 percent or more, about 70 percent or more, about 80 percent or more, about 90 percent or more, about 95 percent or more, or about 99 percent or more. The second wavelength range does not overlap the first wavelength range as measured at 5 percent reflectance (wavelength as a function of reflectance).

**[0042]** The first wavelength range can include at least one peak or a set of peaks, where the optical element imparts the structural color that corresponds substantially to the at least one peak or a set of peaks. The first wavelength range can include at least one peak within the visible wavelength range. The at least one peak can have a minimum percent reflectance of about 50 percent or more (e.g., up to about 70 percent, about 80 percent, about 90 percent, about 95 percent, about 99 percent, or 100 percent) or optionally about 60 percent or more, about 70 percent or more, about 80 percent or more, about 90 percent or more, or about 95 percent or more. The at least one peak can have a width of about 10 to 245 nanometers (optionally about 10 to 200 nanometers, about 10 to 150 nanometers, about 10 to 120 nanometers, about 10 to 100 nanometers, about 10 to 70 nanometers, about 10 to 65 nanometers, about 10 to 35 nanometers, about 10 to 25 nanometers, about 10 to 15 nanometers). The at least one peak or each peak in the set of

peaks can have a spectral width measured according to the full width at half maximum approach (e.g., take the total peak height and multiple by 50 percent and then measure the peak width at that amount). FIG. 3B illustrates a graph showing the first wavelength range, the at least one peak, first peak of the at least one peak, second peak of the at least one peak, first width, second width, and the first minimum percent reflectance (at 50 percent), while FIG. 3C illustrates a graph showing the first wavelength range, first peak of the first set of peaks, second peak of the first set of peaks, third peak of the first set of peaks, the first set of peaks, first width, second width, third width, and the first minimum percent reflectance (at 50 percent).

**[0043]** In an example, the at least one peak can include a first peak with the first wavelength range, where the optical element imparts the structural color that corresponds substantially to the first peak. In addition to the first peak, the at least one peak can include additional peaks, for example a second peak, where the optical element imparts the structural color that corresponds substantially to the first peak, the second peak, or a combination thereof. The first peak, the second peak, or other peaks of the at least one peak can each independently have a minimum percent reflectance of about 50 percent or more (e.g., up to about 70 percent, about 80 percent, about 90 percent, about 95 percent, about 99 percent, or 100 percent) or optionally about 60 percent or more, about 70 percent or more, about 80 percent or more, about 90 percent or more, or about 95 percent or more. The first peak, the second peak, or other peaks of the at least one peak can each independently have a width of about 10 to 245 nanometers (optionally about 10 to 200 nanometers, about 10 to 150 nanometers, about 10 to 120 nanometers, about 10 to 100 nanometers, about 10 to 70 nanometers, about 10 to 65 nanometers, about 10 to 35 nanometers, about 10 to 25 nanometers, about 10 to 15 nanometers). Each of the at least one peak (e.g., first peak and the second peak) can overlap another peak by less than 20 percent or optionally less than 15 percent, less than 10 percent as measured at 5 percent reflectance (wavelength as a function of reflectance). In addition or alternatively, each of the at least one peak (e.g., first peak and the second peak) can overlap another peak by less than 20 nanometers or optionally less than 15 nanometers, less than 10 nanometers as measured at 5 percent reflectance (wavelength as a function of reflectance).

**[0044]** Alternatively, the minimum percent reflectance in the first peak in the first wavelength range can be greater than a reflectance of the second peak in the second wavelength range (e.g., in the visible wavelength range) (e.g., as measured based on the peak height), where the structural color corresponds substantially or totally to the first peak in the first wavelength range and not the second peak in the second wavelength range. The reflectance of the first peak can be greater than the second peak by at least about 60 percent or more, about 70 percent or more, about 80 percent or more, about 90 percent or more, about 95 percent or more, or about 99 percent or more (e.g., as measured based on the peak height). The second wavelength range does not overlap the first wavelength range as measured at 5 percent reflectance (wavelength as a function of reflectance).

**[0045]** In another alternative, the minimum percent reflectance in the first set of peaks in the first wavelength range can be greater than a reflectance of the second set of peaks in the second wavelength range (e.g., in the visible wavelength range), where the structural color corresponds sub-

stantially or totally to the first set of peaks in the first wavelength range and not the second set of peaks in the second wavelength range. The reflectance of the first set of peaks can be greater than the second set of peaks (e.g., comparing the smallest peak height in the first set of peaks vs the largest peak height in the second set of peaks or comparing the average peak height in the first set of peaks to the average peak height of the second set of peaks or comparing full width at half of the smallest peak in the first set of peak vs the largest peak height in the second set of peaks) by at least 60 percent, at least 70 percent, at least 80 percent, at least 90 percent, at least 95 percent, or at least 99 percent. The second wavelength range does not overlap the first wavelength range as measured at 5 percent reflectance (wavelength as a function of reflectance). FIG. 3C illustrates the first wavelength range, the at least one peak, first width, second width, first peak of the at least one peak, second peak of the at least one peak, and the first minimum percent reflectance (at 50 percent).

**[0046]** In another example, the at least one peak comprises a first set of peaks, where the optical element imparts the structural color that corresponds substantially to the first set of peaks. The first set of peaks can include two, three, four, or five or more peaks. Each peak of the first set of peaks can each independently have a minimum percent reflectance of about 50 percent or more (e.g., up to about 70 percent, about 80 percent, about 90 percent, about 95 percent, about 99 percent, or 100 percent) or optionally about 60 percent or more, about 70 percent or more, about 80 percent or more, about 90 percent or more, or about 95 percent or more. Each peak of the first set of peaks can each independently have a width of about 10 to 245 nanometers (optionally about 10 to 200 nanometers, about 10 to 150 nanometers, about 10 to 120 nanometers, about 10 to 100 nanometers, about 10 to 70 nanometers, about 10 to 65 nanometers, about 10 to 35 nanometers, about 10 to 25 nanometers, about 10 to 15 nanometers). Each peak of the first set of peaks can overlap another peak by less than 20 percent or optionally less than 15 percent, less than 10 percent as measured at 5 percent reflectance (wavelength as a function of reflectance). In addition or alternatively, each peak of the first set of peaks can overlap another peak by less than 20 nanometers or optionally less than 15 nanometers, less than 10 nanometers as measured at 5 percent reflectance (wavelength as a function of reflectance).

**[0047]** The first wavelength range or at least the one peak (e.g., the first peak, second peak, or any one of the peaks in the set of peaks) can have widths in addition to those described above. For example, the first wavelength range or at least the one peak can have a wavelength spectral width of about 15 nanometers, about 25 nanometers, about 35 nanometers, about 50 nanometers, about 65 nanometers, about 70 nanometers, about 5 to 20 nanometers, about 20 to 30 nanometers, about 30 to 40 nanometers, about 40 to 60 nanometers, about 60 to 70 nanometers, or about 65 to 75 nanometers, within the wavelength range of 380 to 625 nanometers. In another example, the first wavelength range or at least the one peak have a wavelength spectral width of about 50 nanometers, about 60 nanometers, about 80 nanometers, about 90 nanometers, about 105 nanometers, about 45 to 55 nanometers, about 55 to 65 nanometers, about 75 to 85 nanometers, about 85 to 95 nanometers, or about 100 to 110 nanometers, within the wavelength range of 380 to 625 nanometers. In another example, the first wavelength

range or at least the one peak have a wavelength spectral width of about 105 nanometers, about 115 nanometers, about 125 nanometers, about 120 nanometers, about 100 to 110 nanometers, about 110 to 120 nanometers, about 120 to 130 nanometers, or about 125 to 135 nanometers, within the wavelength range of 380 to 625 nanometers. Each peak is measured according to the full width at half maximum approach (e.g., take the total peak height and multiple by 50 percent and then measure the peak width at that amount).

**[0048]** The first wavelength range or at least the one peak (e.g., the first peak, second peak, or any one of the peaks in the set of peaks) can have a wavelength in addition to those described above. For example, the first wavelength range or at least the one peak can have a wavelength of about 380 to 450 nanometers, about 450 to 485 nanometers, about 485 to 500 nanometers, about 500 to 565 nanometers, about 565 to 590 nanometers, or about 590 to 625 nanometers. In another example, the first wavelength range or at least the one peak can have a wavelength of about 380 to 485 nanometers, about 450 to 500 nanometers, about 485 to 565 nanometers, about 500 to 590 nanometers, or about 590 to 625 nanometers. In yet another example, the first wavelength range or at least the one peak have a wavelength of about 380 to 500 nanometers, about 450 to 565 nanometers, about 485 to 590 nanometers, or about 590 to 625 nanometers. Each peak is measured according to the full width at half maximum approach (e.g., take the total peak height and multiple by 50 percent and then measure the peak width at that amount).

**[0049]** In an aspect, the optical element can have a characteristic that upon exposure to white light imparts the structural color that comprises one of: at least one peak, the first peak, the first set of peaks, as a function of wavelength and percent reflectance. The structural color corresponds substantially to the at least one peak, the first peak, or the first set of peaks.

**[0050]** The phrase “corresponds substantially to” in regard to the structural color can be determined by measuring according to the CIE 1976 color space, described in more detail herein, under a given illumination condition (e.g., about 30 lux of sunlight), also described herein in more detail. The illumination condition can be at a single observation angle of about  $-15$  to  $180$  degrees or about  $-15$  and  $60$  degrees perpendicular the horizontal plane of the optical element (e.g., the plane parallel the layers (e.g., length and width, and not thickness) of the optical element). A first color measurement at a first angle of observation having coordinates  $L_1^*$  and  $a_1^*$  and  $b_1^*$  over the wavelength range of 380 to 625 nanometers can be obtained. In addition, a second color measurement at the first angle of observation having coordinates  $L_2^*$  and  $a_2^*$  and  $b_2^*$  over the first wavelength value can be obtained. The values of  $L_1^*$  and  $L_2^*$  can be the same or different, the  $a_1^*$  and  $a_2^*$  coordinate values can be the same or different, and the  $b_1^*$  and  $b_2^*$  coordinate values can be the same or different.

**[0051]** The structural color can be measured, compared, or evaluated, in different ways. In one approach,  $\Delta E_{ab}^* = [(L_1^* - L_2^*)^2 + (a_1^* - a_2^*)^2 + (b_1^* - b_2^*)^2]^{1/2}$ , described in more detail herein, can be used to compare the first color measurement and the second color measurement. The  $\Delta E_{ab}^*$  between the first color measurement and the second color measurement can be less than or equal to 3, or optionally the  $\Delta E_{ab}^*$  can be between the first color measurement and the second color measurement is less than or equal to 2.2. In this regard, the first color associated with the first color measurement and

the second color associated with the second color measurement are the same or not perceptibly different to an average observer (e.g., an observer having 20/20 visual acuity and normal color vision from a distance of about 1 meter from the object being viewed under light conditions of about 30 lux of sunlight). In other words, the structural color corresponds substantially to the range of the wavelength range. In contrast, when  $\Delta E_{ab}^*$  between the first color measurement and the second color measurement is greater than 3 or optionally greater than about 4 or 5, the first color associated with the first color measurement and the second color associated with the second color measurement are different or perceptibly different to an average observer. In other words, the structural color does not correspond substantially to the range of the wavelength range.

**[0052]** In another approach, the percent difference between one or more of values  $L_1^*$  and  $L_2^*$ ,  $a_1^*$  and  $a_2^*$ , and  $b_1^*$  and  $b_2^*$  is less than 5 percent, optionally, less than 10 percent, less than 15 percent, less than 20 percent. In this regard, the first color associated with the first color measurement and the second color associated with the second color measurement are the same or not perceptibly different to an average observer. In other words, the structural color corresponds substantially to the range of the wavelength range. However, when the percent difference between one or more of values  $L_1^*$  and  $L_2^*$ ,  $a_1^*$  and  $a_2^*$ , and  $b_1^*$  and  $b_2^*$  is greater than 20 percent, the first color associated with the first color measurement and the second color associated with the second color measurement are different or perceptibly different to an average observer (e.g., the structural color does not correspond substantially to the range of the wavelength range).

**[0053]** In regard to the first structural color being distinguishable from a second structural color, the “color” of the article as perceived by a viewer can differ from the actual color of the article, as the color perceived by a viewer is determined by the actual color of the article by the presence of optical element that may absorb, refract, interfere with, or otherwise alter light reflected by the article, by the viewer’s ability to detect the wavelengths of light reflected by the article, by the wavelengths of light used to illuminate the article, as well as other factors such as the coloration of the environment of the article, and the type of incident light (e.g., about 30 lux of sunlight, fluorescent light, and the like). As a result, the color of an object as perceived by a viewer can differ from the actual color of the article. In other words, the first structural color and the second structural color can be considered distinguishable using  $\Delta E_{ab}^*$  above by most individuals but some others may not perceive the difference.

**[0054]** The optical element can have the minimum percent reflectance in the first wavelength range in the wavelength range of about 380 to 625 nanometers, where the minimum percent of reflectance is independent of the angle of incident light upon the optical element. The structural color is independent upon observation angle. Alternatively, the minimum percent of reflectance of the optical element is dependent of the angle of incident light upon the optical element. The structural color is dependent upon observation angle.

**[0055]** At a first observation angle the structural color is a first structural color and at a second observation angle the structural color is a second structural color. The first structural color and the second structural color can be the same or different. The similarity or difference in the first structural

color and the second structural color at their respective angles of observation can be determined according to the CIE 1976 color space under a given illumination condition at two observation angles of about  $-15$  to  $180$  degrees or about  $-15$  degrees and  $+60$  degrees and which are at least  $15$  degrees apart from each other. A first color measurement at the first observation angle, having coordinates  $L_1^*$  and  $a_1^*$  and  $b_1^*$ , can be obtained. A second color measurement at the second observation angle, having coordinates  $L_2^*$  and  $a_2^*$  and  $b_2^*$ , can be obtained.  $L_1^*$  and  $L_2^*$  values may be the same or different, the  $a_1^*$  and  $a_2^*$  coordinate values may be the same or different, and the  $b_1^*$  and  $b_2^*$  coordinate values may be the same or different.  $\Delta E_{ab}^*$ , as described above and herein,  $\Delta E_{ab}^* = [(L_1^* - L_2^*)^2 + (a_1^* - a_2^*)^2 + (b_1^* - b_2^*)^2]^{1/2}$ , can be used to correlate the first structural color and the second structural color at their angles of observation. When the  $\Delta E_{ab}^*$  between the first color measurement and the second color measurement is less than or equal to about  $2.2$ , or optionally the  $\Delta E_{ab}^*$  between the first color measurement and the second color measurement is less than or equal to about  $3$ , then the first structural color and the second structural color are the same or indistinguishable by most observers. The first structural color and the second structural color are considered distinguishable or different by most observers when the  $\Delta E_{ab}^*$  between the first color measurement and the second color measurement is greater than  $3$ , or optionally wherein the  $\Delta E_{ab}^*$  between the first color measurement and the second color measurement is more than or equal to about  $4$  or  $5$ , or  $10$ .

**[0056]** As described herein, the optical element is used to produce the structural color, where the optical element can include a plurality of layers. In an example, the layers can include one or more reflective layers and/or one or more constituent layers to produce the structural color. One of the reflective layers can be a base reflective layer disposed on one side of the optical element; in other words the layer structure is as follows: base reflective layer/ $1^{st}$  constituent layer/ $n^{th}$  constituent layer. Optionally, one of the reflective layers can be a non-base reflective layer disposed between a pair of constituent layers of the optical element; in other words the layer structure is as follows: base reflective layer/ $1^{st}$  constituent layer/ $n^{th}$  constituent layer/non-base reflective layer/ $m^{th}$  constituent layer. Also as described herein, the optical element can also include the optional textured surface, such as a texture layer and/or a textured structure. Additionally and optionally, the optical element can include one or more layers (e.g., protection layer, top layer, and the like).

**[0057]** The base reflective layer can have a percent reflectance of about  $50$  percent or more, about  $60$  percent or more, about  $75$  percent or more, about  $80$  percent or more, about  $85$  percent or more, about  $90$  percent or more, or about  $95$  percent or more. The base reflective layer can have a thickness of at least  $10$  nanometers, optionally at least  $30$  nanometers, at least  $40$  nanometers, at least  $50$  nanometers, at least  $60$  nanometers, at least  $100$  nanometers, at least  $150$  nanometers, optionally a thickness of from about  $10$  nanometers to about  $245$  nanometers or more, about  $10$  nanometers to about  $100$  nanometers, about  $10$  nanometers to about  $100$  nanometers, or of from about  $30$  nanometers to about  $80$  nanometers, or from about  $40$  nanometers to about  $60$  nanometers. For example, the base layer can be about  $30$  to  $150$  nanometers thick.

**[0058]** The optical element can include one or more non-base reflective layers. The non-base reflective layer can have a minimum percent transmittance of at least  $5$  percent, optionally at least  $10$  percent, at least  $15$  percent, at least  $20$  percent, at least  $30$  percent, at least  $40$  percent, or at least  $50$  percent, or at least  $60$  percent. Typically, the base reflective layer has a greater percent reflectance than the non-base reflective layer. The non-base reflective layer can have a thickness of less than  $40$  nanometers, optionally less than  $30$  nanometers, optionally less than  $20$  nanometers, optionally less than  $10$  nanometers. For example, the non-base layer can be  $20$  to  $30$  nanometers thick. The non-base layer is not opaque.

**[0059]** A minimum percent transmittance of greater than  $50$  percent is an opaque layer, a minimum percent transmittance of  $20$  to  $50$  percent to be semi-transparent, and a minimum percent transmittance of less than  $20$  percent is transparent.

**[0060]** The reflective layer (e.g., base or non-base reflective layer) can include a metal layer an oxide layer, an alloy layer, an organic layer, or a mixtures of thereof. The oxide layer can be a metal oxide, a doped metal oxide, or a combination thereof. The metal layer, the metal oxide, the doped metal oxide, or the alloy can include the following: the transition metals, the metalloids, the lanthanides, and the actinides, as well as nitrides, oxynitrides, sulfides, sulfates, selenides, tellurides and a combination of these. The metal layer can be titanium, aluminum, silver, zirconium, chromium, magnesium, silicon, gold, platinum, nobium, alloy thereof, and a combination thereof. The metal oxide can include titanium dioxide, silver oxide, aluminum oxide, silicon dioxide, tin dioxide, chromia, iron oxide, nickel oxide, silver oxide, cobalt oxide, zinc oxide, platinum oxide, palladium oxide, vanadium oxide, molybdenum oxide, lead oxide, nobium oxide, and combinations thereof as well as doped versions of each. In some aspects, the reflective layer can consist essentially of a metal oxide. In some aspects, the reflective layer can consist essentially of titanium dioxide. The metal oxide can be doped with water, inert gasses (e.g., argon), reactive gasses (e.g., oxygen or nitrogen), metals, small molecules, and a combination thereof. In some aspects, the reflective layer can consist essentially of a doped metal oxide or a doped metal oxynitride or both.

**[0061]** The material of the metal layer can be selected based on the desired structural color to be produced. Select materials reflect some wavelengths (e.g., the first wavelength range, at least one peak, a set of peaks) more than other wavelengths. In this way, the material of the reflective layer can be selected based on the desired structural color. The optical element including the reflective layer can have a minimum percent reflectance of about  $60$  percent or more (optionally about  $70$  percent or more, optionally about  $80$  percent or more, or optionally about  $90$  percent or more, or about  $95$  percent or more, or about  $98$  percent or more) for one or more of the wavelengths noted above and herein as well as the following wavelength ranges corresponding to the hue of the structural color: violet:  $380$  to  $450$  nanometers, blue:  $450$  to  $485$  nanometers, cyan:  $485$  to  $500$  nanometers, green:  $500$  to  $565$  nanometers, yellow:  $564$  to  $590$  nanometers, and orange:  $590$  to  $625$  nanometers. The reflective layer can have a minimum percent reflectance for one or more of the wavelength stated above. For the ranges not selected, the minimum reflectivity is lower than that for the selected range, for example, the minimum reflectivity is



lower than that for the selected range by about 10 percent or more, about 20 percent or more, about 30 percent or more, about 40 percent or more, or about 50 percent or more. For example, the base layer can Ti or TiO<sub>x</sub>, where the structural color includes one or more blue hues or one or more green hues, or a combination thereof.

**[0062]** The reflective layer can be a coating on the surface of the article. The coating can be chemically bonded (e.g., covalently bonded, ionically bonded, hydrogen bonded, and the like) to the surface of the article. The coating has been found to bond well to a surface made of a polymeric material. In an example, the surface of the article can be made of a polymeric material such as a polyurethane, including a thermoplastic polyurethane (TPU), as those described herein. Additional details about the optical element and the reflective layer(s) are provided herein.

