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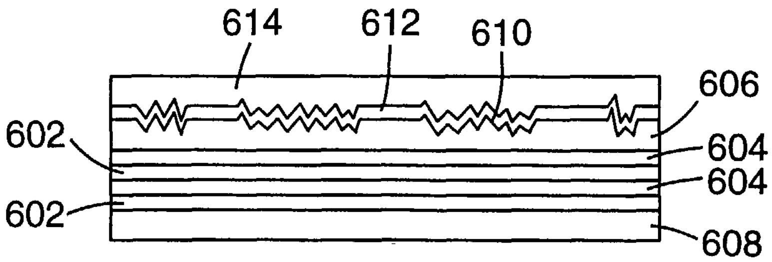
(54) Title: MULTILAYER POLYMER FILM WITH ADDITIONAL COATINGS OR LAYERS



(57) Abstract: A multilayer polymer film has an optical stack including a plurality of alternating polymer layers with skin layers having mechanical, optical, or chemical properties differing from those of the layers in the optical stack. In one embodiment, the multilayer polymeric film has one or more holograms that provide attractive and useful optical effects.

MULTILAYER POLYMER FILM
WITH ADDITIONAL COATINGS OR LAYERS

Background of the Invention

Multilayer optical stacks are well-known for providing a wide variety of optical properties. Such multilayer stacks may act as reflective polarizers or mirrors, reflecting light of all polarizations. They may also function as wavelength selective reflectors such as "cold mirrors" that reflect visible light but transmit infrared or "hot mirrors" that transmit visible and reflect infrared. Examples of a wide variety of multilayer stacks that may be constructed are included in U.S. Patent No. 5,882,774.

A problem with multilayer stacks as known in the art is that the stacks themselves may not have all of the physical, chemical, or optical properties desired. Some way of otherwise supplying these desirable properties would therefore be useful.

Summary of the Invention

According to one embodiment of the invention a multilayer film has adhered to one or both of its major surfaces at least one additional layer selected for mechanical, chemical, or optical properties that differ from the properties of the materials of the layers of the optical stack.

According to another embodiment of the invention a multilayer film has adhered to one or both of its surfaces an additional layer that will protect the multilayer optical stack.

According to another embodiment of the invention, certain constructions including holographic images (also known as "holograms") and multilayer optical film are described.

Brief Description of the Drawings

Figures 1A, 1B, and 2 show the preferred multilayer optical film;

Figures 3 through 8 show transmission spectra for the multilayer optical films of Examples 1 through 6;

Figure 9 shows a multilayer film of the invention having an additional layer adhered to one of its major surfaces;

Figure 10 shows a multilayer film according to the invention having additional layers adhered to both of its major surfaces;

Figure 11 shows a multilayer film having one additional layer adhered to one of its major surfaces and two additional layers adhered to its other major surface;

Figures 12 through 18 show various embodiments of the present invention that include a multilayer film and a hologram;

Figures 19 and 20 illustrate embodiments of the invention that include a hologram, used with a verifying polarizer.

Description of the Preferred Embodiment

Multilayer Optical Film

The advantages, characteristics and manufacturing of multilayer optical films are most completely described in the above-mentioned U.S. Patent No. 5,882,774. The multilayer optical film is useful, for example, as highly efficient mirrors and/or polarizers. A relatively brief description of the properties and characteristics of the multilayer optical film is presented below followed by a description of illustrative embodiments of backlight systems using the multilayer optical film according to the present invention.

Multilayer optical films as used in conjunction with the present invention exhibit relatively low absorption of incident light, as well as high reflectivity for off-axis as well as normal light rays. These properties generally hold whether the films are used for pure reflection or reflective polarization of light. The unique properties and advantages of the multilayer optical film provides an opportunity to design highly-efficient backlight systems which exhibit low absorption losses when compared to known backlight systems.

An exemplary multilayer optical film of the present invention as illustrated in Figures 1A and 1B includes a multilayer stack 10 having alternating layers of at least two materials 12 and 14. At least one of the materials has the property of stress-induced birefringence, such that the index of refraction (n) of the material is affected by the stretching process. Figure 1A shows an exemplary multilayer stack before the stretching process in which both materials have the same index of refraction. Light ray 13 experiences relatively little change in index of refraction and passes through the stack. In

Figure 1B, the same stack has been stretched, thus increasing the index of refraction of material 12. The difference in refractive index at each boundary between layers will cause part of ray 15 to be reflected. By stretching the multilayer stack over a range of uniaxial to biaxial orientation, a film is created with a range of reflectivities for differently oriented plane-polarized incident light. The multilayer stack can thus be made useful as reflective polarizers or mirrors.