**[0063]** In an embodiment, the structural color is not used in combination with a pigment and/or dye. In another aspect, the structural color is used in combination with a pigment and/or dye, but the structural color is not the same color, shade, and/or hue as the pigment and/or dye. In this regard, the structural color is the product of the primer layer, the textured surface, the optical element, and the pigment and/or dye.

**[0064]** In an embodiment, the structural color is used in combination with a pigment and/or dye to enhance the color of the pigment and/or dye in regard to the color of the pigment and/or dye or enhance a tone, tint, shade, or hue associated with the pigment and/or dye.

**[0065]** The article can be an article of manufacture or a component of the article. The article of manufacture can include footwear, apparel (e.g., shirts, jerseys, pants, shorts, gloves, glasses, socks, hats, caps, jackets, undergarments), containers (e.g., backpacks, bags), and upholstery for furniture (e.g., chairs, couches, car seats), bed coverings (e.g., sheets, blankets), table coverings, towels, flags, tents, sails, and parachutes, or components of any one of these. In addition, the optical element or articles including the optical element can be used with or disposed on textiles or other items such as striking devices (e.g., bats, rackets, sticks, mallets, golf clubs, paddles, etc.), athletic equipment (e.g., golf bags, baseball and football gloves, soccer ball restriction structures), protective equipment (e.g., pads, helmets, guards, visors, masks, goggles, etc.), locomotive equipment (e.g., bicycles, motorcycles, skateboards, cars, trucks, boats, surfboards, skis, snowboards, etc.), balls or pucks for use in various sports, fishing or hunting equipment, furniture, electronic equipment, construction materials, eyewear, timepieces, jewelry, and the like.

**[0066]** The article can be an article of footwear. The article of footwear can be designed for a variety of uses, such as sporting, athletic, military, work-related, recreational, or casual use. Primarily, the article of footwear is intended for outdoor use on unpaved surfaces (in part or in whole), such as on a ground surface including one or more of grass, turf, gravel, sand, dirt, clay, mud, pavement, and the like, whether as an athletic performance surface or as a general outdoor surface. However, the article of footwear may also be desirable for indoor applications, such as indoor sports including dirt playing surfaces for example (e.g., indoor baseball fields with dirt infields).

**[0067]** In particular, the article of footwear can be designed for use in indoor or outdoor sporting activities, such as global football/soccer, golf, American football,

rugby, baseball, running, track and field, cycling (e.g., road cycling and mountain biking), and the like. The article of footwear can optionally include traction elements (e.g., lugs, cleats, studs, and spikes as well as tread patterns) to provide traction on soft and slippery surfaces, where components of the present disclosure can be used or applied between or among the traction elements and optionally on the sides of the traction elements but on the surface of the traction element that contacts the ground or surface. Cleats, studs and spikes are commonly included in footwear designed for use in sports such as global football/soccer, golf, American football, rugby, baseball, and the like, which are frequently played on unpaved surfaces. Lugs and/or exaggerated tread patterns are commonly included in footwear including boots design for use under rugged outdoor conditions, such as trail running, hiking, and military use.

**[0068]** In particular, the article can be an article of apparel (i.e., a garment). The article of apparel can be an article of apparel designed for athletic or leisure activities. The article of apparel can be a article of apparel designed to provide protection from the elements (e.g., wind and/or rain), or from impacts.

**[0069]** In particular, the article can be an article of sporting equipment. The article of sporting equipment can be designed for use in indoor or outdoor sporting activities, such as global football/soccer, golf, American football, rugby, baseball, running, track and field, cycling (e.g., road cycling and mountain biking), and the like.

**[0070]** FIGS. 1A-1M illustrates footwear, apparel, athletic equipment, container, electronic equipment, and vision wear that include the structure (e.g., the optical element, optionally the textured surface) of the present disclosure. The structure can include the optical element in the “in-line” configuration and/or the “on its side” configuration. The structure including the optical element is represented by hashed areas 12A'/12M'-12A"/12M". The location of the structure is provided only to indicate one possible area that the structure can be located. Also, two locations are illustrated in some of the figures and one location is illustrated in other figures, but this is done only for illustration purposes as the items can include one or a plurality of structure, where the size and location can be determined based on the item. The structure(s) located on each item can represent a number, letter, symbol, design, emblem, graphic mark, icon, logo, or the like.

**[0071]** FIGS. 1N(a) and 1N(b) illustrate a perspective view and a side view of an article of footwear 100 that include a sole structure 104 and an upper 102. The structure including the optical element is represented by 122a and 122b. The sole structure 104 is secured to the upper 102 and extends between the foot and the ground when the article of footwear 100 is worn. The primary elements of the sole structure 104 are a midsole 114 and an outsole 112. The midsole 114 is secured to a lower area of the upper 102 such as a strobil (not shown) and may include a cushioning element comprising a resilient material such as a polymer foam or another appropriate material. In other configurations, the cushioning element of the midsole 114 can incorporate fluid-filled chambers, plates, moderators, and/or other elements that further attenuate forces, enhance stability, or influence motions of the foot. The outsole 112 is secured to a lower surface of the midsole 114 and may comprise a wear-resistant elastomeric material such as a natural or synthetic rubber material. The outsole can be textured to

impart traction, or can include one or more traction elements. The traction elements can be separate elements affixed to the outsole, or can be integrally formed with the outsole. The upper **102** can be formed from various elements (e.g., lace stays, tongue, collar, medial side, lateral side, vamp, toe box, heel counter) that combine to provide a structure for securely and comfortably receiving a foot. Although the configuration of the upper **102** may vary significantly, the various elements generally define a void within the upper **102** for receiving and securing the foot relative to sole structure **104**. Surfaces of the void within upper **102** are shaped to accommodate the foot and can extend over the instep and toe areas of the foot, along the medial and lateral sides of the foot, under the foot, and around the heel area of the foot. The upper **102** can be made of one or more materials such as films, textiles, cables, yarns, fibers, foams, natural leathers, synthetic leathers, and the like that are knitted, stitched, bonded or otherwise connected together. Although this configuration for the sole structure **104** and the upper **102** provides an example of a sole structure that may be used in connection with an upper, a variety of other conventional or nonconventional configurations for the sole structure **104** and/or the upper **102** can also be utilized. Accordingly, the configuration and features of the sole structure **104** and/or the upper **102** can vary considerably.

[0072] FIGS. 10(a) and 10(b) illustrate a perspective view and a side view of an article of footwear **130** that include a sole structure **134** and an upper **132**. The structure including the optical element is represented by **136a** and **136b/136b'**. The sole structure **134** is secured to the upper **132** and extends between the foot and the ground when the article of footwear **130** is worn. The upper **132** can be formed from various elements (e.g., lace, tongue, collar) that combine to provide a structure for securely and comfortably receiving a foot. Although the configuration of the upper **132** may vary significantly, the various elements generally define a void within the upper **132** for receiving and securing the foot relative to the sole structure **134**. Surfaces of the void within the upper **132** are shaped to accommodate the foot and can extend over the instep and toe areas of the foot, along the medial and lateral sides of the foot, under the foot, and around the heel area of the foot. The upper **132** can be made of one or more materials such as textiles including natural and synthetic leathers, molded polymeric components, polymer foam and the like that are stitched or bonded together.

[0073] The primary sole components of the sole structure **134** can include a forefoot component **142**, a heel component **144**, and an outsole **146**. Each of the forefoot component **142** and the heel component **144** can be directly or indirectly secured to a lower area of the upper **132**. In some aspects, the outsole **146** may include one or both of an integrally-formed heel component and forefoot component (not shown). The sole component can comprise a polymeric material that encloses a fluid, which may be a gas, liquid, or gel. During walking and running, for example, the forefoot component **142** and the heel component **144** may compress between the foot and the ground, thereby attenuating ground reaction forces. That is, the forefoot component **142** and the heel component **144** may be inflated and/or may be pressurized with the fluid to cushion the foot. In aspects where the outsole **146** is a separate sole component, the outsole **146** can be secured to lower areas of the forefoot component **142**

and the heel component **144** and may be formed from a wear-resistant material that is textured to impart traction. The sole component, such as a forefoot component **142** or a heel component **144** or a combination forefoot and heel component (not shown), can comprise one or more polymeric materials (e.g., a film comprising layers of one or more polymeric materials) that form one or more chambers that includes a fluid such as a gas. When the sole component comprises a plurality of chambers, the plurality of chambers can be independent or fluidically interconnected. In some configurations, the sole structure **134** may include a foam material forming at least one layer or region of the sole structure, for example, a layer or region that extends between the upper **132** and one or both of the forefoot component **142** and the heel component **144**, or a foam region may be located within indentations in the lower areas of the forefoot component **142** and the heel component **144**. In other configurations, the sole structure **132** may incorporate plates, moderators, lasting elements, or motion control members that further attenuate forces, enhance stability, or influence the motions of the foot, for example. In some configurations, the sole structure or sole component can consist essentially of one or more plates comprising one or more traction elements, such as a single plate extending from the toe to the heel of the upper, or two or more plates, where a single plate is directly or indirectly affixed to a tip of the region of the upper, a forefoot region of the upper, a midfoot region of the upper, a heel region of the upper, or any combination thereof. Although the depicted configuration for the sole structure **134** and the upper **132** provides an example of a sole structure that may be used in connection with an upper, a variety of other conventional or nonconventional configurations for the sole structure **134** and/or the upper **132** can also be utilized. Accordingly, the configuration and features of the sole structure **134** and/or the upper **132** can vary considerably.

[0074] FIG. 10(c) is a cross-sectional view of A-A that depicts the upper **132** and the heel component **144**. The optical element **136b** can be disposed on the externally-facing surface of the heel component **144** or alternatively or optionally the optical element **136b'** can be disposed on the internally-facing side of the heel component **144**.

[0075] FIGS. 1P(a) and 1P(b) illustrate a perspective view and a side view of an article of footwear **160** that includes traction elements **163**. The structure including the optical element is represented by **172a** and **172b**. The article of footwear **160** includes an upper **162** and a sole structure **164**, where the upper **162** is secured to the sole structure **164**. The sole structure **164** can include one or more of a toe plate **166a**, a mid-foot plate **166b**, and a heel plate **166c**. The plate can include one or more traction elements **168**, or the traction elements can be applied directly to a ground-facing surface of the article of footwear. As shown in FIGS. 1P(a) and (b), the traction elements **168** are cleats, but the traction elements can include lugs, cleats, studs, and spikes as well as tread patterns to provide traction on soft and slippery surfaces. In general, the cleats, studs and spikes are commonly included in footwear designed for use in sports such as global football/soccer, golf, American football, rugby, baseball, and the like, while lugs and/or exaggerated tread patterns are commonly included in footwear (not shown) including boots design for use under rugged outdoor conditions, such as trail running, hiking, and military use. Footwear designed for running on paved surfaces commonly

include tread patterns. The sole structure **164** is secured to the upper **162** and extends between the foot and the ground when the article of footwear **160** is worn.

**[0076]** FIGS. 1Q(a)-1Q(j) illustrate additional views of exemplary articles of athletic footwear including various configurations of upper **176**. FIG. 1Q(a) is an exploded perspective view of an exemplary article of athletic footwear showing insole **174**, upper **176**, optional midsole or optional lasting board **177**, and outsole **178**, which can take the form of a plate. Structures including optical elements are represented by **175a-175d**. FIG. 1Q(b) is a top view of an exemplary article of athletic footwear indicating an opening **183** configured to receive a wearer's foot as well as an ankle collar **181** which may include optical element **182**. The ankle collar is configured to be positioned around a wearers ankle during wear, and optionally can include a cushioning element. Also illustrated are the lateral side **180** and medial side **179** of the exemplary article of athletic footwear. FIG. 1Q(c) is a back view of the article of footwear depicted in FIG. 1Q(b) showing an optional heel clip **184** that can include optical element **185**. FIG. 1Q(d) shows a side view of an exemplary article of athletic footwear, which may optionally also include a tongue **186**, laces **188**, a toe cap **189**, a heel counter **190**, a decorative element such as a logo **191**, and/or eyestays for the laces **192** as well as a toe area **193**, a heel area **193b**, and a vamp **193c**. In some aspects, the heel counter **190** can be covered by a layer of knitted, woven, or nonwoven fabric, natural or synthetic leather, film, or other shoe upper material. In some aspects, the eyestays **192** are formed as one continuous piece; however, they can also comprise several separate pieces or cables individually surrounding a single eyelet or a plurality of eyelets. Structures including optical elements are represented by **187a-187e**. While not depicted, optical elements can be present on the eyestays **192** and/or the laces **188**. In some configurations, the sole structure can include a sole structure, such as a midsole having a cushioning element in part or substantially all of the midsole, and the optical element can be disposed on an externally-facing side of the sole structure, including on an externally-facing side of the midsole. FIG. 1Q(e) is a side view of another exemplary article of athletic footwear. In certain aspects, the upper can comprise one or more containment elements **194** such as wires, cables or molded polymeric component extending from the lace structure over portions of the medial and lateral sides of the exemplary article of athletic footwear to the top of the sole structure to provide lockdown of the foot to the sole structure, where the containment element(s) can have an optical element (not shown) disposed on an externally-facing side thereon. In some configurations, a rand (not shown) can be present across part or all of the biteline **195**.

**[0077]** Now having described embodiments of the present disclosure generally, additional details are provided. As has been described herein, the structural color can include one of a number of colors. The "color" of an article as perceived by a viewer can differ from the actual color of the article, as the color perceived by a viewer is determined by the actual color of the article (e.g., the color of the light leaving the surface of the article), by the presence of optical elements which may absorb, refract, interfere with, or otherwise alter light reflected by the article, the viewer's visual acuity, by the viewer's ability to detect the wavelengths of light reflected by the article, by the characteristics of the perceiving eye

and brain, by the intensity and type of light used to illuminate the article (e.g., sunlight, incandescent light, fluorescent light, and the like), as well as other factors such as the coloration of the environment of the article. As a result, the color of an object as perceived by a viewer can differ from the actual color of the article.

**[0078]** Conventionally, non-structural color is imparted to man-made objects by applying colored materials such as pigments or dyes to the object. Non-structurally colored materials are made of molecules that absorb all but particular wavelengths of light and reflect back the unabsorbed wavelengths, or which absorb and emit particular wavelengths of light. In non-structural color, it is the unabsorbed and/or the emitted wavelengths of light which impart the color to the article. As the color-imparting property is due to molecule's chemical structure, the only way to remove or eliminate the color is to remove the molecules or alter their chemical structure.

**[0079]** More recently, methods of imparting "structural color" to man-made objects have been developed. Structural color is color that is produced, at least in part, by microscopically structured surfaces that interfere with visible light contacting the surface. The structural color is color caused by physical structures which produce optical phenomena including the scattering, refraction, reflection, interference, and/or diffraction of light. In some aspects, structural color can be caused by one or more of these optical phenomena in combination with absorption or emission. For example, optical phenomena which impart structural color can include multilayer interference, thin-film interference, refraction, dispersion, light scattering, including Mie scattering, and diffraction, including diffraction grating. As structural color is produced by physical structures, destroying or altering the physical structures can eliminate or alter the imparted color. The ability to eliminate color by destroying the physical structure, such as by grinding or melting an article can facilitate recycling and reuse colored materials. In various aspects described herein, the structural color imparted to a region of an external surface of an article is visible to a viewer having 20/20 visual acuity and normal color vision from a distance of about 1 meter from the article, when the structurally-colored region is illuminated by about 30 lux of sunlight, incandescent light, or fluorescent light. In some such aspects, the structurally-colored region is at least one square centimeter in size.

**[0080]** As described herein, structural color is produced, at least in part, by the optical element, as opposed to the color being produced solely by pigments and/or dyes. The coloration of a structurally-colored article can be due solely to structural color (i.e., the article, a colored portion of the article, or a colored outer layer of the article can be substantially free of pigments and/or dyes). In another aspect, an optical element can impart a "combined color," where a "combined color" can be described as having a structural component and a non-structural color component. For example, structural color can be used in combination with pigments and/or dyes to alter all or a portion of a structural color, forming a combined color. In a combined color, the structural color component, when viewed without the non-structural color component, imparts a structural color having a first color and the non-structural color component, when viewed without the structural color component imparts a second color, where the first color and the second color differ in hue or chroma. Further in this aspect, when viewed

together, the first color and the second color combine to form a third, combined color, which differs in hue and chroma from either the first color or the second color, for example, through shifting the reflectance spectrum of the optical element.

**[0081]** In another aspect, an optical element can impart a “modified color,” where a “modified color” can be described as having a structural color component and a modifier component. In a modified color, the structural color component, when viewed without the modifier component, imparts a structural color having a specific hue and/or chroma and the modifier component, when viewed without the structural color component, does not impart any color, hue, or chroma. Further in this aspect, when viewed together, the modifier component can expand, narrow, or shift the range of wavelengths of light reflected by the structural color component.

**[0082]** In still another aspect, an optical element can impart a “modified combined color,” where a “modified combined color” can be described as having a structural color component having a first color, a non-structural color component having a second color, and a modifier component not imparting a color but instead functioning to expand, narrow, or shift the range of wavelengths of light reflected by the combined color formed from the structural color component and the non-structural color component.

**[0083]** In one aspect, the structural color component, combined color component, or modified color component disclosed herein is opaque; that is, it prevents light from passing through any articles to which they are applied. Further in this aspect, most wavelengths of light are absorbed by one or more layers of the structural color, combined color, or modified color component, with only a narrow band of light reflected about the wavelength of maximum reflectance.

**[0084]** “Hue” is commonly used to describe the property of color which is discernible based on a dominant wavelength of visible light, and is often described using terms such as magenta, orange, yellow, green, cyan, blue, indigo, violet, etc. or can be described in relation (e.g., as similar or dissimilar) to one of these. The hue of a color is generally considered to be independent of the intensity or lightness of the color. For example, in the Munsell color system, the properties of color include hue, value (lightness) and chroma (color purity). Particular hues are commonly associated with particular ranges of wavelengths in the visible spectrum: the range of about 635 to 590 nanometers is associated with orange, the range of about 590 to 560 nanometers is associated with yellow, the range of about 560 to 520 nanometers is associated with green, the range of about 520 to 490 nanometers is associated with cyan, the range of about 490 nanometers to 450 nanometers is associated with blue, and the range of about 450 to 400 nanometers is associated with violet.

**[0085]** In various aspects described herein, the hue or hues of the structural color imparted to a region of an external surface of an article is visible to a viewer having 20/20 visual acuity and normal color vision from a distance of about 1 meter from the article, when the structurally-colored region is illuminated by about 30 lux of sunlight, incandescent light, or fluorescent light. Similarly, a viewer having 20/20 visual acuity and normal color vision, when viewing two structurally-colored regions under these conditions, where either both regions are on the same article, or the two

regions are individually on different articles, can determine whether or not the hues imparted to the two regions are the same or different. Further, a viewer having 20/20 visual acuity and normal color vision, when viewing one structurally-colored region under these conditions but at two different viewing angles, can determine whether or not the hues imparted to the region are the same or different.

**[0086]** When used in the context of structural color, one can characterize the hue of a structurally-colored article, i.e., an article that has been structurally colored by incorporating an optical element into the article, based on the wavelengths of light the structurally-colored portion of the article absorbs and reflects (e.g., linearly and non-linearly). While the optical element may impart a first structural color, the presence of an optional textured surface and/or primer layer can alter the structural color. Other factors such as coatings or transparent elements may further alter the perceived structural color. The hue of the structurally colored article can include any of the hues described herein as well as any other hues or combination of hues. The structural color can be referred to as a “single hue” (i.e., the hue remains substantially the same, regardless of the angle of observation and/or illumination), or “multihued” (i.e., the hue varies depending upon the angle of observation and/or illumination). The multihued structural color can be iridescent (i.e., the hue changes gradually over two or more hues as the angle of observation or illumination changes). The hue of an iridescent multihued structural color can change gradually across all the hues in the visible spectrum (e.g., like a “rainbow”) as the angle of observation or illumination changes. The hue of an iridescent multihued structural color can change gradually across a limited number of hues in the visible spectrum as the angle of observation or illumination changes, in other words, one or more hues in the visible spectrum (e.g., orange, yellow, etc.) are not observed in the structural color as the angle of observation or illumination changes. Only one hue, or substantially one hue, in the visible spectrum may be present for a single-hued structural color. The hue of a multihued structural color can change more abruptly between a limited number of hues (e.g., between 2-8 hues, or between 2-4 hues, or between 2 hues) as the angle of observation or illumination changes.

**[0087]** The structural color can be a multi-hued structural color in which two or more hues are imparted by the structural color.

**[0088]** The structural color can be iridescent multi-hued structural color in which the hue of the structural color varies over a wide number of hues (e.g., 5, 6, 7, 8 or more hues) when viewed at a single viewing angle, or when viewed from two or more different viewing angles that are at least 15 degrees apart from each other.