Multilayer optical films constructed according to the present invention exhibit a Brewster angle (the angle at which reflectance goes to zero for light incident at any of the layer interfaces), which is very large or is nonexistent for the polymer layer interfaces. In contrast, known multilayer polymer films exhibit relatively small Brewster angles at layer interfaces, resulting in transmission of light and/or undesirable iridescence. The multilayer optical films according to the present invention, however, allow for the construction of mirrors and polarizers whose reflectivity for *p* polarized light decrease slowly with angle of incidence, are independent of angle of incidence, or increase with angle of incidence away from the normal. As a result, multilayer stacks having high reflectivity for both *s* and *p* polarized light over a wide bandwidth, and over a wide range of angles can be achieved.

Figure 2 shows two layers of a multilayer stack, and indicates the three dimensional indices of refraction for each layer. The indices of refraction for each layer are n_{1x}, n_{1y}, and n_{1z} for layer 102, and n_{2x}, n_{2y}, and n_{2z} for layer 104. The relationships between the indices of refraction in each film layer to each other and to those of the other layers in the film stack determine the reflectance behavior of the multilayer stack at any angle of incidence, from any azimuthal direction. The principles and design considerations described in U.S. Patent No. 5,882,774 can be applied to create multilayer stacks having the desired optical effects for a wide variety of circumstances and applications. The indices of refraction of the layers in the multilayer stack can be manipulated and tailored to produce the desired optical properties.

Referring again to Figure 1B, the multilayer stack 10 can include tens, hundreds or thousands of layers, and each layer can be made from any of a number of different materials. The characteristics that determine the choice of materials for a particular stack depend upon the desired optical performance of the stack. The stack can contain as many materials as there are layers in the stack. For ease of manufacture, preferred optical thin film stacks contain only a few different materials.

The boundaries between the materials, or chemically identical materials with different physical properties, can be abrupt or gradual. Except for some simple cases with analytical solutions, analysis of the latter type of stratified media with continuously varying refractive index is usually treated as a much larger number of thinner uniform layers having abrupt boundaries but with only a small change in properties between adjacent layers.

The preferred multilayer stack is comprised of low/high refractive index pairs of film layers, wherein each low/high refractive index pair of layers has a combined optical thickness of 1/2 the center wavelength of the band it is designed to reflect. Stacks of such films are commonly referred to as quarterwave stacks. For multilayer optical films concerned with the visible and the near infrared wavelengths, a quarterwave stack design results in each of the layers in the multilayer stack having an average thickness of not more than 0.5 microns.

In those applications where reflective films (e.g. mirrors) are desired, the desired average transmission for light of each polarization and plane of incidence generally depends upon the intended use of the reflective film. One way to produce a multilayer mirror film is to biaxially stretch a multilayer stack. For a high efficiency reflective film, average transmission along each stretch direction at normal incidence over the visible spectrum (380-750 nm) is desirably less than 10 percent (reflectance greater than 90 percent), preferably less than 5 percent (reflectance greater than 95 percent), more preferably less than 2 percent (reflectance greater than 98 percent), and even more preferably less than 1 percent (reflectance greater than 99 percent). The average transmission at 60 degrees from the normal from 380-750 nm is desirably less than 20 percent (reflectance greater than 80 percent), preferably less than 10 percent (reflectance greater than 90 percent), more preferably less than 5 percent (reflectance greater than 95 percent), and even more preferably less than 2 percent (reflectance greater than 98 percent), and even more preferably less than 1 percent (reflectance greater than 99 percent).

In addition, asymmetric reflective films may be desirable for certain applications. In that case, average transmission along one stretch direction may be desirably less than, for example, 50 percent, while the average transmission along the other stretch direction may be desirably less than, for example 20 percent, over a bandwidth of, for example, the visible spectrum (380-750 nm), or over the visible spectrum and into the near infrared (e.g., 380-850 nm).

Multilayer optical films can also be designed to operate as reflective polarizers. One way to produce a multilayer reflective polarizer is to uniaxially stretch a multilayer stack. The resulting reflective polarizers have high reflectivity for light with its plane of polarization parallel to one axis (in the stretch direction) for a broad range of angles of incidence, and simultaneously have low reflectivity and high transmissivity for light with its plane of polarization parallel to the other axis (in the non-stretch direction) for a broad range of angles of incidence. By controlling the three indices of refraction of each film, n_x, n_y and n_z, the desired polarizer behavior can be obtained.

For many applications, the ideal reflecting polarizer has high reflectance along one axis (the so-called extinction axis) and zero reflectance along the other (the so-called transmission axis), at all angles of incidence. For the transmission axis of a polarizer, it generally desirable to maximize transmission of light polarized in the direction of the transmission axis over the bandwidth of interest and also over the range of angles of interest.