**[0089]** The structural color can be limited iridescent multi-hue structural color in which the hue of the structural color varies, or varies substantially (e.g., about 90 percent, about 95 percent, or about 99 percent) over a limited number of hues (e.g., 2 hues, or 3 hues or 4 hues) when viewed from two or more different viewing angles that are at least 15 degrees apart from each other. In some aspects, a structural color having limited iridescence is limited to two, three or four hues selected from the primary colors of yellow and blue, optionally the primary and secondary colors of yellow, blue, green, orange and purple, or optionally the primary,

secondary and tertiary colors of yellow, blue, green, orange purple, green-yellow, yellow-orange, purple-blue, and blue-green.

**[0090]** The structural color can be single-hue angle-independent structural color in which the hue, the hue and value, or the hue, value and chroma of the structural color is independent of or substantially (e.g., about 90 percent, about 95 percent, or about 99 percent) independent of the angle of observation. For example, the single-hue angle-independent structural color can display the same hue or substantially the same hue when viewed from at least 3 different angles that are at least 15 degrees apart from each other (e.g., single-hue structural color).

**[0091]** The structural color imparted can be a structural color having limited iridescence such that, when each color observed at each possible angle of observation is assigned to a single hue selected from the group consisting of the primary, secondary and tertiary colors on the red, yellow, blue (RYB) color wheel (e.g., pure red is excluded, specifically the structural color is not a pure red structural color), for a single structural color, all of the assigned hues fall into a single hue group, wherein the single hue group is one of a) green-yellow, yellow, and yellow-orange; b) yellow, yellow-orange and orange; c) yellow-orange and orange; d) purple; e) purple and purple-blue; f) purple, purple-blue, and blue; g) purple-blue, blue, and blue-green; h) blue, blue-green and green; and i) blue-green, green, and green-yellow. In other words, in this example of limited iridescence, the hue (or the hue and the value, or the hue, value and chroma) imparted by the structural color varies depending upon the angle at which the structural color is observed, but the hues of each of the different colors viewed at the various angles of observations varies over a limited number of possible hues. The hue visible at each angle of observation can be assigned to a single primary, secondary or tertiary hue on the red, yellow, blue (RYB) color wheel (e.g., red is specifically excluded) (i.e., the group of hues consisting of yellow, blue, green, orange purple, green-yellow, yellow-orange, purple-blue, and blue-green). For example, while a plurality of different colors are observed as the angle of observation is shifted (for example in increments of 15 degrees), when each observed hue is classified as one of yellow, blue, green, orange purple, green-yellow, yellow-orange, purple-blue, and blue-green, the list of assigned hues includes no more than one, two, or three hues selected from the list of RYB primary, secondary and tertiary hues (e.g., red hues can be excluded). In some examples of limited iridescence, all of the assigned hues fall into a single hue group selected from hue groups a)-i), each of which include three adjacent hues on the RYB primary, secondary and tertiary color wheel. For example, all of the assigned hues can be a single hue within hue group h) (e.g., blue), or some of the assigned hues can represent two hues in hue group h) (e.g., purple-blue and blue), or can represent three hues in hue group h) (e.g., purple-blue, blue, and blue-green).

**[0092]** Similarly, other properties of the structural color, such as the lightness of the color, the saturation of the color, and the purity of the color, among others, can be substantially the same regardless of the angle of observation or illumination, or can vary depending upon the angle of observation or illumination. The structural color can have a matte appearance, a glossy appearance, or a metallic appearance, or a combination thereof.

**[0093]** As discussed above, the color (including hue) of a structurally-colored article (e.g., an article including an structural color) can vary depending upon the angle at which the structurally-colored article is observed or illuminated. The hue or hues of an article can be determined by observing the article, or illuminating the article, at a variety of angles using constant lighting conditions. As used herein, the “angle” of illumination or viewing is the angle measured from an axis or plane that is orthogonal to the surface. The viewing or illuminating angles can be set between about 0 and 180 degrees. The viewing or illuminating angles can be set at 0 degrees, 15 degrees, 30 degrees, 45 degrees, 60 degrees, and -15 degrees and the color can be measured using a colorimeter or spectrophotometer (e.g., Konica Minolta), which focuses on a particular area of the article to measure the color. The viewing or illuminating angles can be set at 0 degrees, 15 degrees, 30 degrees, 45 degrees, 60 degrees, 75 degrees, 90 degrees, 105 degrees, 120 degrees, 135 degrees, 150 degrees, 165 degrees, 180 degrees, 195 degrees, 210 degrees, 225 degrees, 240 degrees, 255 degrees, 270 degrees, 285 degrees, 300 degrees, 315 degrees, 330 degrees, and 345 degrees and the color can be measured using a colorimeter or spectrophotometer. In a particular example of a multihued article colored using only structural color, when measured at 0 degrees, 15 degrees, 30 degrees, 45 degrees, 60 degrees, and -15 degrees, the hues measured for article consisted of “blue” at three of the measurement angles, “blue-green” at 2 of the measurement angles and “purple” at one of the measurement angles.

**[0094]** In other aspects, the color (including hue, value and/or chroma) of a structurally-colored article does not change substantially, if at all, depending upon the angle at which the article is observed or illuminated. In instances such as this the structural color can be an angle-independent structural color in that the hue, the hue and value, or the hue, value and chroma observed is substantially independent or is independent of the angle of observation.

**[0095]** Various methodologies for defining color coordinate systems exist. One example is  $L^*a^*b^*$  color space, where, for a given illumination condition,  $L^*$  is a value for lightness, and  $a^*$  and  $b^*$  are values for color-opponent dimensions based on the CIE coordinates (CIE 1976 color space or CIELAB). In an embodiment, a structurally-colored article having structural color can be considered as having a “single” color when the change in color measured for the article is within about 10% or within about 5% of the total scale of the  $a^*$  or  $b^*$  coordinate of the  $L^*a^*b^*$  scale (CIE 1976 color space) at three or more measured observation or illumination angles selected from measured at observation or illumination angles of 0 degrees, 15 degrees, 30 degrees, 45 degrees, 60 degrees, and -15 degrees.

**[0096]** A difference between two color measurements can be described mathematically in the CIELAB space based on the differences between the color coordinates of the two colors. For example, a first measurement has coordinates  $L_1^*$ ,  $a_1^*$  and  $b_1^*$ , and a second measurement has coordinates  $L_2^*$ ,  $a_2^*$  and  $b_2^*$ . The total difference between these two measurements on the CIELAB scale can be expressed as  $\Delta E_{ab}^* = [(L_1^* - L_2^*)^2 + (a_1^* - a_2^*)^2 + (b_1^* - b_2^*)^2]^{1/2}$ . Generally speaking, if two colors have a  $\Delta E_{ab}^*$  of less than or equal to 1, the difference in color is not perceptible to human eyes, and if two colors have a  $\Delta E_{ab}^*$  of greater than 100 the colors are considered

to be opposite colors, while a  $\Delta E^*_{ab}$  of about 2-3, or of 3 or more, is considered the threshold for perceivable color difference by most humans.

**[0097]** In an aspect, a first structural color (e.g., imparted to a first region or article) and a second structural color (e.g., imparted to a second region or article) can be considered different structural colors if they have a  $\Delta E^*_{ab}$  of greater than 2.2, greater than 3, greater than 4, greater than 5, or greater than 10. In another aspect, a first structural color (e.g., imparted to a first region) and a second structural color (e.g., imparted to a second region) can be considered the same structural color if they have a  $\Delta E^*_{ab}$  of less about 3 or less than 2.2.

**[0098]** In another aspect, a first region can be considered as having a “single” color when the  $\Delta E^*_{ab}$  is less than 3, or less than 2.2, between pairs of measurements across three or more measured observation or illumination angles selected from measured at observation or illumination angles of 0 degrees, 15 degrees, 30 degrees, 45 degrees, 60 degrees, and -15 degrees. In yet another aspect, a first region can be considered to be multi-hued when the  $\Delta E^*_{ab}$  between at least one pair of measurements is greater than 2.2, greater than 3, greater than 4, greater than 5, or greater than 10, where the measurements are taken at each of three or more observation or illumination angles chosen from 0 degrees, 15 degrees, 30 degrees, 45 degrees, 60 degrees, and -15 degrees. In an aspect, the first region can be multi-hued by imparting 2 different structural colors, multi-hued by imparting 3 different structural colors, or multi-hued by imparting 4 different structural colors, each at different angles of observation or illumination.

**[0099]** In the CIELAB space, the threshold of perceptible color difference based on the  $\Delta E^*_{ab}$  calculation is about 2-3 and the perception of color by a viewer is dependent upon the physiology of the viewer, the viewing conditions, and the like, an individual viewer observing the first structural color and the second structural color may not be able to detect that the two structural colors are different, while the two structural colors may be considered to be different based on the  $\Delta E^*_{ab}$  calculation, or based on a difference between their a\* coordinates, their b\* coordinates, or their a\* and b\* coordinates.

**[0100]** Similarly, the structural color at two different angles can be considered as corresponding substantially to one another by measuring according to the CIE 1976 color space, under a given illumination condition. The illumination condition can be at a single observation angle of about -15 to 180 degrees or about -15 and 60 degrees perpendicular the horizontal plane of the optical element (e.g., the plane parallel the layers of the optical element). A first color measurement at a first angle of observation having coordinates  $L_1^*$  and  $a_1^*$  and  $b_1^*$  over the wavelength range of 380 to 625 nanometers can be obtained. In addition, a second color measurement at the first angle of observation having coordinates  $L_2^*$  and  $a_2^*$  and  $b_2^*$  over the first wavelength value can be obtained. The structural color can be compared in different ways. In one approach described above,  $\Delta E^*_{ab} = [(L_1^* - L_2^*)^2 + (a_1^* - a_2^*)^2 + (b_1^* - b_2^*)^2]^{1/2}$ , can be used to compare the first color measurement and the second color measurement. The first structural color and the second structural color can be considered the same or substantially indistinguishable when the  $\Delta E^*_{ab}$  between the first color measurement and the second color measurement can be less than or equal to about 3, or optionally the  $\Delta E^*_{ab}$  can be

between the first color measurement and the second color measurement is less than or equal to about 2.2.

**[0101]** In another aspect, the minimum percent of reflectance of the wavelength range, the at least one peak, or set of peaks is independent of the angle of incident light upon the optical element. The structural color is independent upon observation angle. Alternatively, the minimum percent of reflectance of the wavelength range, the at least one peak, or set of peaks is dependent of the angle of incident light upon the optical element. The structural color is dependent upon observation angle.

**[0102]** The independent or dependence can be determined. At a first observation angle the structural color is a first structural color and at a second observation angle the structural color is a second structural color. The first structural color and the second structural color can be the same or different. The similarity or difference in the first structural color and the second structural color at their respective angles of observation can be determined according to the CIE 1976 color space under a given illumination condition at two observation angles of about -15 to 180 degrees or about -15 degrees and +60 degrees and which are at least 15 degrees apart from each other. A first color measurement at the first observation angle having coordinates  $L_1^*$  and  $a_1^*$  and  $b_1^*$  can be obtained. A second color measurement at the second observation angle having coordinates  $L_2^*$  and  $a_2^*$  and  $b_2^*$  can be obtained.  $\Delta E^*_{ab}$ , as described above and herein,  $\Delta E^*_{ab} = [(L_1^* - L_2^*)^2 + (a_1^* - a_2^*)^2 + (b_1^* - b_2^*)^2]^{1/2}$ , can be used to correlate the first structural color and the second structural color at their angles of observation. When the  $\Delta E^*_{ab}$  between the first color measurement and the second color measurement is less than or equal to about 2.2, or optionally the  $\Delta E^*_{ab}$  between the first color measurement and the second color measurement is less than or equal to about 3, then the first structural color and the second structural color are the same or indistinguishable to the average observer. The first structural color and the second structural color are considered distinguishable or different when the  $\Delta E^*_{ab}$  between the first color measurement and the second color measurement is greater than 3, or optionally wherein the  $\Delta E^*_{ab}$  between the first color measurement and the second color measurement is greater than or equal to about 4 or 5, or 10.

**[0103]** Another example of a color scale is the CIELCH color space, where, for a given illumination condition,  $L^*$  is a value for lightness,  $C^*$  is a value for chroma, and  $h^\circ$  denotes a hue as an angular measurement. In an aspect, a first structural color (e.g., imparted to a first region or article using an optical element) and a second structural color (e.g., imparted to a second region or article using an optical element) can be considered to have the same color or hue when the hue measured for the first region is less than 10 degrees different or less than 5 degrees different than the hue measured for the second region at the  $h^\circ$  angular coordinate of the CIELCH color space, at three or more measured observation or illumination angles selected from measured at observation or illumination angles of 0 degrees, 15 degrees, 30 degrees, 45 degrees, 60 degrees, and -15 degrees. In a further aspect, a first structural color (e.g., imparted to a first region or article) and a second structural color (e.g., imparted to a second region or article) can be considered to have different colors or hues when the hue measured for the first region is at least 45 degrees different than the hue measured for the second region at the  $h^\circ$  angular

coordinate of the CIELCH color space, at three or more measured observation or illumination angles selected from measured at observation or illumination angles of 0 degrees, 15 degrees, 30 degrees, 45 degrees, 60 degrees, and -15 degrees. In another aspect, an optical element can be said to be single-hued when all areas of the optical element have the same color in the CIELCH color space as defined herein, or can be multi-hued or multi-colored when at least two areas of the optical element have different colors in the CIELCH color space.

**[0104]** Another system for characterizing color includes the “PANTONE” Matching System (Pantone LLC, Carlstadt, N.J., USA), which provides a visual color standard system to provide an accurate method for selecting, specifying, broadcasting, and matching colors through any medium. In an example, a first optical element and a second optical element can be said to have the same color when the color measured for each optical element is within a certain number of adjacent standards, e.g., within 20 adjacent PANTONE standards, at three or more measured observation or illumination angles selected from 0 degrees, 15 degrees, 30 degrees, 45 degrees, 60 degrees, and 75 degrees. In an alternative aspect, the first optical element and the second optical element can be said to have different colors when the color measured for each optical element is outside a certain number of adjacent standards, e.g., at least 20 adjacent PANTONE standards or farther apart, at three or more measured observation or illumination angles selected from 0 degrees, 15 degrees, 30 degrees, 45 degrees, 60 degrees, and 75 degrees. In another aspect, an optical element can be said to be single-hued when all areas of the optical element have the same PANTONE color as defined herein, or can be multi-hued or multi-colored when at least two areas of the optical element have different PANTONE colors.

**[0105]** Another example of a color scale is the Natural Color System® or NCS, which is built on principles of human physiological vision and describes color by using color similarity relationships. The NCS is based on the premise that the human visual system consists of six elementary color precepts, or colors that can be challenging to define perceptually in terms of other colors. These colors consist of three pairs: (i) the achromatic colors of black (S) and white (W), (ii) the opposing primary color pair of red (R) and green (G), and (iii) the opposing primary color pair of yellow (Y) and blue (B). In the NCS, any color that can be perceived by the human eye can be similar to the two achromatic colors and a maximum of two non-opposing primary colors. Thus, for example, a perceived color can have similarities to red and blue but not to red and green. NCS descriptions of colors are useful for colors that belong to the surfaces of materials, so long as the surfaces are not fluorescent, translucent, luminescent, or the like; the NCS does not encompass other visual properties of the surface such as, for example, gloss and texture.

**[0106]** The NCS color space is a three dimensional model consisting of a flat circle at which the four primary colors are positioned in order at 0 degrees, 90 degrees, 180 degrees, and 270 degrees. For example, if yellow is at 0 degrees, red is at 90 degrees, blue is at 180 degrees, and green is at 270 degrees. White is represented above the circle and black below such that a hue triangle forms between the black/white (grayscale) axis and any point on the circle.

**[0107]** Percentage “blackness” (s) is defined in the NCS as a color’s similarity to the elementary color black. Percentage “chromaticness” (c) represents similarity to the most saturated color in a hue triangle. “Hue” ( $\phi$ ) in the NCS, meanwhile, represents similarity of a color to one or at most two non-opposing primary colors. Blackness and chromaticness add up to a value less than or equal to 100 percent; any remaining value is referred to as “whiteness” (w) of a color. In some cases, the NCS can be used to further describe “saturation” (m), a value from 0 to 1 determined in terms of chromaticness and whiteness (e.g.,  $m=c/(w+c)$ ). NCS can further be used to describe “lightness” (v), a description of whether the color contains more of the achromatic elementary colors black or white. A pure black article would have a lightness of 0 and a pure white article would have a lightness of 1. Purely neutral grays ( $c=0$ ) have lightness defined by  $v=(100-s)/100$ , while chromatic colors are first compared to a reference scale of grays and lightness is then calculated as for grays.

**[0108]** NCS notation takes the generic form  $sc-A\phi B$ , where  $sc$  defines “nuance,”  $ss$  is the percent blackness and  $cc$  refers to the chromaticity; A and B are the two primary colors to which the color relates; and  $\phi$  is a measure of where a color falls between A and B. Thus, a color (e.g., orange) that has equal amounts of yellow and red could be represented such that  $A\phi B=Y50R$  (e.g., yellow with 50 percent red), whereas a color having relatively more red than yellow is represented such that  $A\phi B=Y60R, Y70R, Y80R, Y90R$ , or the like. The color having equal amounts of yellow and red with a relatively low (10 percent) amount of darkness and a medium (50 percent) level of chromaticity would thus be represented as 1050-Y50R. In this system, neutral colors having no primary color components are represented by  $sc-N$ , where  $sc$  is defined in the same manner as with a non-neutral color and N indicates neutrality, while a pure color would have a notation such as, for example, 3050-B (for a blue with 30 percent darkness and 50 percent chromaticity). A capital “S” in front of the notation indicates that a value was present in the NCS 1950 Standard, a reduced set of samples. As of 2004, the NCS system contains 1950 standard colors.

**[0109]** The NCS is more fully described in ASTM E2970-15, “Standard Practice for Specifying Color by the Natural Colour System (NCS).” Although the NCS is based on human perception and other color scales such as the CIELAB or CIELCH spaces may be based on physical properties of objects, NCS and CIE tristimulus values are interconvertible.

**[0110]** In an example, a first optical element and a second optical element can be considered as being the same color when the colors measured for each optical element are within a certain number of adjacent standards, e.g., within 20 adjacent NCS values, at three or more measured observation or illumination angles selected from 0 degrees, 15 degrees, 30 degrees, 45 degrees, 60 degrees, and -15 degrees. In another example, the first optical element and the second optical element can be considered as being different colors when the colors measured for each optical element are outside a certain number of adjacent standards, e.g., farther apart than at least 20 adjacent NCS values, at three or more measured observation or illumination angles selected from 0 degrees, 15 degrees, 30 degrees, 45 degrees, 60 degrees, and -15 degrees. In another aspect, an optical element can be said to be single-hued when all areas of the

optical element have the same NCS color as defined herein, or can be multi-hued or multi-colored when at least two areas of the optical element have different NCS colors. In a still further aspect, a single optical element can be said to be iridescent if it exhibits at least five different NCS colors as defined herein at different measured observation or illumination angles.

**[0111]** The method of making articles including the optical element (e.g., structurally colored article) can include disposing (e.g., positioning, affixing, attaching, bonding, fastening, joining, appending, connecting, binding) the optical element onto an article (e.g., an article of footwear, an article of apparel, an article of sporting equipment, etc.). The article includes a component, and the component has a surface upon which the optical element can be disposed. The surface of the article can be made of a material such as a thermoplastic material or thermoset material, as described herein. For example, the article has a surface including a thermoplastic material (i.e., a first thermoplastic material), for example an externally-facing surface of the component or an internally-facing surface of the component (e.g., an externally-facing surface or an internally-facing surface a bladder). The optical element can be disposed onto the thermoplastic material, for example.

**[0112]** In an aspect, the temperature of at least a portion of the first surface of the article including the thermoplastic material is increased to a temperature at or above creep relaxation temperature ( $T_{cr}$ ), Vicat softening temperature ( $T_{vs}$ ), heat deflection temperature ( $T_{hd}$ ), and/or melting temperature ( $T_m$ ) of the thermoplastic material, for example to soften or melt the thermoplastic material. The temperature can be increased to a temperature at or above the creep relaxation temperature. The temperature can be increased to a temperature at or above the Vicat softening temperature. The temperature can be increased to a temperature at or above the heat deflection temperature. The temperature can be increased to a temperature at or above the melting temperature. While the temperature of the at least a portion of the first side of the article is at or above the increased temperature (e.g., at or above the creep relaxation temperature, the heat deflection temperature, the Vicat softening temperature, or the melting temperature of the thermoplastic material), the optical element is affixed to the thermoplastic material within the at least a portion of the first side of the article. Following the affixing, the temperature of the thermoplastic material is decreased to a temperature below its creep relaxation temperature to at least partially re-solidify the thermoplastic material. The thermoplastic material can be actively cooled (e.g., removing the source that increases the temperature and actively (e.g., flowing cooler gas adjacent the article reducing the temperature of the thermoplastic material) or passively cooled (e.g., removing the source that increases the temperature and allowing the thermoplastic layer to cool on its own).

**[0113]** The method of making the structurally-colored article can include disposing (e.g., positioning, affixing, attaching, bonding, fastening, joining, appending, connecting, binding, which includes operably disposing etc.) the optical element onto a surface of an article (e.g., an article of footwear, an article of apparel, an article of sporting equipment, etc.) or a surface of a component of an article. The article can include a component, and the component can include the surface upon which the optical element is disposed. The surface of the article can be made of a material

such as a thermoplastic material or thermoset material, as described herein. For example, the article can have a surface including a thermoplastic material (i.e., a first thermoplastic material), for example an externally-facing surface of the component or article or an internally-facing surface of the component or article (e.g., an externally-facing surface or an internally-facing surface a bladder). The optical element can be disposed onto the thermoplastic material, for example.

**[0114]** Now having described color and other aspects generally, additional details regarding the optical element are provided. As described herein, the article includes the optical element. The optical element includes can include a reflection layer and/or a constituent layer. In an aspect, the optical element includes at least one reflective layer (e.g., base and/or non-base reflective layers) and at least one constituent layer.

**[0115]** The optical element that can be or include a single or multilayer reflector or a multilayer filter. The optical element can function to modify the light that impinges thereupon so that structural color is imparted to the article, where the structural color corresponds substantially to the first wavelength range, the at least one peak, or a set of peaks. The optical element can also optionally include one or more additional layers (e.g., a protective layer, the textured layer, a polymer layer, and the like). The optical element can have a thickness of about 100 to about 1,500 nanometers, about 100 to about 1,200 nanometers, about 100 to about 700 nanometers, or of about 200 to about 500 nanometers.

**[0116]** The optical element can be an inorganic optical element, an organic optical element, or a mixed inorganic/organic optical element, where the layers (e.g., reflective layer, constituent layer) can be made of these types of materials. The organic optical element has at least one layer and that layer is made of an organic material. The organic material can include a polymer, such as those described herein. The organic material is made of a non-metal or non-metal oxide material. The organic material that does not include a metal or metal oxide. The organic material is made of a polymeric material that does not include a metal or metal oxide.

**[0117]** The inorganic optical element has at least one layer and that layer is made of a non-organic material. As described in detail herein, the non-organic material can be a metal or metal oxide. The non-organic material does not include any organic material.

**[0118]** The optical element can be a mixed inorganic/organic optical element, meaning that one or more of the layers can be made of an inorganic material, one or more layers can be made of an organic material, and/or one or more layers can be made of a layer of a mixture of inorganic and organic materials (e.g., a polymer include metal or metal oxide particles (e.g., micro- or nano-particles).

**[0119]** The optical element has a first side (including the outer surface) and a second side opposing the first side (including the opposing outer surface), where the first side or the second side is adjacent the article. For example, when the optical element is used in conjunction with a component having internally-facing and externally-facing surfaces, such as a film or a bladder, the first side of the optical element can be disposed on the internally-facing surface of the component, such as in the following order: second side of the optical element/core of the optical element/first side of the optical element/internally-facing surface of the compo-



ment/core of the component/externally-facing surface of the component. Alternatively, the second side the optical element can be disposed on the internally-facing surface of the component, such as in the following order: first side of the optical element/core of the optical element/second side of the optical element/internally-facing surface of the component/core of the component wall/externally-facing surface of the component. In another example, the first side of the optical element can be disposed on the externally-facing surface of the component, such as in the following order: internally-facing surface of the component/core of the component/externally-facing surface of the component/first side of the optical element/core of the optical element/second side of the optical element. Similarly, the second side of the optical element can be disposed on the externally-facing surface of the component, such as in the following order: internally-facing surface of the component/core of the component/externally-facing surface of the component/second side of the optical element/core of the optical element/first side of the optical element. In examples where the optional textured surface, the textured surface can be located at the interface between the surface of the component and a side of the optical element.

**[0120]** In regard to the components of the optical element, when the optical element is on and visible from an outside surface of the article, the base reflective layer is between the at least two constituent layers and the surface. When the optical element is on an inside surface of the article and is visible through an outside surface of the article, the at least two constituent layers are between the base reflective layer and the surface.

**[0121]** The optical element or layers or portions thereof (e.g., reflective layer, constituent layer) can be formed using known techniques such as physical vapor deposition, electron beam deposition, atomic layer deposition, molecular beam epitaxy, cathodic arc deposition, pulsed laser deposition, sputtering deposition (e.g., radio frequency, direct current, reactive, non-reactive), chemical vapor deposition, plasma-enhanced chemical vapor deposition, low pressure chemical vapor deposition and wet chemistry techniques such as layer-by-layer deposition, sol-gel deposition, Langmuir blodgett, and the like. The temperature of the first side can be adjusted using the technique to form the optical element and/or a separate system to adjust the temperature.

**[0122]** The optical element can comprise a single layer reflector or a multilayer reflector (e.g., reflective layer(s) and/or constituent layer(s)). The multilayer reflector can be configured to have a certain reflectivity at a given wavelength of light (or range of wavelengths) depending, at least in part, on the material selection, thickness and number of the layers of the multilayer reflector. In other words, one can carefully select the materials, thicknesses, and numbers of the layers of a multilayer reflector and optionally its interaction with one or more other layers, so that it can reflect a certain wavelength of light (e.g., wavelength range, at least one peak, set of peaks), to produce a desired structural color.

**[0123]** The optical element can include at least one reflective layer and at least two adjacent constituent layers, where the adjacent constituent layers (e.g., and the non-base reflective layer(s) when present) have different refractive indices. The difference in the index of refraction of adjacent layers of the constituent layer and the non-reflective layer when present can be about 0.0001 to about 50 percent, about 0.1 to about 40 percent, about 0.1 to about 30 percent, about 0.1

to about 20 percent, about 0.1 to about 10 percent (and other ranges there between (e.g., the ranges can be in increments of 0.0001 to 5 percent)). The index of refraction depends at least in part upon the material of the constituent and can range from about 1.3 to about 2.6.

**[0124]** The combination of the reflective(s) layer and the constituent layer(s) can include 2 to 20 layers, 2 to 15, 2 to 10 layer, 2 to 6 layers, or 2 to 4 layers. Each of the reflective layer(s) or the constituent layer(s) can have a thickness that is about one-fourth of the wavelength of light to be reflected to produce the desired structural color. Each of the reflective layer(s) or the constituent layer(s) can have a thickness of about 10 to about 500 nanometers or about 90 to about 200 nanometers. The optical element can have at least two constituent layers, where adjacent constituent layers have different thicknesses and optionally the same or different refractive indices.

**[0125]** The optical element can comprise a single layer filter or a multilayer filter. The multilayer filter destructively interferes with light that impinges upon the article, where the destructive interference of the light and optionally interaction with one or more other layers or structures of the optical element (e.g., a multilayer reflector, a textured structure) impart the structural color. In this regard, the layers of the multilayer filter can be designed (e.g., material selection, thickness, number of layer, and the like) so that certain wavelengths (e.g., wavelength range, at least one peak, a set of peaks) make up the structural color. In one example, the range of wavelengths of light can be limited to a range within plus or minus 30 percent of a wavelength (e.g., wavelength range, at least one peak, a set of peaks), or within plus or minus 20 percent of a wavelength, or within plus or minus 10 percent of a wavelength, or within plus or minus 5 percent of a wavelength. The range of wavelengths can be selected (e.g., wavelength range, at least one peak, a set of peaks) to produce a more iridescent structural color.

**[0126]** The reflective layer(s) and/or constituent layer(s) can include a single layer or multiple layers where each layer independently comprises a material selected from: the transition metals, the metalloids, the lanthanides, and the actinides, as well as nitrides, oxynitrides, sulfides, sulfates, selenides, and tellurides of these, as well as others described herein. The reflective layer(s) and/or constituent layer(s) can be titanium, aluminum, silver, zirconium, chromium, magnesium, silicon, gold, platinum, alloys thereof, and a combination thereof as well as oxides of each. The material for the constituent layer(s) can be selected to provide an index of refraction that when optionally combined with the other layers of the optical element achieves the desired result. One or more layers of the constituent layer can be made of liquid crystals. Each layer of the constituent layer can be made of liquid crystals. One or more layers of the constituent layer can be made of a material such as: silicon dioxide, titanium dioxide, zinc sulfide, magnesium fluoride, tantalum pentoxide, aluminum oxide, or a combination thereof. Each layer of the constituent layer can be made of a material such as: silicon dioxide, titanium dioxide, zinc sulfide, magnesium fluoride, tantalum pentoxide, aluminum oxide, or a combination thereof. To improve adhesion between layers, a metal layer is adjacent a metal oxide layer comprising the same metal. For example, Ti and TiO<sub>x</sub> can be positioned adjacent one another to improve adhesion.

**[0127]** The optical element can be uncolored (e.g., no pigments or dyes added to the structure or its layers), colored

(e.g., pigments and/or dyes are added to the structure or its layers (e.g., dark or black color)). The surface of the component upon which the optical element is disposed can be uncolored (e.g., no pigments or dyes added to the material), colored (e.g., pigments and/or dyes are added to the material (e.g., dark or black color)), reflective, and/or transparent (e.g., percent transmittance of about 75 percent or more).

**[0128]** The reflective layer(s) and/or the constituent layer(s) can be formed in a layer-by-layer manner, where each layer has a different index of refraction. Each of the reflective layer(s) and the constituent layer(s) can be formed using known techniques such as those described above and herein.

**[0129]** As mentioned above, the optical element can include one or more layers in addition to the reflective layer(s) and the constituent layer(s). The optical element has a first side (e.g., the side having a surface) and a second side (e.g., the side having a surface), where the first side or the second side is adjacent the surface of the component. The one or more other layers of the optical element can be on the first side and/or the second side of the optical element. For example, the optical element can include the top layer (e.g., non-stoichiometric metal layer), a protective layer and/or a polymeric layer such as a thermoplastic polymeric layer, where the protective layer and/or the polymeric layer can be on one or both of the first side and the second side of the optical element. One or more of the optional other layers can include a textured surface. Alternatively or in addition, one or more of the reflective layer(s) and/or one or more constituent layer(s) of the optical element can include a textured surface.

**[0130]** A protective layer can be disposed on the first and/or second side of the constituent layer to protect the constituent layer. The protective layer is more durable or more abrasion resistant than the constituent layer. The protective layer is optically transparent to visible light. The protective layer can be on the first side of the optical element to protect the constituent layer. All or a portion of the protective layer can include a dye or pigment in order to alter an appearance of the structural color. The protective layer can include silicon dioxide, glass, combinations of metal oxides, or mixtures of polymers. The protective layer can have a thickness of about 3 nanometers to about 1 millimeter.

**[0131]** The protective layer can be formed using physical vapor deposition, chemical vapor deposition, pulsed laser deposition, evaporative deposition, sputtering deposition (e.g., radio frequency, direct current, reactive, non-reactive), plasma enhanced chemical vapor deposition, electron beam deposition, cathodic arc deposition, low pressure chemical vapor deposition and wet chemistry techniques such as layer by layer deposition, sol-gel deposition, Langmuir blodgett, and the like. Alternatively or in addition, the protective layer can be applied by spray coating, dip coating, brushing, spin coating, doctor blade coating, and the like.

**[0132]** A polymeric layer can be disposed on the first and/or the second side of the optical element. The polymeric layer can be used to dispose the optical element onto an article, such as, for example, when the article does not include a thermoplastic material to adhere the optical element. The polymeric layer can comprise a polymeric adhesive material, such as a hot melt adhesive. The polymeric layer can be a thermoplastic material and can include one or more layers. The thermoplastic material can be any one of

the thermoplastic material described herein. The polymeric layer can be applied using various methodologies, such as spin coating, dip coating, doctor blade coating, and so on. The polymeric layer can have a thickness of about 3 nanometer to about 1 millimeter.

**[0133]** As described above, one or more embodiments of the present disclosure provide articles that incorporate the optical element (e.g., single or multilayer structures) on a side of a component of the article to impart structural color. The optical element can be disposed onto the thermoplastic material of the side of the article, and the side of the article can include a textile, including a textile comprising the thermoplastic material

**[0134]** Having described aspects, additional details will now be described for the optional textured surface. As described herein, the component includes the optical element and the optical element can include at least one reflective layer and at least one constituent layer and optionally a textured surface. The textured surface can be a surface of a textured structure or a textured layer. The textured surface may be provided as part of the optical element. For example, the optical element may comprise a textured layer or a textured structure that comprises the textured surface. The textured surface may be formed on the first or second side of the optical element. For example, a side of the reflective layer and/or the constituent layer may be formed or modified to provide a textured surface, or a textured layer or textured structure can be affixed to the first or second side of the optical element. The textured surface may be provided as part of the component to which the optical element is disposed. For example, the optical element may be disposed onto the surface of the component where the surface of the component is a textured surface, or the surface of the component includes a textured structure or a textured layer affixed to it.

**[0135]** The textured surface (or a textured structure or textured layer including the textured surface) may be provided as a feature on or part of another medium, such as a transfer medium, and imparted to a side or layer of the optical element or to the surface of the component. For example, a mirror image or relief form of the textured surface may be provided on the side of a transfer medium, and the transfer medium contacts a side of the optical element or the surface of the component in a way that imparts the textured surface to the optical element or article. While the various embodiments herein may be described with respect to a textured surface of the optical element, it will be understood that the features of the textured surface, or a textured structure or textured layer, may be imparted in any of these ways.

**[0136]** The textured surface can contribute to the structural color (e.g., corresponding substantially to the wavelength range, the at least one peak, the set of peaks) resulting from the optical element. As described herein, structural coloration is imparted, at least in part, due to optical effects caused by physical phenomena such as scattering, diffraction, reflection, interference or unequal refraction of light rays from an optical element. The textured surface (or its mirror image or relief) can include a plurality of profile features and flat or planar areas. The plurality of profile features included in the textured surface, including their size, shape, orientation, spatial arrangement, etc., can affect the light scattering, diffraction, reflection, interference and/or refraction resulting from the optical element. The flat or

planar areas included in the textured surface, including their size, shape, orientation, spatial arrangement, etc., can affect the light scattering, diffraction, reflection, interference and/or refraction resulting from the optical element. The desired structural color can be designed, at least in part, by adjusting one or more of properties of the profile features and/or flat or planar areas of the textured surface.

**[0137]** The profile features can extend from a side of the flat areas, so as to provide the appearance of projections and/or depressions therein. A flat area can be a flat planar area. A profile feature may include various combinations of projections and depressions. For example, a profile feature may include a projection with one or more depressions therein, a depression with one or more projections therein, a projection with one or more further projections thereon, a depression with one or more further depressions therein, and the like. The flat areas do not have to be completely flat and can include texture, roughness, and the like. The texture of the flat areas may not contribute much, if any, to the imparted structural color. The texture of the flat areas typically contributes to the imparted structural color. For clarity, the profile features and flat areas are described in reference to the profile features extending above the flat areas, but the inverse (e.g., dimensions, shapes, and the like) can apply when the profile features are depressions in the textured surface.

**[0138]** The textured surface can comprise a thermoplastic material. The profile features and the flat areas can be formed using a thermoplastic material. For example, when the thermoplastic material is heated above its softening temperature a textured surface can be formed in the thermoplastic material such as by molding, stamping, printing, compressing, cutting, etching, vacuum forming, etc., the thermoplastic material to form profile features and flat areas therein. The textured surface can be imparted on a side of a thermoplastic material. The textured surface can be formed in a layer of thermoplastic material. The profile features and the flat areas can be made of the same thermoplastic material or a different thermoplastic material.

**[0139]** The textured surface generally has a length dimension extending along an x-axis, and a width dimension extending along a z-axis, and a thickness dimension extending along a y-axis. The textured surface has a generally planar portion extending in a first plane that extends along the x-axis and the z-axis. A profile feature can extend outward from the first plane, so as to extend above or below the plane x. A profile feature may extend generally orthogonal to the first plane, or at an angle greater to or less than 90 degrees to the first plane.

**[0140]** The dimensional measurements in reference to the profile features (e.g., length, width, height, diameter, and the like) described herein refer to an average dimensional measurement of profile features in 1 square centimeter in the optical element.

**[0141]** The dimension (e.g., length, width, height, diameter, depending upon the shape of the profile feature) of each profile feature can be within the nanometer to micrometer range. A textured surface can have a profile feature and/or flat area with a dimension of about 10 nanometers to about 500 micrometers. The profile feature can have dimensions in the nanometer range, e.g., from about 10 nanometers to about 1000 nanometers. All of the dimensions of the profile feature (e.g., length, width, height, diameter, depending on the geometry) can be in the nanometer range, e.g., from

about 10 nanometers to about 1000 nanometers. The textured surface can have a plurality of profile features having dimensions that are 1 micrometer or less. In this context, the phrase “plurality of the profile features” is meant to mean that about 50 percent or more, about 60 percent or more, about 70 percent or more, about 80 percent or more, about 90 percent or more, or about 99 percent or more of the profile features have a dimension in this range. The profile features can have a ratio of width:height and/or length: height dimensions of about 1:2 and 1:100, or 1:5 and 1:50, or 1:5 and 1:10.

**[0142]** The textured surface can have a profile feature and/or flat area with a dimension within the micrometer range of dimensions. A textured surface can have a profile feature and/or flat area with a dimension of about 1 micrometer to about 500 micrometers. All of the dimensions of the profile feature (e.g., length, width, height, diameter, depending on the geometry) can be in the micrometer range, e.g., from about 1 micrometer to about 500 micrometers. The textured surface can have a plurality of profile features having dimensions that are from about 1 micrometer to about 500 micrometer. In this context, the phrase “plurality of the profile features” is meant to mean that about 50 percent or more, about 60 percent or more, about 70 percent or more, about 80 percent or more, about 90 percent or more, or about 99 percent or more of the profile features have a dimension in this range. The height of the profile features (or depth if depressions) can be about 0.1 and 50 micrometers, about 1 to 5 micrometers, or 2 to 3 micrometers. The profile features can have a ratio of width:height and/or length: height dimensions of about 1:2 and 1:100, or 1:5 and 1:50, or 1:5 and 1:10.

**[0143]** A textured surface can have a plurality of profile features having a mixture of size dimensions within the nanometer to micrometer range (e.g., a portion of the profile features are on the nanometer scale and a portion of the profile features are on the micrometer scale). A textured surface can have a plurality of profile features having a mixture of dimensional ratios. The textured surface can have a profile feature having one or more nanometer-scale projections or depressions on a micrometer-scale projection or depression.

**[0144]** The profile feature can have height and width dimensions that are within a factor of three of each other ( $0.33 w \leq h \leq 3 w$  where  $w$  is the width and  $h$  is the height of the profile feature) and/or height and length dimensions that are within a factor of three of each other ( $0.33 l \leq h \leq 3 l$  where  $l$  is the length and  $h$  is the height of the profile feature). The profile feature can have a ratio of length:width that is from about 1:3 to about 3:1, or about 1:2 to about 2:1, or about 1:1.5 to about 1.5:1, or about 1:1.2 to about 1.2:1, or about 1:1. The width and length of the profile features can be substantially the same or different.

**[0145]** In another aspect, the textured surface can have a profile feature and/or flat area with at least one dimension in the mid-micrometer range and higher (e.g., greater than 500 micrometers). The profile feature can have at least one dimension (e.g., the largest dimension such as length, width, height, diameter, and the like depending upon the geometry or shape of the profile feature) of greater than 500 micrometers, greater than 600 micrometers, greater than 700 micrometers, greater than 800 micrometers, greater than 900 micrometers, greater than 1000 micrometers, greater than 2 millimeters, greater than 10 millimeters, or more. For

example, the largest dimension of the profile feature can range from about 600 micrometers to about 2000 micrometers, or about 650 micrometers to about 1500 micrometers, or about 700 micrometers to about 1000 micrometers. At least one or more of the dimensions of the profile feature (e.g., length, width, height, diameter, depending on the geometry) can be in the micrometer range, while one or more of the other dimensions can be in the nanometer to micrometer range (e.g., less than 500 micrometers, less than 100 micrometers, less than 10 micrometers, or less than 1 micrometer). The textured surface can have a plurality of profile features having at least one dimension that is in the mid-micrometer or more range (e.g., 500 micrometers or more). In this context, the phrase “plurality of the profile features” is meant to mean that about 50 percent or more, about 60 percent or more, about 70 percent or more, about 80 percent or more, about 90 percent or more, or about 99 percent or more of the profile features have at least one dimension that is greater than 500 micrometers. In particular, at least one of the length and width of the profile feature is greater than 500 micrometers or both the length and the width of the profile feature is greater than 500 micrometers. In another example, the diameter of the profile feature is greater than 500 micrometers. In another example, when the profile feature is an irregular shape, the longest dimension is greater than 500 micrometers.