The average transmission at normal incidence for a polarizer in the transmission axis across the visible spectrum (380-750 nm for a bandwidth of 300 nm) is desirably at least 50 percent, preferably at least 70 percent, more preferably at least 80 percent, and even more preferably at least 90 percent. The average transmission at 60 degrees from the normal (measured along the transmission axis for p-polarized light) for a polarizer from 380-750 nm is desirably at least 50 percent, preferably at least 70 percent, more preferably at least 80 percent, and even more preferably at least 90 percent.

The average transmission for a multilayer reflective polarizer at normal incidence for light polarized in the direction of the extinction axis across the visible spectrum (380-750 nm for a bandwidth of 300 nm) is desirably at less than 50 percent, preferably less than 30 percent, more preferably less than 15 percent, and even more preferably less than 5 percent. The average transmission at 60 degrees from the normal (measured along the transmission axis for p-polarized light) for a polarizer for light polarized in the direction of the extinction axis from 380-750 nm is desirably less than 50 percent, preferably less than

30 percent, more preferably less than 15 percent, and even more preferably less than 5 percent.

For certain applications, high reflectivity for p-polarized light with its plane of polarization parallel to the transmission axis at off-normal angles are preferred. The average reflectivity for light polarized along the transmission axis should be more than 20 percent at an angle of at least 20 degrees from the normal.

In addition, although reflective polarizing films and asymmetric reflective films are discussed separately herein, it should be understood that two or more of such films could be provided to reflect substantially all light incident on them (provided they are properly oriented with respect to each other to do so). This construction is typically desired when the multilayer optical film is used as a reflector in a backlight system according to the present invention.

If some reflectivity occurs along the transmission axis, the efficiency of the polarizer at off-normal angles may be reduced. If the reflectivity along the transmission axis is different for various wavelengths, color may be introduced into the transmitted light. One way to measure the color is to determine the root mean square (RMS) value of the transmissivity at a selected angle or angles over the wavelength range of interest. The percent RMS color can be determined according to the equation:

$$C_{RMS} = \frac{\int_{\lambda 1}^{\lambda 2} ((T-\overline{T})^2)^{1/2} d\lambda}{\overline{T}}$$

wherein the range λ1 to λ2 is the wavelength range, or bandwidth, of interest, T is the transmissivity along the transmission axis, and $\overline{T}$ is the average transmissivity along the transmission axis in the wavelength range of interest. For applications where a low color polarizer is desirable, the percent RMS color should be less than 10 percent, preferably less than 8 percent, more preferably less than 3.5 percent, and even more preferably less than 2 percent at an angle of at least 30 degrees from the normal, preferably at least 45 degrees from the normal, and even more preferably at least 60 degrees from the normal.

Preferably, a reflective polarizer combines the desired percent RMS color along the transmission axis for the particular application with the desired amount of reflectivity along the extinction axis across the bandwidth of interest. For polarizers having a bandwidth in the visible range (400-700 nm, or a bandwidth of 300 nm), average transmission along the extinction axis at normal incidence is desirably less than 40 percent, more desirably less than 25 percent, preferably less than 15 percent, more preferably less than 5 percent and even more preferably less than 3 percent.

Materials Selection and Processing

With the design considerations described in the above mentioned U.S. Patent No. 5,882,774, one of ordinary skill will readily appreciate that a wide variety of materials can be used to form multilayer reflective films or polarizers according to the invention when processed under conditions selected to yield the desired refractive index relationships. The desired refractive index relationships can be achieved in a variety of ways, including stretching during or after film formation (e.g., in the case of organic polymers), extruding (e.g., in the case of liquid crystalline materials), or coating. In addition, it is preferred that the two materials have similar rheological properties (e.g., melt viscosities) such that they can be co-extruded.

In general, appropriate combinations may be achieved by selecting, as the first material, a crystalline or semi-crystalline, or liquid crystalline material, preferably a polymer. The second material, in turn, may be crystalline, semi-crystalline, or amorphous. The second material may have a birefringence opposite to or the same as that of the first material. Or, the second material may have no birefringence. It should be understood that in the polymer art it is generally recognized that polymers are typically not entirely crystalline, and therefore in the context of the present invention, crystalline or semi-crystalline polymers refer to those polymers that are not amorphous and includes any of those materials commonly referred to as crystalline, partially crystalline, semi-crystalline, etc. The second material may have a birefringence opposite to or the same as that of the first material. Or, the second material may have no birefringence.

Specific examples of suitable materials include polyethylene naphthalate (PEN) and isomers thereof (e.g., 2,6-, 1,4-, 1,5-, 2,7-, and 2,3-PEN), polyalkylene terephthalates (e.g., polyethylene terephthalate, polybutylene terephthalate, and poly-1,4-cyclohexanedimethylene terephthalate), polyimides (e.g., polyacrylic imides), polyetherimides, atactic polystyrene, polycarbonates, polymethacrylates (e.g., polyisobutyl methacrylate, polypropylmethacrylate, polyethylmethacrylate, and polymethylmethacrylate), polyacrylates (e.g., polybutylacrylate and polymethylacrylate), syndiotactic polystyrene (sPS), syndiotactic poly-alpha-methyl styrene, syndiotactic polydichlorostyrene, copolymers and blends of any of these polystyrenes, cellulose derivatives (e.g., ethyl cellulose, cellulose acetate, cellulose propionate, cellulose acetate butyrate, and cellulose nitrate), polyalkylene polymers (e.g., polyethylene, polypropylene, polybutylene, polyisobutylene, and poly(4-methyl)pentene), fluorinated polymers (e.g., perfluoroalkoxy resins, polytetrafluoroethylene, fluorinated ethylene-propylene copolymers, polyvinylidene fluoride, and polychlorotrifluoroethylene), chlorinated polymers (e.g., polyvinylidene chloride and polyvinylchloride), polysulfones, polyethersulfones, polyacrylonitrile, polyamides, silicone resins, epoxy resins, polyvinylacetate, polyether-amides, ionomeric resins, elastomers (e.g., polybutadiene, polyisoprene, and neoprene), and polyurethanes. Also suitable are copolymers, e.g., copolymers of PEN (coPEN) (e.g., copolymers of 2,6-, 1,4-, 1,5-, 2,7-, and/or 2,3-naphthalene dicarboxylic acid, or esters thereof, with (a) terephthalic acid, or esters thereof; (b) isophthalic acid, or esters thereof; (c) phthalic acid, or esters thereof; (d) alkane glycols; (e) cycloalkane glycols (e.g., cyclohexane dimethane diol); (f) alkane dicarboxylic acids; and/or (g) cycloalkane dicarboxylic acids (e.g., cyclohexane dicarboxylic acid)), copolymers of polyalkylene terephthalates (e.g., copolymers of terephthalic acid, or esters thereof, with (a) naphthalene dicarboxylic acid, or esters thereof; (b) isophthalic acid, or esters thereof; (c) phthalic acid, or esters thereof; (d) alkane glycols; (e) cycloalkane glycols (e.g., cyclohexane dimethanel diol); (f) alkane dicarboxylic acids; and/or (g) cycloalkane dicarboxylic acids (e.g., cyclohexane dicarboxylic acid)), and styrene copolymers (e.g., styrene-butadiene copolymers and styrene-acrylonitrile copolymers), 4,4'-bibenzoic acid and ethylene glycol. In addition, each individual layer may include blends of two or more of the above-described polymers or copolymers (e.g., blends of sPS and atactic polystyrene). The coPEN described may also be a blend of pellets where at least one component is a polymer based on naphthalene dicarboxylic acid and other components are other polyesters or polycarbonates, such as a PET, a PEN or a coPEN.

Particularly preferred combinations of layers in the case of polarizers include PEN/coPEN, polyethylene terephthalate (PET)/coPEN, PEN/sPS, PET/sPS, PEN/Estar, and PET/Estar, where "coPEN" refers to a copolymer or blend based upon naphthalene dicarboxylic acid (as described above) and Estar is polycyclohexanedimethylene terephthalate commercially available from Eastman Chemical Co.

Particularly preferred combinations of layers in the case of reflective films include PET/Ecdel, PEN/Ecdel, PEN/sPS, PEN/THV, PEN/co-PET, and PET/sPS, where "co-PET" refers to a copolymer or blend based upon terephthalic acid (as described above), Ecdel is a thermoplastic polyester commercially available from Eastman Chemical Co., and THV is a fluoropolymer commercially available from Minnesota Mining and Manufacturing Company, St. Paul, Minnesota.

The number of layers in the film is selected to achieve the desired optical properties using the minimum number of layers for reasons of film thickness, flexibility and economy. In the case of both polarizers and reflective films, the number of layers is preferably less than 10,000, more preferably less than 5,000, and even more preferably less than 2,000.

As discussed above, the ability to achieve the desired relationships among the various indices of refraction (and thus the optical properties of the multilayer film) is influenced by the processing conditions used to prepare the multilayer film. In the case of organic polymers which can be oriented by stretching, the films are generally prepared by co-extruding the individual polymers to form a multilayer film and then orienting the film by stretching at a selected temperature, optionally followed by heat-setting at a selected temperature. Alternatively, the extrusion and orientation steps may be performed simultaneously. In the case of polarizers, the film is stretched substantially in one direction (uniaxial orientation), while in the case of reflective films the film is stretched substantially in two directions (biaxial orientation).

The film may be allowed to dimensionally relax in the cross-stretch direction from the natural reduction in cross-stretch (equal to the square root of the stretch ratio); it may simply be constrained to limit any substantial change in cross-stretch dimension; or it may be actively stretched in the cross-stretch dimension. The film may be stretched in the machine direction, as with a length orienter, or in width using a tenter.