**[0146]** In aspects, the height of the profile features can be greater than 50 micrometers. In this context, the phrase “plurality of the profile features” is meant to mean that about 50 percent or more, about 60 percent or more, about 70 percent or more, about 80 percent or more, about 90 percent or more, or about 99 percent or more of the profile features have at height that is greater than 50 micrometers. The height of the profile feature can be 50 micrometers, about 60 micrometers, about 70 micrometers, about 80 micrometers, about 90 micrometers, or about 100 micrometers to about 60 micrometers, about 70 micrometers, about 80 micrometers, about 90 micrometers, about 100 micrometers, about 150 micrometers, about 250 micrometers, about 500 micrometers or more. For example, the ranges can include 50 micrometers to 500 micrometers, about 60 micrometers to 250 micrometers, about 60 micrometers to about 150 micrometers, and the like. One or more of the other dimensions (e.g., length, width, diameter, or the like) can be in the nanometer to micrometer range (e.g., less than 500 micrometers, less than 100 micrometers, less than 10 micrometers, or less than 1 micrometer). In particular, at least one of the length and width of the profile feature is less than 500 micrometers or both the length and the width of the profile feature is less than 500 micrometers, while the height is greater than 50 micrometers. One or more of the other dimensions (e.g., length, width, diameter, or the like) can be in the micrometer to millimeter range (e.g., greater than 500 micrometers to 10 millimeters).

**[0147]** The dimension (e.g., length, width, height, diameter, depending upon the shape of the profile feature) of each profile feature can be within the nanometer to micrometer range. The textured surface can have a profile feature and/or flat area with a dimension of about 10 nanometers to about 500 micrometers or higher (e.g., about 1 millimeter, about 2 millimeters, about 5 millimeters, or about 10 millimeters). At least one of the dimensions of the profile feature (e.g., length, width, height, diameter, depending on the geometry) can be in the nanometer range (e.g., from about 10 nano-

micrometers to about 1000 nanometers), while at least one other dimension (e.g., length, width, height, diameter, depending on the geometry) can be in the micrometer range (e.g., 5 micrometers to 500 micrometers or more (e.g., about 1 to 10 millimeters)). The textured surface can have a plurality of profile features having at least one dimension in the nanometer range (e.g., about 10 to 1000 nanometers) and the other in the micrometer range (e.g., 5 micrometers to 500 micrometers or more). In this context, the phrase “plurality of the profile features” is meant to mean that about 50 percent or more, about 60 percent or more, about 70 percent or more, about 80 percent or more, about 90 percent or more, or about 99 percent or more of the profile features have at least one dimension in the nanometer range and at least one dimension in the micrometer range. In particular, at least one of the length and width of the profile feature is in the nanometer range, while the other of the length and the width of the profile feature is in the micrometer range.

**[0148]** In aspects, the height of the profile features can be greater than 250 nanometers. In this context, the phrase “plurality of the profile features” is meant to mean that about 50 percent or more, about 60 percent or more, about 70 percent or more, about 80 percent or more, about 90 percent or more, or about 99 percent or more of the profile features have at height that is greater than 250 nanometers. The height of the profile feature can be 250 nanometers, about 300 nanometers, about 400 nanometers, or about 500 nanometers, to about 300 nanometers, about 400 nanometers, about 500 nanometers, or about 1000 nanometers or more. For example, the range can be 250 nanometers to about 1000 nanometers, about 300 nanometers to 500 nanometers, about 400 nanometers to about 1000 nanometers, and the like. One or more of the other dimensions (e.g., length, width, diameter, or the like) can be in the micrometer to millimeter range (e.g., greater than 500 micrometers to 10 millimeters). In particular, at least one of the length and width of the profile feature is in the nanometer range (e.g., about 10 to 1000 nanometers) and the other in the micrometer range (e.g., 5 micrometers to 500 micrometers or more), while the height is greater than 250 nanometers.

**[0149]** The profile features can have a certain spatial arrangement. The spatial arrangement of the profile features may be uniform, such as spaced evenly apart or forming a pattern. The spatial arrangement can be random. Adjacent profile features can be about 10 to 500 nanometers apart, about 100 to 1000 nanometers apart, about 1 to 100 micrometers apart or about 5 to 100 micrometers apart. Adjacent profile features can overlap one another or be adjacent one another so little or no flat regions are positioned there between. The desired spacing can depend, at least in part, on the size and/or shape of the profile structures and the desired structural color effect.

**[0150]** The profile features can have a certain cross-sectional shape (with respect to a plane parallel the first plane). The textured surface can have a plurality of profile features having the same or similar cross-sectional shape. The textured surface has a plurality of profile features having a mixture of different cross-sectional shapes. The cross-sectional shapes of the profile features can include polygonal (e.g., square or triangle or rectangle cross section), circular, semi-circular, tubular, oval, random, high and low aspect ratios, overlapping profile features, and the like.

**[0151]** The profile feature (e.g., about 10 nanometers to 500 micrometers) can include an upper, flat surface. The

profile feature (e.g., about 10 nanometers to 500 micrometers) can include an upper, concavely curved surface. The concave curved surface may extend symmetrically either side of an uppermost point. The concave curved surface may extend symmetrically across only 50 percent of the uppermost point. The profile feature (e.g., about 10 nanometers to 500 micrometers) can include an upper, convexly curved surface. The curved surface may extend symmetrically either side of an uppermost point. The curved surface may extend symmetrically across only 50 percent of the uppermost point.

**[0152]** The profile feature can include protrusions from the textured surface. The profile feature can include indents (hollow areas) formed in the textured surface. The profile feature can have a smooth, curved shape (e.g., a polygonal cross-section with curved corners).

**[0153]** The profile features (whether protrusions or depressions) can be approximately conical or frusto-conical (i.e. the projections or indents may have horizontally or diagonally flattened tops) or have an approximately part-spherical surface (e.g., a convex or concave surface respectively having a substantially even radius of curvature).

**[0154]** The profile features may have one or more sides or edges that extend in a direction that forms an angle to the first plane of the textured surface. The angle between the first plane and a side or edge of the profile feature is about 45 degrees or less, about 30 degrees or less, about 25 degrees or less, or about 20 degrees or less. The one or more sides or edges may extend in a linear or planar orientation, or may be curved so that the angle changes as a function of distance from the first plane. The profile features may have one or more sides that include step(s) and/or flat side(s). The profile feature can have one or more sides (or portions thereof) that can be orthogonal or perpendicular to the first plane of the textured surface, or extend at an angle of about 10 degrees to 89 degrees to the first plane (90 degrees being perpendicular or orthogonal to the first plane)). The profile feature can have a side with a stepped configuration, where portions of the side can be parallel to the first plane of the textured surface or have an angle of about 1 degrees to 179 degrees (0 degrees being parallel to the first plane)).

**[0155]** The textured surface can have profile features with varying shapes (e.g., the profile features can vary in shape, height, width and length among the profile features) or profile features with substantially uniform shapes and/or dimensions. The structural color produced by the textured surface can be determined, at least in part, by the shape, dimensions, spacing, and the like, of the profile features.

**[0156]** The profile features can be shaped so as to result in a portion of the surface (e.g., about 25 to 50 percent or more) being about normal to the incoming light when the light is incident at the normal to the first plane of the textured surface. The profile features can be shaped so as to result in a portion of the surface (e.g., about 25 to 50 percent or more) being about normal to the incoming light when the light is incident at an angle of up to 45 degrees to the first plane of the textured surface.

**[0157]** The spatial orientation of the profile features on the textured surface can be used to produce the structural color, or to effect the degree to which the structural color shifts at different viewing angles. The spatial orientation of the profile features on the textured surface can be random, a semi-random pattern, or in a set pattern. A set pattern of profile features is a known set up or configuration of profile

features in a certain area (e.g., about 50 nanometers squared to about 10 millimeters squared depending upon the dimensions of the profile features (e.g., any increment between about 50 nanometers and about 10 millimeters is included)). A semi-random pattern of profile features is a known set up of profile features in a certain area (e.g., about 50 nanometers squared to 10 millimeters squared) with some deviation (e.g., 1 to 15% deviation from the set pattern), while random profile features are present in the area but the pattern of profile features is discernable. A random spatial orientation of the profile features in an area produces no discernable pattern in a certain area, (e.g., about 50 nanometers squared to 10 millimeters squared).

**[0158]** The spatial orientation of the profile features can be periodic (e.g., full or partial) or non-periodic. A periodic spatial orientation of the profile features is a recurring pattern at intervals. The periodicity of the periodic spatial orientation of the profile features can depend upon the dimensions of the profile features but generally are periodic from about 50 nanometers to 100 micrometers. For example, when the dimensions of the profile features are submicron, the periodicity of the periodic spatial orientation of the profile features can be in the 50 to 500 nanometer range or 100 to 1000 nanometer range. In another example, when the dimensions of the profile features are at the micron level, the periodicity of the periodic spatial orientation of the profile features can be in the 10 to 500 micrometer range or 10 to 1000 micrometer range. Full periodic pattern of profile features indicates that the entire pattern exhibits periodicity, whereas partial periodicity indicates that less than all of the pattern exhibits periodicity (e.g., about 70-99 percent of the periodicity is retained). A non-periodic spatial orientation of profile features is not periodic and does not show periodicity based on the dimensions of the profile features, in particular, no periodicity in the 50 to 500 nanometer range or 100 to 1000 nanometer range where the dimensions are of the profile features are submicron or no periodicity in the 10 to 500 micrometer range or 10 to 1000 micrometer range where the dimensions are of the profile features are in the micron range.

**[0159]** In an aspect, the spatial orientation of the profile features on the textured surface can be set to reduce distortion effects, e.g., caused by the interference of one profile feature with another in regard to the structural color of the article. Since the shape, dimension, relative orientation of the profile features can vary considerably across the textured surface, the desired spacing and/or relative positioning for a particular area (e.g., in the micrometer range or about 1 to 10 square micrometers) having profile features can be appropriately determined. As discussed herein, the shape, dimension, relative orientation of the profile features affect the contours of the reflective layer(s) and/or constituent layer(s), so the dimensions (e.g., thickness), index of refraction, number of layers in the optical element (e.g., reflective layer(s) and constituent layer(s)) are considered when designing the textured side of the texture layer.

**[0160]** The profile features are located in nearly random positions relative to one another across a specific area of the textured surface (e.g., in the micrometer range or about 1 to 10 square micrometers to centimeter range or about 0.5 to 5 square centimeters, and all range increments therein), where the randomness does not defeat the purpose of producing the structural color. In other words, the randomness is consistent with the spacing, shape, dimension, and relative orientation

of the profile features, the dimensions (e.g., thickness), index of refraction, and number of layers (e.g., the reflective layer(s), the constituent layer(s), and the like, with the goal to achieve the structural color.

**[0161]** The profile features are positioned in a set manner relative to one another across a specific area of the textured surface to achieve the purpose of producing the structural color. The relative positions of the profile features do not necessarily follow a pattern, but can follow a pattern consistent with the desired structural color. As mentioned above and herein, various parameters related to the profile features, flat areas, and reflective layer(s) and/or the constituent layer can be used to position the profile features in a set manner relative to one another.

**[0162]** The textured surface can include micro and/or nanoscale profile features that can form gratings (e.g., a diffractive grating), photonic crystal structure, a selective mirror structure, crystal fiber structures, deformed matrix structures, spiraled coiled structures, surface grating structures, and combinations thereof. The textured surface can include micro and/or nanoscale profile features that form a grating having a periodic or non-periodic design structure to impart the structural color. The micro and/or nanoscale profile features can have a peak-valley pattern of profile features and/or flat areas to produce the desired structural color. The grating can be an Echelette grating.

**[0163]** The profile features and the flat areas of the textured surface in the optical element can appear as topographical undulations in each layer (e.g., reflective layer(s) and/or the constituent layer(s)). For example, referring to FIG. 2A, an optical element 200 includes a textured structure 220 having a plurality of profile features 222 and flat areas 224. As described herein, one or more of the profile features 222 can be projections from a surface of the textured structure 220, and/or one or more of the profile features can be depressions in a surface of the textured structure 220 (not shown). One or more constituent layers 240 are disposed on the textured structure 220 and then a reflective layer 230 and one or more constituent layers 245 are disposed on the preceding layers. In some embodiments, the resulting topography of the textured structure 220 and the one or more constituent layers 240 and 245 and the reflective layer 230 are not identical, but rather, the one or more constituent layers 240 and 245 and the reflective layer 230 can have elevated or depressed regions 242 which are either elevated or depressed relative to the height of the planar regions 244 and which roughly correspond to the location of the profile features 222 of the textured structure 220. The one or more constituent layers 240 and 245 and the reflective layer 230 have planar regions 244 that roughly correspond to the location of the flat areas 224 of the textured structure 220. Due to the presence of the elevated or depressed regions 242 and the planar regions 244, the resultant overall topography of the one or more constituent layers 240 and 245 and the reflective layer 230 can be that of an undulating or wave-like structure. The dimension, shape, and spacing of the profile features along with the number of layers of the constituent layer, the reflective layer, the thickness of each of the layers, refractive index of each layer, and the type of material, can be used to produce an optical element which results in a particular structural color.

**[0164]** While the textured surface can produce the structural color in some embodiments, or can affect the degree to which the structural color shifts at different viewing angles,

in other embodiments, a “textured surface” or surface with texture may not produce the structural color, or may not affect the degree to which the structural color shifts at different viewing angles. The structural color can be produced by the design of the optical element with or without the textured surface. As a result, the optical element can include the textured surface having profile elements of dimensions in the nanometer to millimeter range, but the structural color or the shifting of the structural color is not attributable to the presence or absence of the textured surface. In other words, the optical element imparts the same structural color where or not the textured surface is present. The design of the textured surface can be configured to not affect the structural color imparted by the optical element, or not affect the shifting of the structural color imparted by the optical element. The shape of the profile features, dimensions of the shapes, the spatial orientation of the profile features relative to one another, and the like can be selected so that the textured surface does not affect the structural color attributable to the optical element.

**[0165]** The structural color imparted by a first optical element and a second optical element, where the only difference between the first and second optical element is that the first optical element includes the textured surface, can be compared. A color measurement can be performed for each of the first and second optical element at the same relative angle, where a comparison of the color measurements can determine what, if any, change is correlated to the presence of the textured surface. For example, at a first observation angle the structural color is a first structural color for the first optical element and at first observation angle the structural color is a second structural color for the second optical element. The first color measurement can be obtained and has coordinates  $L_1^*$  and  $a_1^*$  and  $b_1^*$ , while a second color measurement can be obtained and has coordinates  $L_2^*$  and  $a_2^*$  and  $b_2^*$  can be obtained, according to the CIE 1976 color space under a given illumination condition.

**[0166]** When  $\Delta E_{ab}^*$  between the first color measurement and the second color measurement is less than or equal to about 2.2 or is less than or equal to about 3, the first structural color associated with the first color measurement and the second structural color associated with the second color measurement are the same or not perceptibly different to an average observer (e.g., the textured surface does not cause or change the structural color by more than 20 percent, 10 percent, or 5 percent). When  $\Delta E_{ab}^*$  between the first color measurement and the second color measurement is greater than 3 or optionally greater than about 4 or 5, the first structural color associated with the first color measurement and the second structural color associated with the second color measurement are different or perceptibly different to an average observer (e.g., the textured surface does cause or change the structural color by more than 20 percent, 10 percent, or 5 percent).

**[0167]** In another approach, when the percent difference between one or more of values  $L_1^*$  and  $L_2^*$ ,  $a_1^*$  and  $a_2^*$ , and  $b_1^*$  and  $b_2^*$  is less than 20 percent, the first structural color associated with the first color measurement and the second structural color associated with the second color measurement are the same or not perceptibly different to an average observer (e.g., the textured surface does not cause or change the structural color by less than 20 percent, 10 percent, or 5 percent). When the percent difference between one or more of values  $L_1^*$  and  $L_2^*$ ,  $a_1^*$  and  $a_2^*$ , and  $b_1^*$  and  $b_2^*$  is greater

than 20 percent, the first structural color associated with the first color measurement and the second structural color associated with the second color measurement are different or perceptibly different to an average observer (e.g., the textured surface does cause or change the structural color by more than 20 percent, 10 percent, or 5 percent).

**[0168]** In another case, the structural color imparted by a first optical element and a second optical element, where the only difference between the first and second optical element is that the first optical element includes the textured surface, can be compared at different angles of incident light upon the optical element or different observation angles. A color measurement can be performed for each of the first and second optical element at different angles (e.g., angle of about  $-15$  and  $180$  degrees or about  $-15$  degrees and  $+60$  degrees and which are at least  $15$  degrees apart from each other), where a comparison of the color measurements can determine what, if any, change is correlated to the presence of the textured surface at different angles. For example, at a first observation angle the structural color is a first structural color for the first optical element and at second observation angle the structural color is a second structural color for the second optical element. The first color measurement can be obtained and has coordinates  $L_1^*$  and  $a_1^*$  and  $b_1^*$ , while a second color measurement can be obtained and has coordinates  $L_2^*$  and  $a_2^*$  and  $b_2^*$  can be obtained, according to the CIE 1976 color space under a given illumination condition.

**[0169]** When  $\Delta E_{ab}^*$  between the first color measurement and the second color measurement is less than or equal to about 2.2 or is less than or equal to about 3, the first structural color associated with the first color measurement and the second structural color associated with the second color measurement are the same or not perceptibly different to an average observer (e.g., the textured surface does not cause or change the structural color based on different angles of incident light upon the optical element or different observation angles). When  $\Delta E_{ab}^*$  between the first color measurement and the second color measurement is greater than 3 or optionally greater than about 4 or 5, the first structural color associated with the first color measurement and the second structural color associated with the second color measurement are different or perceptibly different to an average observer (e.g., the textured surface does cause or change the structural color at different angles of incident light upon the optical element or different observation angles).

**[0170]** In another approach, when the percent difference between one or more of values  $L_1^*$  and  $L_2^*$ ,  $a_1^*$  and  $a_2^*$ , and  $b_1^*$  and  $b_2^*$  is less than 20 percent, the first structural color associated with the first color measurement and the second structural color associated with the second color measurement are the same or not perceptibly different to an average observer (e.g., the textured surface does not cause or change the structural color by more than 20 percent, 10 percent, or 5 percent at different angles of incident light upon the optical element or different observation angles). When the percent difference between one or more of values  $L_1^*$  and  $L_2^*$ ,  $a_1^*$  and  $a_2^*$ , and  $b_1^*$  and  $b_2^*$  is greater than 20 percent, the first structural color associated with the first color measurement and the second structural color associated with the second color measurement are different or perceptibly different to an average observer (e.g., the textured surface does cause or change the structural color by more than 20 percent, 10

percent, or 5 percent at different angles of incident light upon the optical element or different observation angles).

**[0171]** In another embodiment, the structural color can be imparted by the optical element without the textured surface. The surface of the layers of the optical element are substantially flat (or substantially three dimensional flat planar surface) or flat (or three dimensional flat planar surface) at the microscale (e.g., about 1 to 500 micrometers) and/or nanoscale (e.g., about 50 to 500 nanometers). In regard to substantially flat or substantially planar the surface can include some minor topographical features (e.g., nanoscale and/or microscale) such as those that might be caused due to unintentional imperfections, slight undulations that are unintentional, other topographical features (e.g., extensions above the plane of the layer or depressions below or into the plane of the layer) caused by the equipment and/or process used and the like that are unintentionally introduced. The topographical features do not resemble profile features of the textured surface. In addition, the substantially flat (or substantially three dimensional flat planar surface) or flat (or three dimensional flat planar surface) may include curvature as the dimensions of the optical element increase, for example about 500 micrometers or more, about 10 millimeter or more, about 10 centimeters or more, depending upon the dimensions of the optical element, as long as the surface is flat or substantially flat and the surface only includes some minor topographical features.