The pre-stretch temperature, stretch temperature, stretch rate, stretch ratio, heat set temperature, heat set time, heat set relaxation, and cross-stretch relaxation are selected to yield a multilayer film having the desired refractive index relationship. These variables are interdependent; thus, for example, a relatively low stretch rate could be used if coupled with, e.g., a relatively low stretch temperature. It will be apparent to one of ordinary skill how to select the appropriate combination of these variables to achieve the desired

3multilayer film. In general, however, a stretch ratio in the range from 1:2 to 1:10 (more preferably 1:3 to 1:7) in the stretch direction and from 1:0.2 to 1:10 (more preferably from 1:0.2 to 1:7) orthogonal to the stretch direction is preferred.

Suitable multilayer films may also be prepared using techniques such as spin coating (e.g., as described in Boese et al., J. Polym. Sci.: Part B, 30:1321 (1992) for birefringent polyimides, and vacuum deposition (e.g., as described by Zang et. al., Appl. Phys. Letters, 59:823 (1991) for crystalline organic compounds; the latter technique is particularly useful for certain combinations of crystalline organic compounds and inorganic materials.

Exemplary multilayer reflective mirror films and multilayer reflective polarizers will now be described in the following examples.

Example 1

(PEN:THV 500, 449, Mirror)

A coextruded film containing 449 layers was made by extruding the cast web in one operation and later orienting the film in a laboratory film-stretching apparatus. A polyethylene naphthalate (PEN) with an Intrinsic Viscosity of 0.53 dl/g (as measured in a solution of 60 weight percent phenol/40 weight percent dichlorobenzene) was delivered by one extruder at a rate of 56 pounds per hour and THV 500 (a fluoropolymer available from Minnesota Mining and Manufacturing Company) was delivered by another extruder at a rate of 11 pounds per hour. The PEN was on the skin layers and 50 percent of the PEN was present in the two skin layers. The feedblock method was used to generate 57 layers which were passed through three multipliers producing an extrudate of 449 layers. The cast web was 20 mils thick and 30.4 cm wide. The web was later biaxially oriented using a laboratory stretching device that uses a pantograph to grip a square section of film and simultaneously stretch it in both directions at a uniform rate. A 7.46 cm square of web was loaded into the stretcher at about 100°C and heated to 140°C in 60 seconds. Stretching then commenced at 10 percent/sec (based on original dimensions) until the sample was stretched to about 3.5x3.5. Immediately after the stretching the sample was cooled by blowing room temperature air at it.

Figure 3 shows the transmission of this multilayer film. Curve (a) shows the response at normal incidence for light polarized in the transmission direction, while curve

(b) shows the response at 60 degrees for p-polarized light polarized in the transmission direction.

Example 2

(PEN:PMMA, 601, Mirror)

A coextruded film containing 601 layers was made on a sequential flat-film-making line via a coextrusion process. Polyethylene Naphthalate (PEN) with an Intrinsic Viscosity of 0.57 dl/g (as measured in a solution of 60 weight percent phenol/40 weight percent dichlorobenzene) was delivered by extruder A at a rate of 114 pounds per hour with 64 pounds per hour going to the feedblock and the rest going to skin layers described below. PMMA (CP-82 from ICI of Americas) was delivered by extruder B at a rate of 61 pounds per hour with all of it going to the feedblock. PEN was on the skin layers of the feedblock. The feedblock method was used to generate 151 layers using the feedblock such as those described in U.S. Patent No. 3,801,429, after the feedblock two symmetric skin layers were coextruded using extruder C metering about 30 pounds per hour of the same type of PEN delivered by extruder A. This extrudate passed through two multipliers producing an extrudate of about 601 layers. U.S. Patent No. 3,565,985 describes similar coextrusion multipliers. The extrudate passed through another device that coextruded skin layers at a total rate of 50 pounds per hour of PEN from extruder A. The web was length oriented to a draw ratio of about 3.2 with the web temperature at about 138°C. The film was subsequently preheated to about 154°C in about 38 seconds and drawn in the transverse direction to a draw ratio of about 4.5 at a rate of about 11 percent per second. The film was then heat-set at 227°C with no relaxation allowed. The finished film thickness was about 3 mil.

As seen in Figure 4, curve (a), the bandwidth at normal incidence is about 350 nm with an average in-band extinction of greater than 99 percent. The amount of optical absorption is difficult to measure because of its low value, but is less than 1 percent. At an incidence angle of 50 percent from the normal both s (curve (b)) and p-polarized (curve (c)) light showed similar extinctions, and the bands were shifted to shorter wavelengths as expected. The red band-edge for s-polarized light is not shifted to the blue as much as for p-polarized light due to the expected larger bandwidth for s-polarized light, and due to the lower refractive index seen by the p-polarized light in the PEN layers.