**[0172]** FIG. 2B is a cross-section illustration of a substantially flat (or substantially three dimensional flat planar surface) or flat (or three dimensional flat planar surface) optical element **300**. The optical element **300** includes one or more constituent layers **340** are disposed on the flat or three dimensional flat planar surface structure **320** and then a reflective layer **330** and one or more constituent layers **345** are disposed on the preceding layers. The material that makes up the constituent layers and the reflective layer, number of layers of the constituent layer, the reflective layer, the thickness of each of the layers, refractive index of each layer, and the like, can produce an optical element which results in a particular structural color. Additional details are provided regarding the polymeric materials referenced herein for example, the polymers described in reference to the article, components of the article, structures, layers, films, bladders, foams, primer layer, coating, and like the. The polymeric material includes at least one polymer. The polymer can be a thermoset polymer or a thermoplastic polymer. The polymer can be an elastomeric polymer, including an elastomeric thermoset polymer or an elastomeric thermoplastic polymer. The polymer can be selected from: polyurethanes (including elastomeric polyurethanes, thermoplastic polyurethanes (TPUs), and elastomeric TPUs), polyesters, polyethers, polyamides, vinyl polymers (e.g., copolymers of vinyl alcohol, vinyl esters, ethylene, acrylates, methacrylates, styrene, and so on), polyacrylonitriles, polyphenylene ethers, polycarbonates, polyureas, polystyrenes, co-polymers thereof (including polyester-polyurethanes, polyether-polyurethanes, polycarbonate-polyurethanes, polyether block polyamides (PEBAs), and styrene block copolymers), and any combination thereof, as described herein. The polymer can include one or more polymers selected from the group consisting of polyesters, polyethers, polyamides, polyurethanes, polyolefins copolymers of each, and combinations thereof.

**[0173]** The term “polymer” refers to a chemical compound formed of a plurality of repeating structural units referred to as monomers. Polymers often are formed by a polymerization reaction in which the plurality of structural units become covalently bonded together. When the monomer units forming the polymer all have the same chemical structure, the polymer is a homopolymer. When the polymer includes two or more monomer units having different chemical structures, the polymer is a copolymer. One example of a type of copolymer is a terpolymer, which includes three different types of monomer units. The co-polymer can include two or more different monomers randomly distributed in the polymer (e.g., a random co-polymer). Alternatively, one or more blocks containing a plurality of a first type of monomer can be bonded to one or more blocks containing a plurality of a second type of monomer, forming a block copolymer. A single monomer unit can include one or more different chemical functional groups.

**[0174]** Polymers having repeating units which include two or more types of chemical functional groups can be referred to as having two or more segments. For example, a polymer having repeating units of the same chemical structure can be referred to as having repeating segments. Segments are commonly described as being relatively harder or softer based on their chemical structures, and it is common for polymers to include relatively harder segments and relatively softer segments bonded to each other in a single monomeric unit or in different monomeric units. When the polymer includes repeating segments, physical interactions or chemical bonds can be present within the segments or between the segments or both within and between the segments. Examples of segments often referred to as hard segments include segments including a urethane linkage, which can be formed from reacting an isocyanate with a polyol to form a polyurethane. Examples of segments often referred to as soft segments include segments including an alkoxy functional group, such as segments including ether or ester functional groups, and polyester segments. Segments can be referred to based on the name of the functional group present in the segment (e.g., a polyether segment, a polyester segment), as well as based on the name of the chemical structure which was reacted in order to form the segment (e.g., a polyol-derived segment, an isocyanate-derived segment). When referring to segments of a particular functional group or of a particular chemical structure from which the segment was derived, it is understood that the polymer can contain up to 10 mole percent of segments of other functional groups or derived from other chemical structures. For example, as used herein, a polyether segment is understood to include up to 10 mole percent of non-polyether segments.

**[0175]** As previously described, the polymer can be a thermoplastic polymer. In general, a thermoplastic polymer softens or melts when heated and returns to a solid state when cooled. The thermoplastic polymer transitions from a solid state to a softened state when its temperature is increased to a temperature at or above its softening temperature, and a liquid state when its temperature is increased to a temperature at or above its melting temperature. When sufficiently cooled, the thermoplastic polymer transitions from the softened or liquid state to the solid state. As such, the thermoplastic polymer may be softened or melted, molded, cooled, re-softened or re-melted, re-molded, and cooled again through multiple cycles. For amorphous thermoplastic polymers, the solid state is understood to be the

“rubbery” state above the glass transition temperature of the polymer. The thermoplastic polymer can have a melting temperature from about 90 degrees C. to about 190 degrees C. when determined in accordance with ASTM D3418-97 as described herein below, and includes all subranges therein in increments of 1 degree. The thermoplastic polymer can have a melting temperature from about 93 degrees C. to about 99 degrees C. when determined in accordance with ASTM D3418-97 as described herein below. The thermoplastic polymer can have a melting temperature from about 112 degrees C. to about 118 degrees C. when determined in accordance with ASTM D3418-97 as described herein below.

**[0176]** The glass transition temperature is the temperature at which an amorphous polymer transitions from a relatively brittle “glassy” state to a relatively more flexible “rubbery” state. The thermoplastic polymer can have a glass transition temperature from about -20 degrees C. to about 30 degrees C. when determined in accordance with ASTM D3418-97 as described herein below. The thermoplastic polymer can have a glass transition temperature (from about -13 degree C. to about -7 degrees C. when determined in accordance with ASTM D3418-97 as described herein below. The thermoplastic polymer can have a glass transition temperature from about 17 degrees C. to about 23 degrees C. when determined in accordance with ASTM D3418-97 as described herein below.

**[0177]** The thermoplastic polymer can have a melt flow index from about 10 to about 30 cubic centimeters per 10 minutes (cm<sup>3</sup>/10 min) when tested in accordance with ASTM D1238-13 as described herein below at 160 degrees C. using a weight of 2.16 kilograms (kg). The thermoplastic polymer can have a melt flow index from about 22 cm<sup>3</sup>/10 min to about 28 cm<sup>3</sup>/10 min when tested in accordance with ASTM D1238-13 as described herein below at 160 degrees C. using a weight of 2.16 kg.

**[0178]** The thermoplastic polymer can have a cold Ross flex test result of about 120,000 to about 180,000 cycles without cracking or whitening when tested on a thermoformed plaque of the thermoplastic polymer in accordance with the cold Ross flex test as described herein below. The thermoplastic polymer can have a cold Ross flex test result of about 140,000 to about 160,000 cycles without cracking or whitening when tested on a thermoformed plaque of the thermoplastic polymer in accordance with the cold Ross flex test as described herein below.

**[0179]** The thermoplastic polymer can have a modulus from about 5 megaPascals (MPa) to about 100 MPa when determined on a thermoformed plaque in accordance with ASTM D412-98 Standard Test Methods for Vulcanized Rubber and Thermoplastic Rubbers and Thermoplastic Elastomers-Tension with modifications described herein below. The thermoplastic polymer can have a modulus from about 20 MPa to about 80 MPa when determined on a thermoformed plaque in accordance with ASTM D412-98 Standard Test Methods for Vulcanized Rubber and Thermoplastic Rubbers and Thermoplastic Elastomers-Tension with modifications described herein below.

**[0180]** The polymer can be a thermoset polymer. As used herein, a “thermoset polymer” is understood to refer to a polymer which cannot be heated and melted, as its melting temperature is at or above its decomposition temperature. A “thermoset material” refers to a material which comprises at least one thermoset polymer. The thermoset polymer and/or



thermoset material can be prepared from a precursor (e.g., an uncured or partially cured polymer or material) using thermal energy and/or actinic radiation (e.g., ultraviolet radiation, visible radiation, high energy radiation, infrared radiation) to form a partially cured or fully cured polymer or material which no longer remains fully thermoplastic. In some cases, the cured or partially cured polymer or material may remain thermoelastic properties, in that it is possible to partially soften and mold the polymer or material at elevated temperatures and/or pressures, but it is not possible to melt the polymer or material. The curing can be promoted, for example, with the use of high pressure and/or a catalyst. In many examples, the curing process is irreversible since it results in cross-linking and/or polymerization reactions of the precursors. The uncured or partially cured polymers or materials can be malleable or liquid prior to curing. In some cases, the uncured or partially cured polymers or materials can be molded into their final shape, or used as adhesives. Once hardened, a thermoset polymer or material cannot be re-melted in order to be reshaped. The textured surface can be formed by partially or fully curing an uncured precursor material to lock in the textured surface.

#### Polyurethane

**[0181]** The polymer can be a polyurethane, such as a thermoplastic polyurethane (also referred to as “TPU”). Alternatively, the polymer can be a thermoset polyurethane. Additionally, polyurethane can be an elastomeric polyurethane, including an elastomeric TPU or an elastomeric thermoset polyurethane. The elastomeric polyurethane can include hard and soft segments. The hard segments can comprise or consist of urethane segments (e.g., isocyanate-derived segments). The soft segments can comprise or consist of alkoxy segments (e.g., polyol-derived segments including polyether segments, or polyester segments, or a combination of polyether segments and polyester segments). The polyurethane can comprise or consist essentially of an elastomeric polyurethane having repeating hard segments and repeating soft segments.

**[0182]** One or more of the polyurethanes can be produced by polymerizing one or more isocyanates with one or more polyols to produce polymer chains having carbamate linkages ( $\text{—N(CO)O—}$ ), where the isocyanate(s) each preferably include two or more isocyanate ( $\text{—NCO}$ ) groups per molecule, such as 2, 3, or 4 isocyanate groups per molecule (although, mono-functional isocyanates can also be optionally included, e.g., as chain terminating units).

**[0183]** Additionally, the isocyanates can also be chain extended with one or more chain extenders to bridge two or more isocyanates, increasing the length of the hard segment.

**[0184]** The term “aliphatic” refers to a saturated or unsaturated organic molecule or portion of a molecule that does not include a cyclically conjugated ring system having delocalized pi electrons. In comparison, the term “aromatic” refers to an organic molecule or portion of a molecule having a cyclically conjugated ring system with delocalized pi electrons, which exhibits greater stability than a hypothetical ring system having localized pi electrons.

**[0185]** Examples of suitable aliphatic diisocyanates for producing the polyurethane polymer chains include hexamethylene diisocyanate (HDI), isophorone diisocyanate (IPDI), butylenediisocyanate (BDI), bisisocyanatocyclohexylmethane (HMDI), 2,2,4-trimethylhexamethylene diisocyanate (TMDI), bisisocyanatomethylcyclohexane, bisiso-

cyanatomethyltricyclodecane, norbornane diisocyanate (NDI), cyclohexane diisocyanate (CHDI), 4,4'-dicyclohexylmethane diisocyanate (H12MDI), diisocyanatododecane, lysine diisocyanate, and combinations thereof.

**[0186]** The isocyanate-derived segments can include segments derived from aliphatic diisocyanate. A majority of the isocyanate-derived segments can comprise segments derived from aliphatic diisocyanates. At least 90% of the isocyanate-derived segments are derived from aliphatic diisocyanates. The isocyanate-derived segments can consist essentially of segments derived from aliphatic diisocyanates. The aliphatic diisocyanate-derived segments can be derived substantially (e.g., about 50 percent or more, about 60 percent or more, about 70 percent or more, about 80 percent or more, about 90 percent or more) from linear aliphatic diisocyanates. At least 80% of the aliphatic diisocyanate-derived segments can be derived from aliphatic diisocyanates that are free of side chains. The segments derived from aliphatic diisocyanates can include linear aliphatic diisocyanates having from 2 to 10 carbon atoms.

**[0187]** Examples of suitable aromatic diisocyanates for producing the polyurethane polymer chains include toluene diisocyanate (TDI), TDI adducts with trimethylolpropane (TMP), methylene diphenyl diisocyanate (MDI), xylene diisocyanate (XDI), tetramethylxylene diisocyanate (TMXDI), hydrogenated xylene diisocyanate (HXDI), naphthalene 1,5-diisocyanate (NDI), 1,5-tetrahydronaphthalene diisocyanate, para-phenylene diisocyanate (PPDI), 3,3'-dimethyldiphenyl-4, 4'-diisocyanate (DDDI), 4,4'-dibenzyl diisocyanate (DBDI), 4-chloro-1,3-phenylene diisocyanate, and combinations thereof. The polymer chains can be substantially free of aromatic groups.

**[0188]** The polyurethane polymer chains can be produced from diisocyanates including HMDI, TDI, MDI, H12 aliphatics, and combinations thereof. For example, the polyurethane can comprise one or more polyurethane polymer chains produced from diisocyanates including HMDI, TDI, MDI, H12 aliphatics, and combinations thereof.

**[0189]** Polyurethane chains which are at least partially crosslinked or which can be crosslinked, can be used in accordance with the present disclosure. It is possible to produce crosslinked or crosslinkable polyurethane chains by reacting multi-functional isocyanates to form the polyurethane. Examples of suitable triisocyanates for producing the polyurethane chains include TDI, HDI, and IPDI adducts with trimethylolpropane (TMP), uretdiones (i.e., dimerized isocyanates), polymeric MDI, and combinations thereof.

**[0190]** Examples of suitable chain extender polyols for producing the polyurethane include ethylene glycol, lower oligomers of ethylene glycol (e.g., diethylene glycol, triethylene glycol, and tetraethylene glycol), 1,2-propylene glycol, 1,3-propylene glycol, lower oligomers of propylene glycol (e.g., dipropylene glycol, tripropylene glycol, and tetrapropylene glycol), 1,4-butylene glycol, 2,3-butylene glycol, 1,6-hexanediol, 1,8-octanediol, neopentyl glycol, 1,4-cyclohexanedimethanol, 2-ethyl-1,6-hexanediol, 1-methyl-1,3-propanediol, 2-methyl-1,3-propanediol, dihydroxyalkylated aromatic compounds (e.g., bis(2-hydroxyethyl) ethers of hydroquinone and resorcinol, xylene-a,a-diols, bis(2-hydroxyethyl) ethers of xylene-a,a-diols, and combinations thereof.

**[0191]** In some examples of the polyurethane, the polyurethane includes a polyester group. The polyester group can be derived from the polyesterification of one or more

dihydric alcohols (e.g., ethylene glycol, 1,3-propylene glycol, 1,2-propylene glycol, 1,4-butanediol, 1,3-butanediol, 2-methylpentanediol, 1,5-diethylene glycol, 1,5-pentanediol, 1,5-hexanediol, 1,2-dodecanediol, cyclohexanedimethanol, and combinations thereof) with one or more dicarboxylic acids (e.g., adipic acid, succinic acid, sebacic acid, suberic acid, methyladipic acid, glutaric acid, pimelic acid, azelaic acid, thiodipropionic acid and citraconic acid and combinations thereof). The polyester group also can be derived from polycarbonate prepolymers, such as poly(hexamethylene carbonate) glycol, poly(propylene carbonate) glycol, poly(tetramethylene carbonate) glycol, and poly(nonanemethylene carbonate) glycol. Suitable polyesters can include, for example, polyethylene adipate (PEA), poly(1,4-butylene adipate), poly(tetramethylene adipate), poly(hexamethylene adipate), polycaprolactone, polyhexamethylene carbonate, poly(propylene carbonate), poly(tetramethylene carbonate), poly(nonanemethylene carbonate), and combinations thereof.

**[0192]** The polyurethane can include a polyether (e.g., a polyethylene oxide (PEO) group, a polyethylene glycol (PEG) group), a polyvinylpyrrolidone group, a polyacrylic acid group, or combinations thereof.

**[0193]** Optionally, the polyurethane can include an at least partially crosslinked polymeric network that includes polymer chains that are derivatives of polyurethane. The level of crosslinking can be such that the polyurethane retains thermoplastic properties (i.e., the crosslinked thermoplastic polyurethane can be melted and re-solidified under the processing conditions described herein). The crosslinked polyurethane can be a thermoset polymer. This crosslinked polymeric network can be produced by polymerizing one or more isocyanates with one or more polyamino compounds, polysulfhydryl compounds, or combinations thereof.

**[0194]** The polyurethane chain can be physically crosslinked to another polyurethane chain through e.g., nonpolar or polar interactions between the urethane or carbamate groups of the polymers (the hard segments)

**[0195]** The polyurethane can be a thermoplastic polyurethane composed of MDI, PTMO, and 1,4-butylene glycol, as described in U.S. Pat. No. 4,523,005. Commercially available polyurethanes suitable for the present use include, but are not limited to those under the tradename "SANCURE" (e.g., the "SANCURE" series of polymer such as "SANCURE" 20025F) or "TECOPHILIC" (e.g., TG-500, TG-2000, SP-80A-150, SP-93A-100, SP-60D-60) (Lubrizol, Countryside, Ill., USA), "PELLETHANE" 2355-85AIP and 2355-95AE (Dow Chemical Company of Midland, Mich., USA.), "ESTANE" (e.g., ALR G 500, or 58213; Lubrizol, Countryside, Ill., USA).

**[0196]** Polyamides

**[0197]** The polymer can comprise a polyamide, such as a thermoplastic polyamide, or a thermoset polyamide. The polyamide can be an elastomeric polyamide, including an elastomeric thermoplastic polyamide or an elastomeric thermoset polyamide. The polyamide can be a polyamide homopolymer having repeating polyamide segments of the same chemical structure. Alternatively, the polyamide can comprise a number of polyamide segments having different polyamide chemical structures (e.g., polyamide 6 segments, polyamide 11 segments, polyamide 12 segments, polyamide 66 segments, etc.). The polyamide segments having different chemical structure can be arranged randomly, or can be arranged as repeating blocks.

**[0198]** The polyamide can be a co-polyamide (i.e., a co-polymer including polyamide segments and non-polyamide segments). The polyamide segments of the co-polyamide can comprise or consist of polyamide 6 segments, polyamide 11 segments, polyamide 12 segments, polyamide 66 segments, or any combination thereof. The polyamide segments of the co-polyamide can be arranged randomly, or can be arranged as repeating segments. The polyamide segments can comprise or consist of polyamide 6 segments, or polyamide 12 segments, or both polyamide 6 segment and polyamide 12 segments. In the example where the polyamide segments of the co-polyamide include of polyamide 6 segments and polyamide 12 segments, the segments can be arranged randomly. The non-polyamide segments of the co-polyamide can comprise or consist of polyether segments, polyester segments, or both polyether segments and polyester segments. The co-polyamide can be a block co-polyamide, or can be a random co-polyamide. The copolyamide can be formed from the polycondensation of a polyamide oligomer or prepolymer with a second oligomer prepolymer to form a copolyamide (i.e., a co-polymer including polyamide segments. Optionally, the second prepolymer can be a hydrophilic prepolymer.

**[0199]** The polyamide can be a polyamide-containing block co-polymer. For example, the block co-polymer can have repeating hard segments, and repeating soft segments. The hard segments can comprise polyamide segments, and the soft segments can comprise non-polyamide segments. The polyamide-containing block co-polymer can be an elastomeric co-polyamide comprising or consisting of polyamide-containing block co-polymers having repeating hard segments and repeating soft segments. In block co-polymers, including block co-polymers having repeating hard segments and soft segments, physical crosslinks can be present within the segments or between the segments or both within and between the segments.

**[0200]** The polyamide itself, or the polyamide segment of the polyamide-containing block co-polymer can be derived from the condensation of polyamide prepolymers, such as lactams, amino acids, and/or diamino compounds with dicarboxylic acids, or activated forms thereof. The resulting polyamide segments include amide linkages ( $-(CO)NH-$ ). The term "amino acid" refers to a molecule having at least one amino group and at least one carboxyl group. Each polyamide segment of the polyamide can be the same or different.

**[0201]** The polyamide or the polyamide segment of the polyamide-containing block co-polymer can be derived from the polycondensation of lactams and/or amino acids.

**[0202]** Optionally, in order to increase the relative degree of hydrophilicity of the polyamide-containing block co-polymer, the polyamide can include a polyamide-polyether block copolymer segment.

**[0203]** The polyamide can comprise or consist essentially of a poly(ether-block-amide). The poly(ether-block-amide) can be formed from the polycondensation of a carboxylic acid terminated polyamide prepolymer and a hydroxyl terminated polyether prepolymer to form a poly(ether-block-amide).

**[0204]** Exemplary commercially available copolymers include, but are not limited to, those available under the tradenames of "VESTAMID" (Evonik Industries, Essen, Germany); "PLATAMID" (Arkema, Colombes, France), e.g., product code H2694; "PEBAX" (Arkema), e.g., prod-

uct code “PEBAX MH1657” and “PEBAX MV1074”; “PEBAX RNEW” (Arkema); “GRILAMID” (EMS-Chemie AG, Domat-Ems, Switzerland), or also to other similar materials produced by various other suppliers.

**[0205]** The polyamide can be physically crosslinked through, e.g., nonpolar or polar interactions between the polyamide groups of the polymers. In examples where the polyamide is a copolyamide, the copolyamide can be physically crosslinked through interactions between the polyamide groups, and optionally by interactions between the copolymer groups. When the co-polyamide is physically crosslinked through interactions between the polyamide groups, the polyamide segments can form the portion of the polymer referred to as the hard segment, and copolymer segments can form the portion of the polymer referred to as the soft segment. For example, when the copolyamide is a poly(ether-block-amide), the polyamide segments form the hard segments of the polymer, and polyether segments form the soft segments of the polymer. Therefore, in some examples, the polymer can include a physically crosslinked polymeric network having one or more polymer chains with amide linkages.

**[0206]** The polyamide segment of the co-polyamide can include polyamide-11 or polyamide-12 and the polyether segment can be a segment selected from the group consisting of polyethylene oxide, polypropylene oxide, and polytetramethylene oxide segments, and combinations thereof.

**[0207]** The polyamide can be partially or fully covalently crosslinked, as previously described herein. In some cases, the degree of crosslinking present in the polyamide is such that, when it is thermally processed, e.g., in the form of a yarn or fiber to form the articles of the present disclosure, the partially covalently crosslinked thermoplastic polyamide retains sufficient thermoplastic character that the partially covalently crosslinked thermoplastic polyamide is melted during the processing and re-solidifies. In other cases, the crosslinked polyamide is a thermoset polymer.

#### Polyesters

**[0208]** The polymers can comprise a polyester. The polyester can comprise a thermoplastic polyester, or a thermoset polyester. Additionally, the polyester can be an elastomeric polyester, including a thermoplastic polyester or a thermoset elastomeric polyester. The polyester can be formed by reaction of one or more carboxylic acids, or its ester-forming derivatives, with one or more bivalent or multivalent aliphatic, alicyclic, aromatic or araliphatic alcohols or a bisphenol. The polyester can be a polyester homopolymer having repeating polyester segments of the same chemical structure. Alternatively, the polyester can comprise a number of polyester segments having different polyester chemical structures (e.g., polyglycolic acid segments, polylactic acid segments, polycaprolactone segments, polyhydroxyalkanoate segments, polyhydroxybutyrate segments, etc.). The polyester segments having different chemical structure can be arranged randomly, or can be arranged as repeating blocks.

**[0209]** Exemplary carboxylic acids that can be used to prepare a polyester include, but are not limited to, adipic acid, pimelic acid, suberic acid, azelaic acid, sebacic acid, nonane dicarboxylic acid, decane dicarboxylic acid, undecane dicarboxylic acid, terephthalic acid, isophthalic acid, alkyl-substituted or halogenated terephthalic acid, alkyl-substituted or halogenated isophthalic acid, nitro-tereph-

thalic acid, 4,4'-diphenyl ether dicarboxylic acid, 4,4'-diphenyl thioether dicarboxylic acid, 4,4'-diphenyl sulfone-dicarboxylic acid, 4,4'-diphenyl alkylenedicarboxylic acid, naphthalene-2,6-dicarboxylic acid, cyclohexane-1,4-dicarboxylic acid and cyclohexane-1,3-dicarboxylic acid. Exemplary diols or phenols suitable for the preparation of the polyester include, but are not limited to, ethylene glycol, diethylene glycol, 1,3-propanediol, 1,4-butanediol, 1,6-hexanediol, 1,8-octanediol, 1,10-decanediol, 1,2-propanediol, 2,2-dimethyl-1,3-propanediol, 2,2,4-trimethylhexanediol, p-xylenediol, 1,4-cyclohexanediol, 1,4-cyclohexane dimethanol, and bis-phenol A.

**[0210]** The polyester can be a polybutylene terephthalate (PBT), a polytrimethylene terephthalate, a polyhexamethylene terephthalate, a poly-1,4-dimethylcyclohexane terephthalate, a polyethylene terephthalate (PET), a polyethylene isophthalate (PEI), a polyarylate (PAR), a polybutylene naphthalate (PBN), a liquid crystal polyester, or a blend or mixture of two or more of the foregoing.

**[0211]** The polyester can be a co-polyester (i.e., a copolymer including polyester segments and non-polyester segments). The co-polyester can be an aliphatic co-polyester (i.e., a co-polyester in which both the polyester segments and the non-polyester segments are aliphatic). Alternatively, the co-polyester can include aromatic segments. The polyester segments of the co-polyester can comprise or consist essentially of polyglycolic acid segments, polylactic acid segments, polycaprolactone segments, polyhydroxyalkanoate segments, polyhydroxybutyrate segments, or any combination thereof. The polyester segments of the co-polyester can be arranged randomly, or can be arranged as repeating blocks.

**[0212]** For example, the polyester can be a block copolyester having repeating blocks of polymeric units of the same chemical structure which are relatively harder (hard segments), and repeating blocks of the same chemical structure which are relatively softer (soft segments). In block copolyesters, including block copolyesters having repeating hard segments and soft segments, physical crosslinks can be present within the blocks or between the blocks or both within and between the blocks. The polymer can comprise or consist essentially of an elastomeric copolyester having repeating blocks of hard segments and repeating blocks of soft segments.

**[0213]** The non-polyester segments of the co-polyester can comprise or consist essentially of polyether segments, polyamide segments, or both polyether segments and polyamide segments. The co-polyester can be a block copolyester, or can be a random copolyester. The co-polyester can be formed from the polycondensation of a polyester oligomer or prepolymer with a second oligomer prepolymer to form a block copolyester. Optionally, the second prepolymer can be a hydrophilic prepolymer. For example, the copolyester can be formed from the polycondensation of terephthalic acid or naphthalene dicarboxylic acid with ethylene glycol, 1,4-butanediol, or 1,3-propanediol. Examples of copolyesters include polyethylene adipate, polybutylene succinate, poly(3-hydroxybutyrate-co-3-hydroxyvalerate), polyethylene terephthalate, polybutylene terephthalate, polytrimethylene terephthalate, polyethylene naphthalate, and combinations thereof. The co-polyamide can comprise or consist of polyethylene terephthalate.

**[0214]** The polyester can be a block copolymer comprising segments of one or more of polybutylene terephthalate

(PBT), a polytrimethylene terephthalate, a polyhexamethylene terephthalate, a poly-1,4-dimethylcyclohexane terephthalate, a polyethylene terephthalate (PET), a polyethylene isophthalate (PEI), a polyarylate (PAR), a polybutylene naphthalate (PBN), and a liquid crystal polyester. For example, a suitable polyester that is a block copolymer can be a PET/PEI copolymer, a polybutylene terephthalate/tetraethylene glycol copolymer, a polyoxyalkylenediimide diacid/polybutylene terephthalate copolymer, or a blend or mixture of any of the foregoing.

[0215] The disclosed polyesters can be prepared by a variety of polycondensation methods known to the skilled artisan, such as a solvent polymerization or a melt polymerization process.

#### Polyolefins

[0216] The polymers can comprise or consist essentially of a polyolefin. The polyolefin can be a thermoplastic polyolefin or a thermoset polyolefin. Additionally, the polyolefin can be an elastomeric polyolefin, including a thermoplastic elastomeric polyolefin or a thermoset elastomeric polyolefin. Exemplary polyolefins can include polyethylene, polypropylene, and olefin elastomers (e.g., metallocene-catalyzed block copolymers of ethylene and  $\alpha$ -olefins having 4 to about 8 carbon atoms). The polyolefin can be a polymer comprising a polyethylene, an ethylene- $\alpha$ -olefin copolymer, an ethylene-propylene rubber (EPDM), a polybutene, a polyisobutylene, a poly-4-methylpent-1-ene, a polyisoprene, a polybutadiene, a ethylene-methacrylic acid copolymer, and an olefin elastomer such as a dynamically crosslinked polymer obtained from polypropylene (PP) and an ethylene-propylene rubber (EPDM), and blends or mixtures of the foregoing. Further exemplary polyolefins include polymers of cycloolefins such as cyclopentene or norbornene.

[0217] It is to be understood that polyethylene, which optionally can be crosslinked, is inclusive a variety of polyethylenes, including low density polyethylene (LDPE), linear low density polyethylene (LLDPE), (VLDPE) and (ULDPE), medium density polyethylene (MDPE), high density polyethylene (HDPE), high density and high molecular weight polyethylene (HDPE-HMW), high density and ultra-high molecular weight polyethylene (HDPE-UHMW), and blends or mixtures of any the foregoing polyethylenes. A polyethylene can also be a polyethylene copolymer derived from monomers of monolefins and diolefins copolymerized with a vinyl, acrylic acid, methacrylic acid, ethyl acrylate, vinyl alcohol, and/or vinyl acetate. Polyolefin copolymers comprising vinyl acetate-derived units can be a high vinyl acetate content copolymer, e.g., greater than about 50 weight percent vinyl acetate-derived composition.

[0218] The polyolefin can be formed through free radical, cationic, and/or anionic polymerization by methods well known to those skilled in the art (e.g., using a peroxide initiator, heat, and/or light).

[0219] Suitable polyolefins can be prepared by polymerization of monomers of monolefins and diolefins as described herein. Exemplary monomers that can be used to prepare the polyolefin include, but are not limited to, ethylene, propylene, 1-butene, 1-pentene, 1-hexene, 2-methyl-1-propene, 3-methyl-1-pentene, 4-methyl-1-pentene, 5-methyl-1-hexene and mixtures thereof.

[0220] Suitable ethylene- $\alpha$ -olefin copolymers can be obtained by copolymerization of ethylene with an  $\alpha$ -olefin

such as propylene, butene-1, hexene-1, octene-1,4-methyl-1-pentene or the like having carbon numbers of 3 to 12.

[0221] The polyolefin can be a mixture of polyolefins, such as a mixture of two or more polyolefins disclosed herein above. For example, a suitable mixture of polyolefins can be a mixture of polypropylene with polyisobutylene, polypropylene with polyethylene (for example PP/HDPE, PP/LDPE) or mixtures of different types of polyethylene (for example LDPE/HDPE).

[0222] The polyolefin can be a copolymer of suitable monolefin monomers or a copolymer of a suitable monolefin monomer and a vinyl monomer. Exemplary polyolefin copolymers include ethylene/propylene copolymers, linear low density polyethylene (LLDPE) and mixtures thereof with low density polyethylene (LDPE), propylene/but-1-ene copolymers, propylene/isobutylene copolymers, ethylene/but-1-ene copolymers, ethylene/hexene copolymers, ethylene/methylpentene copolymers, ethylene/heptene copolymers, ethylene/octene copolymers, propylene/butadiene copolymers, isobutylene/isoprene copolymers, ethylene/alkyl acrylate copolymers, ethylene/alkyl methacrylate copolymers, ethylene/vinyl acetate copolymers and their copolymers with carbon monoxide or ethylene/acrylic acid copolymers and their salts (ionomers) as well as terpolymers of ethylene with propylene and a diene such as hexadiene, dicyclopentadiene or ethylidene-norbornene; and mixtures of such copolymers with one another and with polymers mentioned in 1) above, for example polypropylene/ethylene-propylene copolymers, LDPE/ethylene-vinyl acetate copolymers (EVA), LDPE/ethylene-acrylic acid copolymers (EAA), LLDPE/EVA, LLDPE/EAA and alternating or random polyalkylene/carbon monoxide copolymers and mixtures thereof with other polymers, for example polyamides.

[0223] The polyolefin can be a polypropylene homopolymer, a polypropylene copolymers, a polypropylene random copolymer, a polypropylene block copolymer, a polyethylene homopolymer, a polyethylene random copolymer, a polyethylene block copolymer, a low density polyethylene (LDPE), a linear low density polyethylene (LLDPE), a medium density polyethylene, a high density polyethylene (HDPE), or blends or mixtures of one or more of the preceding polymers.

[0224] The polyolefin can be a polypropylene. The term "polypropylene," as used herein, is intended to encompass any polymeric composition comprising propylene monomers, either alone or in mixture or copolymer with other randomly selected and oriented polyolefins, dienes, or other monomers (such as ethylene, butylene, and the like). Such a term also encompasses any different configuration and arrangement of the constituent monomers (such as atactic, syndiotactic, isotactic, and the like). Thus, the term as applied to fibers is intended to encompass actual long strands, tapes, threads, and the like, of drawn polymer. The polypropylene can be of any standard melt flow (by testing); however, standard fiber grade polypropylene resins possess ranges of Melt Flow Indices between about 1 and 1000.

[0225] The polyolefin can be a polyethylene. The term "polyethylene," as used herein, is intended to encompass any polymeric composition comprising ethylene monomers, either alone or in mixture or copolymer with other randomly selected and oriented polyolefins, dienes, or other monomers (such as propylene, butylene, and the like). Such a term also encompasses any different configuration and arrangement of the constituent monomers (such as atactic, syndiotactic,

isotactic, and the like). Thus, the term as applied to fibers is intended to encompass actual long strands, tapes, threads, and the like, of drawn polymer. The polyethylene can be of any standard melt flow (by testing); however, standard fiber grade polyethylene resins possess ranges of Melt Flow Indices between about 1 and 1000.

**[0226]** The thermoplastic and/or thermosetting material can further comprise one or more processing aids. The processing aid can be a non-polymeric material. These processing aids can be independently selected from the group including, but not limited to, curing agents, initiators, plasticizers, mold release agents, lubricants, antioxidants, flame retardants, dyes, pigments, reinforcing and non-reinforcing fillers, fiber reinforcements, and light stabilizers.

**[0227]** In articles that include a textile, the optical element can be disposed onto the textile. The textile or at least an outer layer of the textile can include a thermoplastic material that the optical element can be disposed onto. The textile can be a nonwoven textile, a synthetic leather, a knit textile, or a woven textile. The textile can comprise a first fiber or a first yarn, where the first fiber or the first yarn can include at least an outer layer comprising the first thermoplastic material. A region of the first or second side of the structure onto which the optical element is disposed can include the first fiber or the first yarn in a non-filamentous conformation. The optical element can be disposed onto the textile or the textile can be processed so that the optical element can be disposed onto the textile. The textured surface can be made of or formed from the textile surface. The optical element can be disposed onto the primer layer. The textile surface can be used to form the textured surface, and either before or after this, the optical element can be applied to the textile.

**[0228]** A "textile" may be defined as any material manufactured from fibers, filaments, or yarns characterized by flexibility, fineness, and a high ratio of length to thickness. Textiles generally fall into two categories. The first category includes textiles produced directly from webs of filaments or fibers by randomly interlocking to construct non-woven fabrics and felts. The second category includes textiles formed through a mechanical manipulation of yarn, thereby producing a woven fabric, a knitted fabric, a braided fabric, a crocheted fabric, and the like.

**[0229]** The terms "filament," "fiber," or "fibers" as used herein refer to materials that are in the form of discrete elongated pieces that are significantly longer than they are wide. The fiber can include natural, manmade or synthetic fibers. The fibers may be produced by conventional techniques, such as extrusion, electrospinning, interfacial polymerization, pulling, and the like. The fibers can include carbon fibers, boron fibers, silicon carbide fibers, titania fibers, alumina fibers, quartz fibers, glass fibers, such as E, A, C, ECR, R, S, D, and NE glasses and quartz, or the like. The fibers can be fibers formed using polymeric materials comprising polymers capable of forming fibers such as poly(ether ketone), polyimide, polybenzoxazole, poly(phenylene sulfide), polyesters, polyolefins (e.g., polyethylene, polypropylene), aromatic polyamides (e.g., an aramid polymer such as para-aramid fibers and meta-aramid fibers), aromatic polyimides, polybenzimidazoles, polyetherimides, polytetrafluoroethylene, acrylic, modacrylic, poly(vinyl alcohol), polyamides, polyurethanes, and copolymers such as polyether-polyurea copolymers, polyester-polyurethanes, polyether block amide copolymers, or the like. The fibers

can be natural fibers (e.g., silk, wool, cashmere, vicuna, cotton, flax, hemp, jute, sisal). The fibers can be man-made fibers from regenerated natural polymers, such as rayon, lyocell, acetate, triacetate, rubber, and poly(lactic acid).

**[0230]** The fibers can have an indefinite length. For example, man-made and synthetic fibers are generally extruded in substantially continuous strands. Alternatively, the fibers can be staple fibers, such as, for example, cotton fibers or extruded synthetic polymer fibers can be cut to form staple fibers of relatively uniform length. The staple fiber can have a length of about 1 millimeter to 100 centimeters or more as well as any increment therein (e.g., 1 millimeter increments).

**[0231]** The fiber can have any of a variety of cross-sectional shapes. Natural fibers can have a natural cross-section, or can have a modified cross-sectional shape (e.g., with processes such as mercerization). Man-made or synthetic fibers can be extruded to provide a strand having a predetermined cross-sectional shape. The cross-sectional shape of a fiber can affect its properties, such as its softness, luster, and wicking ability. The fibers can have round or essentially round cross sections. Alternatively, the fibers can have non-round cross sections, such as flat, oval, octagonal, rectangular, wedge-shaped, triangular, dog-bone, multi-lobal, multi-channel, hollow, core-shell, or other shapes.

**[0232]** The fiber can be processed. For example, the properties of fibers can be affected, at least in part, by processes such as drawing (stretching) the fibers, annealing (hardening) the fibers, and/or crimping or texturizing the fibers.

**[0233]** In some cases a fiber can be a multi-component fiber, such as one comprising two or more co-extruded polymeric materials. The two or more co-extruded polymeric materials can be extruded in a core-sheath, islands-in-the-sea, segmented-pie, striped, or side-by-side configuration. A multi-component fiber can be processed in order to form a plurality of smaller fibers (e.g., microfibers) from a single fiber, for example, by remove a sacrificial material.

**[0234]** The fiber can be a carbon fiber such as TARIFYL produced by Formosa Plastics Corp. of Kaohsiung City, Taiwan, (e.g., 12,000, 24,000, and 48,000 fiber tows, specifically fiber types TC-35 and TC-35R), carbon fiber produced by SGL Group of Wiesbaden, Germany (e.g., 50,000 fiber tow), carbon fiber produced by Hyosung of Seoul, South Korea, carbon fiber produced by Toho Tenax of Tokyo, Japan, fiberglass produced by Jushi Group Co., LTD of Zhejiang, China (e.g., E6, 318, silane-based sizing, filament diameters 14, 15, 17, 21, and 24 micrometers), and polyester fibers produced by Amann Group of Bonningheim, Germany (e.g., SERAFILE 200/2 non-lubricated polyester filament and SERAFILE COMPHIL 200/2 lubricated polyester filament).

**[0235]** A plurality of fibers includes 2 to hundreds or thousands or more fibers. The plurality of fibers can be in the form of bundles of strands of fibers, referred to as tows, or in the form of relatively aligned staple fibers referred to as sliver and roving. A single type fiber can be used either alone or in combination with one or more different types of fibers by co-mingling two or more types of fibers. Examples of co-mingled fibers include polyester fibers with cotton fibers, glass fibers with carbon fibers, carbon fibers with aromatic polyimide (aramid) fibers, and aromatic polyimide fibers with glass fibers.

**[0236]** As used herein, the term “yarn” refers to an assembly including one or more fibers, wherein the strand has a substantial length and a relatively small cross-section, and is suitable for use in the production of textiles by hand or by machine, including textiles made using weaving, knitting, crocheting, braiding, sewing, embroidery, or ropemaking techniques. Thread is a type of yarn commonly used for sewing.

**[0237]** Yarns can be made using fibers comprising natural, man-made and synthetic materials. Synthetic fibers are most commonly used to make spun yarns from staple fibers, and filament yarns. Spun yarn is made by arranging and twisting staple fibers together to make a cohesive strand. The process of forming a yarn from staple fibers typically includes carding and drawing the fibers to form sliver, drawing out and twisting the sliver to form roving, and spinning the roving to form a strand. Multiple strands can be plied (twisted together) to make a thicker yarn. The twist direction of the staple fibers and of the plies can affect the final properties of the yarn. A filament yarn refer to a single long, substantially continuous filament, which is conventionally referred to as a “monofilament yarn,” or a plurality of individual filaments grouped together. A filament yarn can also refer to two or more long, substantially continuous filaments which are grouped together by grouping the filaments together by twisting them or entangling them or both. As with staple yarns, multiple strands can be plied together to form a thicker yarn.

**[0238]** Once formed, the yarn can undergo further treatment such as texturizing, thermal or mechanical treating, or coating with a material such as a synthetic polymer. The fibers, yarns, or textiles, or any combination thereof, used in the disclosed articles can be sized. Sized fibers, yarns, and/or textiles are coated on at least part of their surface with a sizing composition selected to change the absorption or wear characteristics, or for compatibility with other materials. The sizing composition facilitates wet-out and wet-through of the coating or resin upon the surface and assists in attaining desired physical properties in the final article. An exemplary sizing composition can comprise, for example, epoxy polymers, urethane-modified epoxy polymers, polyester polymers, phenol polymers, polyamide polymers, polyurethane polymers, polycarbonate polymers, polyetherimide polymers, polyamideimide polymers, polystylylpyridine polymers, polyimide polymers bismaleimide polymers, polysulfone polymers, polyethersulfone polymers, epoxy-modified urethane polymers, polyvinyl alcohol polymers, polyvinyl pyrrolidone polymers, and mixtures thereof.

**[0239]** Two or more yarns can be combined, for example, to form composite yarns such as single- or double-covered yarns, and co-spun yarns. Accordingly, yarns may have a variety of configurations that generally conform to the descriptions provided herein.