Example 3

(PEN:PCTG, 449, Polarizer)

A coextruded film containing 481 layers was made by extruding the cast web in one operation and later orienting the film in a laboratory film-stretching apparatus. The feedblock method was used with a 61 layer feedblock and three (2x) multipliers. Thick skin layers were added between the final multiplier and the die. Polyethylene naphthalate (PEN) with an intrinsic viscosity of 0.47 dl/g (as measured in a solution of 60 weight percent phenol/40 weight percent dichlorobenzene) was delivered to the feedblock by one extruder at a rate of 25.0 pounds per hour. Glycol modified polyethylene dimethyl cyclohexane terephthalate (PCTG 5445 from Eastman) was delivered by another extruder at a rate of 25.0 pounds per hour. Another stream of PEN from the above extruder was added as skin layers after the multipliers at a rate of 25.0 pounds per hour. The cast web was 0.18 mm thick and 30.5 cm wide. The web was layer uniaxially oriented using a laboratory stretching device that uses a pantograph to grip a section of film and stretch it in one direction at a uniform rate while it is allowed to freely relax in the other direction. The sample of web loaded was about 5.40 cm wide (the unconstrained direction) and 7.45 cm long between the grippers of the pantograph. The web was loaded into the stretcher at about 100°C and heated to 135°C for 45 seconds. Stretching was then commenced at 20 percent/second (based on original dimensions) until the sample was stretched to about 6:1 (based on gripper to gripper measurements). Immediately after stretching, the sample was cooled by blowing room temperature air at it. In the center, the sample was found to relax by a factor of 2.0.

Figure 5 shows the transmission of this multilayer film where curve a shows transmission of light polarized in the non-stretch direction at normal incidence, curve b shows transmission of p-polarized light polarized in the non-stretched direction at 60 degree incidence, and curve c shows the transmission of light polarized in the stretch direction at normal incidence. Average transmission for curve a from 400-700 nm is 89.7 percent, average transmission for curve b from 400-700 nm is 96.9 percent, and average transmission for curve c from 400-700 nm is 4.0 percent. Percent RMS color for curve a is 1.05 percent, and percent RMS color for curve b is 1.44 percent.

Example 4

(PEN:coPEN, 601, Polarizer)

A coextruded film containing 601 layers was made on a sequential flat-film-making line via a coextrusion process. A Polyethylene naphthalate (PEN) with an intrinsic viscosity of 0.54 dl/g (as measured in a solution of 60 weight percent Phenol /40 weight percent dichlorobenzene) was delivered by on extruder at a rate of 75 pounds per hour and the coPEN was delivered by another extruder at 65 pounds per hour. The coPEN was a copolymer of 70 mole percent 2,6 naphthalene dicarboxylate methyl ester, 15 percent dimethyl isophthalate and 15 percent dimethyl terephthalate with ethylene glycol. The feedblock method was used to generate 151 layers. The feedblock was designed to produce a stack of films having a thickness gradient from top to bottom, with a thickness ratio of 1.22 from the thinnest layers to the thickest layers. The PEN skin layers were coextruded on the outside of the optical stack with a total thickness of 8 percent of the coextruded layers. The optical stack was multiplied by two sequential multipliers. The nominal multiplication ratio of the multipliers were 1.2 and 1.27, respectively. The film was subsequently preheated to 154°C in about 40 seconds and drawn in the transverse direction to a draw ratio of about 5.0 at a rate of 6 percent per second. The finished film thickness was about 2 mils.

Figure 6 shows the transmission for this multilayer film. Curve a shows transmission of light polarized in the non-stretch direction at normal incidence, curve b shows transmission of p-polarized light at 60 degree incidence, and curve c shows transmission of light polarized in the stretch direction at normal incidence. Note the very high transmission of p-polarized light in the non-stretch direction at both normal and 60 degree incidence (80-100 percent). Also note the very high reflectance of light polarized in the stretched direction in the visible range (400-700 nm) shown by curve c. Reflectance is nearly 100 percent between 500 and 650 nm.

Example 5

(PEN:sPS, 481, Polarizer)

A 481 layer multilayer film was made from a polyethylene naphthalate (PEN) with an intrinsic viscosity of 0.56 dl/g (as measured in a solution of 60 weight percent phenol/40 weight percent dichlorobenzene) purchased from Eastman Chemicals and a syndiotactic polystyrene (sPS) homopolymer (weight average molecular weight = 200,000 Daltons, sampled from Dow Corporation). The PEN was on the outer layers and was extruded at 26 pounds per hour and the sPS at 23 pounds per hour. The feedblock used produced 61 layers with each of the 61 being approximately the same thickness. After the feedblock three (2x) multipliers were used. Equal thickness skin layers containing the same PEN fed to the feedblock were added after the final multiplier at a total rate of 22 pounds per hour. The web was extruded through a 30.5 cm wide die to a thickness of about 0.276 mm. The extrusion temperature was 290°C.

This web was stored at ambient conditions for nine days and then uniaxially oriented on a tenter. The film was preheated to about 160°C) in about 25 seconds and drawn in the transverse direction to a draw ratio of about 6:1 at a rate of about 28 percent per second. No relaxation was allowed in the stretched direction. The finished film thickness was about 0.046 mm.

Figure 7 shows the optical performance of this PEN:sPS reflective polarizer containing 481 layers. Curve a shows transmission of light polarized in the non-stretch direction at normal incidence, curve b shows transmission of p-polarized light at 60 degree incidence, and curve c shows transmission of light polarized in the stretch direction at normal incidence. Note the very high transmission of p-polarized light at both normal and 60 degree incidence. Average transmission for curve a over 400-700 nm is 86.2 percent, the average transmission for curve b over 400-700 nm is 79.7 percent. Also note the very high reflectance of light polarized in the stretched direction in the visible range (400-700 nm) shown by curve c. The film has an average transmission of 1.6 percent for curve c between 400 and 700 nm. The percent RMS color for curve a is 3.2 percent, while the percent RMS color for curve b is 18.2 percent.

Example 6

(PEN:coPEN, 603, Polarizer)

A reflecting polarizer comprising 603 layers was made on a sequential flat-film making line via a coextrusion process. A polyethylene naphthalate (PEN) with an intrinsic viscosity of 0.47 dl/g (as measured in a solution of 60 weight percent phenol/40 weight percent dichlorobenzene) was delivered by an extruder at a rate of 83 pounds (38 kg) per hour and the coPEN was delivered by another extruder at 75 pounds (34 kg) per hour. The coPEN was a copolymer of 70 mole percent, 2,6 naphthalene dicarboxylate methyl ester, 15 mole percent dimethyl terephthalate, and 15 mole percent dimethyl isophthalate with ethylene glycol. The feedblock method was used to generate 151 layers. The feedblock was designed to produce a stack of films having a thickness gradient from top to bottom, with a thickness ratio of 1.22 from the thinnest layers to the thickest layers. This optical stack was multiplied by two sequential multipliers. The nominal multiplication ratio of the multipliers was 1.2 and 1.4, respectively. Between the final multiplier and the die, skin layers were added composed of the same coPEN described above, delivered by a third extruder at a total rate of 106 pounds (48 kg) per hour. The film was subsequently preheated to 150°C in about 30 seconds and drawn in the transverse direction to a draw ratio of approximately 6 at an initial rate of about 20 percent per second. The finished film thickness was approximately 0.089 mm.

Figure 8 shows the optical performance of the polarizer of Example 6. Curve a shows transmission of light polarized in the non-stretch direction at normal incidence, curve b shows transmission of p-polarized light in the nonstretch direction at 50 degree angle of incidence, and curve c shows transmission of light polarized in the stretch direction at normal incidence. Note the very high transmission of light polarized in the non-stretch direction. Average transmission for curve a over 400-700 nm is 87 percent. Also note the very high reflectance of light polarized in the stretched direction in the visible range (400-700 nm) shown by curve b. The film has an average transmission of 2.5 percent for curve b between 400 and 700 nm. In addition, the percent RMS color of this polarizer is very low. The percent RMS color for curve b is 5 percent.

While the multilayer optical stacks, as described above, can provide significant and desirable optical properties, other properties, which may be mechanical, optical, or chemical, are difficult to provide in the optical stack itself without degrading the performance of the optical stack. Such properties may be provided by including one or more layers with the optical stack that provide these properties while not contributing to the primary optical function of the optical stack itself. Since these layers are typically provided on the major surfaces of the optical stack, they are often known as “skin layers.”