**[0240]** The yarn can comprise at least one thermoplastic material (e.g., one or more of the fibers can be made using a thermoplastic material). The yarn can be made of a thermoplastic material. The yarn can be coated with a layer of a material such as a thermoplastic material.

**[0241]** Various techniques exist for mechanically manipulating yarns to form a textile. Such techniques include, for example, interweaving, intertwining and twisting, and interlooping. Interweaving is the intersection of two yarns that cross and interweave at right angles to each other. The yarns utilized in interweaving are conventionally referred to as

“warp” and “weft.” A woven textile includes include a warp yarn and a weft yarn. The warp yarn extends in a first direction, and the weft strand extends in a second direction that is substantially perpendicular to the first direction. Intertwining and twisting encompasses various procedures, such as braiding and knotting, where yarns intertwine with each other to form a textile. Interlooping involves the formation of a plurality of columns of intermeshed loops, with knitting being the most common method of interlooping. The textile may be primarily formed from one or more yarns that are mechanically-manipulated, for example, through interweaving, intertwining and twisting, and/or interlooping processes, as mentioned above.

**[0242]** The textile can be a nonwoven textile. Generally, a nonwoven textile or fabric is a sheet or web structure made from fibers and/or yarns that are bonded together. The bond can be a chemical and/or mechanical bond, and can be formed using heat, solvent, adhesive or a combination thereof. Exemplary nonwoven fabrics are flat or tufted porous sheets that are made directly from separate fibers, molten plastic and/or plastic film. They are not made by weaving or knitting and do not necessarily require converting the fibers to yarn, although yarns can be used as a source of the fibers. Nonwoven textiles are typically manufactured by putting small fibers together in the form of a sheet or web (similar to paper on a paper machine), and then binding them either mechanically (as in the case of felt, by interlocking them with serrated or barbed needles, or hydro-entanglement such that the inter-fiber friction results in a stronger fabric), with an adhesive, or thermally (by applying binder (in the form of powder, paste, or polymer melt) and melting the binder onto the web by increasing temperature). A nonwoven textile can be made from staple fibers (e.g., from wetlaid, airlaid, carding/crosslapping processes), or extruded fibers (e.g., from meltblown or spunbond processes, or a combination thereof), or a combination thereof. Bonding of the fibers in the nonwoven textile can be achieved with thermal bonding (with or without calendaring), hydro-entanglement, ultrasonic bonding, needlepunching (needlefelting), chemical bonding (e.g., using binders such as latex emulsions or solution polymers or binder fibers or powders), meltblown bonding (e.g., fiber is bonded as air attenuated fibers intertangle during simultaneous fiber and web formation).

**[0243]** Now having described various aspects of the present disclosure, additional discussion is provided regarding when the optical element is used in conjunction with a bladder. The bladder can be unfilled, partially inflated, or fully inflated when the structural design (e.g., optical element) is disposed onto the bladder. The bladder is a bladder capable of including a volume of a fluid. An unfilled bladder is a fluid-fillable bladder and a filled bladder that has been at least partially inflated with a fluid at a pressure equal to or greater than atmospheric pressure. When disposed onto or incorporated into an article of footwear, apparel, or sports equipment, the bladder is generally, at that point, a fluid-filled bladder. The fluid be a gas or a liquid. The gas can include air, nitrogen gas (N<sub>2</sub>), or other appropriate gas.

**[0244]** The bladder can have a gas transmission rate for nitrogen gas, for example, where a bladder wall of a given thickness has a gas transmission rate for nitrogen that is at least about ten times lower than the gas transmission rate for nitrogen of a butyl rubber layer of substantially the same thickness as the thickness of the bladder described herein.

The bladder can have a first bladder wall having a first bladder wall thickness (e.g., about 0.1 to 40 mils). The bladder can have a first bladder wall that can have a gas transmission rate (GTR) for nitrogen gas of less than about  $15 \text{ cm}^3/\text{m}^2\cdot\text{atm}\cdot\text{day}$ , less than about  $10 \text{ m}^3/\text{m}^2\cdot\text{atm}\cdot\text{day}$ , less than about  $5 \text{ cm}^3/\text{m}^2\cdot\text{atm}\cdot\text{day}$ , less than about  $1 \text{ cm}^3/\text{m}^2\cdot\text{atm}\cdot\text{day}$  (e.g., from about  $0.001 \text{ cm}^3/\text{m}^2\cdot\text{atm}\cdot\text{day}$  to about  $1 \text{ cm}^3/\text{m}^2\cdot\text{atm}\cdot\text{day}$ , about  $0.01 \text{ cm}^3/\text{m}^2\cdot\text{atm}\cdot\text{day}$  to about  $1 \text{ cm}^3/\text{m}^2\cdot\text{atm}\cdot\text{day}$  or about  $0.1 \text{ cm}^3/\text{m}^2\cdot\text{atm}\cdot\text{day}$  to about  $1 \text{ cm}^3/\text{m}^2\cdot\text{atm}\cdot\text{day}$ ) for an average wall thickness of 20 mils. The bladder can have a first bladder wall having a first bladder wall thickness, where the first bladder wall has a gas transmission rate of  $15 \text{ cm}^3/\text{m}^2\cdot\text{atm}\cdot\text{day}$  or less for nitrogen for an average wall thickness of 20 mils.

**[0245]** In an aspect, the bladder has a bladder wall having an interior-facing side and an exterior (or externally)-facing side, where the interior (or internally)-facing side defines at least a portion of an interior region of the bladder. The single layer or multi-layer optical film (or optical element) having a first side and a second opposing side can be disposed on the exterior-facing side of the bladder, the interior-facing side of the bladder, or both. The exterior-facing side of the bladder, the interior-facing side of the bladder, or both can include a plurality of topographical structures (or profile features) extending from the exterior-facing side of the bladder wall, the interior-facing side of the bladder, or both, where the first side or the second side of the multi-layer optical film is disposed on the exterior-facing side of the bladder wall and covering the plurality of topographical structures, the interior-facing side of the bladder wall and covering the plurality of topographical structures, or both, and wherein the multi-layer optical film imparts a structural color to the bladder wall.

**[0246]** In a particular aspect, the bladder can include a top wall operably secured to the footwear upper, a bottom wall opposite the top wall, and one or more sidewalls extending between the top wall and the bottom wall of the inflated bladder. The top wall, the bottom wall, and the one or more sidewalls collectively define an interior region of the inflated bladder, and wherein the one or more sidewalls each comprise an exterior-facing side. The multi-layer optical film having a first side and a second opposing side can be disposed on the exterior-facing side of the bladder, the interior-facing side of the bladder, or both. The exterior-facing side of the bladder, the interior-facing side of the bladder, or both can include a plurality of topographical structures extending from the exterior-facing side of the bladder wall, the interior-facing side of the bladder, or both, where the first side or the second side of the multi-layer optical film is disposed on the exterior-facing side of the bladder wall and covering the plurality of topographical structures, the interior-facing side of the bladder wall and covering the plurality of topographical structures, or both, and wherein the multi-layer optical film imparts a structural color to the bladder wall.

**[0247]** An accepted method for measuring the relative permeance, permeability, and diffusion of inflated bladders is ASTM D-1434-82-V. See, e.g., U.S. Pat. No. 6,127,026, which is incorporated by reference as if fully set forth herein. According to ASTM D-1434-82-V, permeance, per-

meability and diffusion are measured by the following formulae:

Permeance

$$\frac{\text{(quantity of gas)}}{\text{[(area)×(time)×(pressure difference)]}} = \text{permeance (GTR)/(pressure difference)} \\ = \text{cm}^3/\text{m}^2\cdot\text{atm}\cdot\text{day (i.e., 24 hours)}$$

Permeability

$$\frac{\text{[(quantity of gas)×(film thickness)]}}{\text{[(area)×(time)×(pressure difference)]}} = \text{permeability [(GTR)×(film thickness)]/(pressure difference)} = \text{[(cm}^3\text{)(mil)]}/\text{m}^2\cdot\text{atm}\cdot\text{day (i.e., 24 hours)}$$

Diffusion at one atmosphere

$$\frac{\text{(quantity of gas)}}{\text{[(area)×(time)]}} = \text{GTR} = \text{cm}^3/\text{m}^2\cdot\text{day (i.e., 24 hours)}$$

**[0248]** The bladder can include a bladder wall that includes a film including at least one polymeric layer or at least two or more polymeric layers. Each of the polymeric layers can be about 0.1 to 40 mils in thickness.

**[0249]** The polymeric layer can include a polymeric material such as a thermoplastic material as described above and herein and can be the thermoplastic layer upon which the primer layer, the optical element can be disposed, upon which the textured layer can be disposed, can be used to form the textured layer, and the like. The thermoplastic material can include an elastomeric material, such as a thermoplastic elastomeric material. The thermoplastic materials can include thermoplastic polyurethane (TPU), such as those described above and herein. The thermoplastic materials can include polyester-based TPU, polyether-based TPU, polycaprolactone-based TPU, polycarbonate-based TPU, polysiloxane-based TPU, or combinations thereof. Non-limiting examples of thermoplastic material that can be used include: “PELLETHANE” 2355-85ATP and 2355-95AE (Dow Chemical Company of Midland, Mich., USA), “ELASTOLLAN” (BASF Corporation, Wyandotte, Mich., USA) and “ESTANE” (Lubrizol, Brecksville, Ohio, USA), all of which are either ester or ether based. Additional thermoplastic material can include those described in U.S. Pat. Nos. 5,713,141; 5,952,065; 6,082,025; 6,127,026; 6,013,340; 6,203,868; and 6,321,465, which are incorporated herein by reference.

**[0250]** The polymeric layer can include a polymeric material including one or more of the following polymers: ethylene-vinyl alcohol copolymers (EVOH), poly(vinyl chloride), polyvinylidene polymers and copolymers (e.g., polyvinylidene chloride), polyamides (e.g., amorphous polyamides), acrylonitrile polymers (e.g., acrylonitrile-methyl acrylate copolymers), polyurethane engineering plastics, polymethylpentene resins, ethylene-carbon monoxide copolymers, liquid crystal polymers, polyethylene terephthalate, polyether imides, polyacrylic imides, and other polymeric materials known to have relatively low gas transmission rates. Blends and alloys of these materials as well as with the TPUs described herein and optionally including combinations of polyimides and crystalline polymers, are also suitable. For instance, blends of polyimides and liquid crystal polymers, blends of polyamides and polyethylene terephthalate, and blends of polyamides with styrenics are suitable.

**[0251]** Specific examples of polymeric materials of the polymeric layer can include acrylonitrile copolymers such as

“BAREX” resins, available from Ineos (Rolle, Switzerland); polyurethane engineering plastics such as “ISPLAST” ETPU available from Lubrizol (Brecksville, Ohio, USA); ethylene-vinyl alcohol copolymers marketed under the tradenames “EVAL” by Kuraray (Houston, Tex., USA), “SOARNOL” by Nippon Gohsei (Hull, England), and “SELAR OH” by DuPont (Wilmington, Del., USA); polyvinylidene chloride available from S.C. Johnson (Racine, Wis., USA) under the tradename “SARAN”, and from Solvay (Brussels, Belgium) under the tradename “IXAN”; liquid crystal polymers such as “VECTRA” from Celanese (Irving, Tex., USA) and “XYDAR” from Solvay; “MDX6” nylon, and amorphous nylons such as “NOVAMID” X21 from Koninklijke DSM N.V (Heerlen, Netherlands), “SELAR PA” from DuPont; polyetherimides sold under the tradename “ULTEM” by SABIC (Riyadh, Saudi Arabia); poly(vinyl alcohol)s; and polymethylpentene resins available from Mitsui Chemicals (Tokyo, Japan) under the tradename “TPX”.

**[0252]** Each polymeric layer of the film can include a thermoplastic material which can include a combination of thermoplastic polymers. In addition to one or more thermoplastic polymers, the thermoplastic material can optionally include a colorant, a filler, a processing aid, a free radical scavenger, an ultraviolet light absorber, and the like. Each polymeric layer of the film can be made of a different of thermoplastic material including a different type of thermoplastic polymer.

**[0253]** The bladder can be made by applying heat, pressure and/or vacuum to a film. In this regard, the primer layer, the optical element, the textured layer, and the like can be disposed, formed from, or the like prior to, during, and/or after these steps. The bladder (e.g., one or more polymeric layers) can be formed using one or more polymeric materials, and forming the bladder using one or more processing techniques including, for example, extrusion, blow molding, injection molding, vacuum molding, rotary molding, transfer molding, pressure forming, heat sealing, casting, low-pressure casting, spin casting, reaction injection molding, radio frequency (RF) welding, and the like. The bladder can be made by co-extrusion followed by heat sealing or welding to give an inflatable bladder, which can optionally include one or more valves (e.g., one way valves) that allows the bladder to be filled with the fluid (e.g., gas).

**[0254]** Now having described the optical element, the optional textured surface, and methods of making the article are now described. In an aspect, the method includes forming the reflective layer (base reflective layer) of the optical element. In an aspect, the method includes forming the reflective layer on a surface of an article such as a textile, film, fiber, or monofilament yarn, where the surface can optionally be the textured surface. The reflective layer can be formed using one or more techniques described herein.

**[0255]** The method provides for the reflective layer being formed on the textured surface. Subsequently, the constituent layers can be disposed on the reflective layer. Alternatively, the textured surface can be formed in/on the reflective layer, and then the constituent layers are disposed on the reflective layer. As described herein, the optical element can be formed in a layer-by-layer manner, where each constituent layer has a different index of refraction. As each layer is formed the undulations and flat regions are altered. The combination of the optional textured surface (e.g., dimensions, shape, and/or spacing of the profile elements) and the

layers of the optical element (e.g., number of layers, thickness of layers, material of the layers) and the resultant undulations and planar areas impart the structural color when exposed to visible light. The method includes optionally forming a protective layer over the optical element to protect the optical element.

**[0256]** Another embodiment of the present disclosure includes providing reflective layer and the textured surface on the substrate, where the reflective layer (base reflective layer) can be disposed on the textured surface. Each constituent layer of the optical element can be formed in turn, where each layer can be formed then after an appropriate amount of time, additional processing, cooling, or the like, the next layer of the optical element can be formed. Optionally, non-base reflective layer(s) can be formed between constituent layers. Optionally, the top layer, by itself or in combinations with one or more reflective layers, can be formed on the last constituent layer (one on the side opposite the base reflective layer).

**[0257]** It should be emphasized that the above-described aspects of the present disclosure are merely possible examples of implementations, and are set forth only for a clear understanding of the principles of the disclosure. Many variations and modifications may be made to the above-described aspects of the disclosure without departing substantially from the spirit and principles of the disclosure. All such modifications and variations are intended to be included herein within the scope of this disclosure.

**[0258]** The word “disposing” can be replaced with “operably disposing” in each of the claims.

**[0259]** Measurements for visible light transmittance and visible light reflectance were performed using a Shimadzu UV-2600 Spectrophotometer (Shimadzu Corporation, Japan). The spectrometer was calibrated using a standard prior to the measurements. The incident angle for all measurements was zero, unless the incident angle is intentionally altered. The wavelength resolution can be measured at 0.1 nm.

**[0260]** The visible light transmittance was the measurement of visible light (or light energy) that was transmitted through a sample material when visible light within the spectral range of 400 nanometers to 800 nanometers was directed through the material. The results of all transmittance over the range of 400 nanometers to 800 nanometers was collected and recorded. For each sample, a minimum value for the visible light transmittance was determined for this range.

**[0261]** The visible light reflectance was a measurement of the visible light (or light energy) that was reflected by a sample material when visible light within the spectral range of 400 nanometers to 800 nanometers was directed through the material. The results of all reflectance over the range of 400 nanometers to 800 nanometers was collected and recorded. For each sample, a minimum value for the visible light reflectance was determined for this range.

**[0262]** It should be noted that ratios, concentrations, amounts, and other numerical data may be expressed herein in a range format. It is to be understood that such a range format is used for convenience and brevity, and thus, should be interpreted in a flexible manner to include not only the numerical values explicitly recited as the limits of the range, but also to include all the individual numerical values or sub-ranges encompassed within that range as if each numerical value and sub-range is explicitly recited. To illustrate, a



concentration range of “about 0.1 percent to about 5 percent” should be interpreted to include not only the explicitly recited concentration of about 0.1 weight percent to about 5 weight percent but also include individual concentrations (e.g., 1 percent, 2 percent, 3 percent, and 4 percent) and the sub-ranges (e.g., 0.5 percent, 1.1 percent, 2.2 percent, 3.3 percent, and 4.4 percent) within the indicated range. The term “about” can include traditional rounding according to significant figures of the numerical value. In addition, the phrase “about ‘x’ to ‘y’” includes “about ‘x’ to about ‘y’”.

**[0263]** The term “providing”, such as for “providing an article” and the like, when recited in the claims, is not intended to require any particular delivery or receipt of the provided item. Rather, the term “providing” is merely used to recite items that will be referred to in subsequent elements of the claim(s), for purposes of clarity and ease of readability.

**[0264]** Many variations and modifications may be made to the above-described aspects. All such modifications and variations are intended to be included herein within the scope of this disclosure and protected by the following claims.

We claim:

1. An article comprising:  
an optical element on a surface of the article, wherein the optical element has a first minimum percent reflectance in a first wavelength range within the wavelength range of about 380 to 625 nanometers, wherein the first wavelength range has a first width of about 10 to 245 nanometers, wherein the first minimum percent reflectance is about 50 percent or more, wherein the optical element imparts a structural color that corresponds substantially to the range of first wavelength range.
2. The article of claim 1, wherein the first wavelength range has a first width of about 10 to 100 nanometers and wherein the first minimum percent reflectance is about 80 percent or more.
3. The article of claim 1, wherein the optical element has a second minimum percent reflectance in a second wavelength range within the wavelength range of about 380 to 625 nanometers, wherein the second minimum percent reflectance is about 50 percent or more, wherein the optical element imparts the structural color that corresponds substantially to the range of the first wavelength value, the second wavelength value, or a combination of both.
4. The article of claim 1, wherein the first wavelength range comprises a first set of peaks, wherein the first set of peaks comprises at least two peaks, where one or more of the two peaks has a minimum percent reflectance of about 50 percent or more within the wavelength range of about 380 to 625 nanometers, wherein the each peak independently has a width of about 10 to 150 nanometers, wherein the optical element imparts the structural color that corresponds substantially to the first set of peaks.
5. The article of claim 1, wherein the optical element has a characteristic that upon exposure to white light imparts the structural color that comprises one of: at least one peak, the

first peak, and the first set of peaks, as a function of wavelength and percent reflectance.

6. The article of claim 1, wherein at a first observation angle the structural color is a first structural color and at a second observation angle the structural color is a second structural color, optionally, wherein the first structural color and the second structural color are different hues.

7. The article of claim 1, first wavelength range within the wavelength range of about 350 to 520 nanometers.

8. The article of claim 1, wherein the structural color has limited iridescence such that, when each color visible at each possible angle of observation is assigned to a single hue selected from the group consisting of the primary, secondary and tertiary colors on the yellow and blue (RYB) color wheel, all of the assigned hues fall into a single hue group, wherein the single hue group is one of a) green-yellow, yellow, and yellow-orange; b) yellow, yellow-orange and orange; c) yellow-orange and orange; d) purple; e) purple and purple-blue; f) purple, purple-blue, and blue; g) purple-blue, blue, and blue-green; h) blue, blue-green and green; and i) blue-green, green, and green-yellow.

9. The article of claim 1, wherein the structural color is multihued purple, optionally the multihued structural color is selected from: purple-blue, blue-green, or a combination thereof.

10. The article of claim 1, wherein the structural color is a single hue, optionally a blue hue.

11. The article of claim 1, wherein the article is an article of footwear.

12. The article of claim 11, wherein the article is a sole component of an article of footwear.

13. The article of claim 11, wherein the article is an upper component of an article of footwear.

14. The article of claim 13, wherein the upper component is a synthetic leather upper.

15. The article of claim 14, wherein the optical element is an inorganic optical element, an organic optical element, or a mixed inorganic/organic optical element.

16. The article of claim 15, wherein each layer of the inorganic optical element comprises a material selected from metal, metal oxide, or alloy.

17. The article of claim 16, wherein the metal is selected from the group consisting of: titanium, aluminum, silver, zirconium, chromium, magnesium, silicon, gold, platinum, alloy thereof, and a combination thereof.

18. A method, comprising:

disposing an optical element on a surface of an article, wherein the optical element is one according to any one of claims 1 to 17.

19. The method of claim 18, wherein disposing the optical element comprises forming the optical element on the surface of the article.

20. The method of claim 19, wherein disposing the optical element comprises depositing at least one reflective layer and the at least two constituent layers of the optical element using a deposition process.

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