A skin layer may be coextruded on one or both major surfaces of the multilayer stack during its manufacture to protect the multilayer stack from the high shear along the feedblock and die walls, and often an outer layer with the desired chemical or physical properties can be obtained by mixing an additive, such as, for example, a UV stabilizer, into the polymer melt that makes up the skin layer, and coextruding the skin layer with altered properties onto one or both sides of the multilayer optical stack during manufacture. Alternately, additional layers may be coextruded on the outside of the skin layers during manufacture of the multilayer film; they may be coated onto the multilayer film in a separate coating operation; or they may be laminated to the multilayer film as a separate film, foil, or rigid or semi-rigid reinforcing substrate such as polyester (PET), acrylic (PMMA), polycarbonate, metal, or glass. Adhesives useful for laminating the multilayer polymer film to another surface include both optically clear and diffuse adhesives and include both pressure sensitive and non-pressure sensitive adhesives. Pressure sensitive adhesives are normally tacky at room temperature and can be adhered to a surface by application of, at most, light finger pressure, while non-pressure sensitive adhesives include solvent, heat, or radiation activated adhesive systems. Examples of adhesives useful in the present invention include those based on general compositions of polyacrylate; polyvinyl ether; diene-containing rubber such as natural rubber, polyisoprene, and polyisobutylene; polychloroprene; butyl rubber; butadiene-acrylonitrile polymer; thermoplastic elastomer;. block copolymers such as styrene-isoprene and styrene-isoprene-styrene block copolymers, ethylene-propylene-diene polymers, and styrene-butadiene polymer; poly-alpha-olefin; amorphous polyolefin; silicone; ethylene-containing copolymer such as ethylene vinyl acetate, ethylacrylate, and ethyl methacrylate; polyurethane; polyamide; epoxy; polyvinylpyrrolidone and vinylpyrrolidone copolymers; polyesters; and mixtures of the above. Additionally, the adhesives can contain additives such as tackifiers, plasticizers, fillers, antioxidants, stabilizers, pigments, diffusing particles, curatives, biocides, and solvents. Preferred adhesives useful in the present invention include VITEL 3300, a hot melt adhesive available from Shell Chemical Co. (Akron, OH), or an acrylic pressure sensitive adhesive such as a 90/10 IOA/AA acrylic adhesive from Minnesota Mining and Manufacturing Company, St. Paul, Minnesota. When a laminating adhesive is used to adhere the multilayer film to another surface, the adhesive composition and thickness are preferably selected so as not to interfere with the optical properties of the multilayer stack. For example, when laminating additional layers to a multilayer polymer polarizer or mirror wherein a high degree of transmission is desired, the laminating adhesive should be optically clear in the wavelength region that the polarizer or mirror is designed to be transparent.

Figures 10 and 11 illustrate multilayer stacks having respectively one and two additional layers, respectively. Figures 10 and 11 will be used below to describe a variety of additional layers that could be applied.

One area in which a skin layer having differing mechanical properties is desirable relates particularly to uniaxially oriented multilayer optical stacks, such as reflective polarizers. Such stacks often tend to show a low tear resistance in the principal draw direction. This can lead to reduced yields during the manufacturing process or to subsequent breakage of the film during handling. In order to resist this, tear resistant layers may be adhered to the outer major surfaces of the optical stack. These tough layers may be of any appropriate material and could even be the same as one of the materials used in the optical stack. Factors to be considered in selecting a material for a tear resistant layer include percent elongation to break, Young's modulus, tear strength, adhesion to interior layers, percent transmittance and absorbance in an electromagnetic bandwidth of interest, optical clarity or haze, refractive indices as a function of frequency, texture and roughness, melt thermal stability, molecular weight distribution, melt rheology and coextrudability, miscibility and rate of inter-diffusion between materials in the tough and optical layers, viscoelastic response, relaxation and crystallization behavior under draw conditions, thermal stability at use temperatures, weatherability, ability to adhere to coatings and permeability to various gases and solvents. Of course, as previously stated, it is important that the material chosen not have optical properties deleterious to those of the optical stack. They may be applied during the manufacturing process or later coated onto or laminated to the optical stack. Adhering these layers to the optical stack during the manufacturing process, such as by a coextrusion process, provides the advantage that the optical stack is protected during the manufacturing process.

Using Figure 10 to illustrate this aspect of the invention, a multilayer optical stack having tear resistant layers 400 is shown. Film 400 includes an optical stack 410. Optical stack 410 includes alternating layers 412 and 414 of two polymers having differing optical properties. Attached to the major surfaces of optical stack 410 are tear resistant layers 416 and 418. It should be noted that, although layers 416 and 418 are shown in Figure 10 as thicker than layers 412 and 414, Figure 10 is not to scale for a generally preferred embodiment. In general it is desirable that each of layers 416 and 418 have a thickness greater than 5 percent of the thickness of the optical stack. It is preferred that each of layers 416 and 418 have a thickness in the range of 5 percent to 60 percent of the thickness of the optical stack to provide tear resistance without unnecessarily increasing the amount of material used. Thus, if the optical stack has 600 layers, in such a preferred embodiment the thickness of each of tear resistant layers 416 and 418 would be equal to the thickness of 30 to 360 of the layers of the stack. In a more preferred embodiment each of the tear resistant layers 416 and 418 would have a thickness in the range of 30 percent to 50 percent of that of the optical stack.

In a particularly desirable embodiment, tear resistant outer layers may be of one of the same materials used in alternating layers 412 and 414. In particular, it has been discovered that in a reflective polarizer comprising alternating layers of PEN and coPEN, tear resistant outer layers of coPEN may be coextruded during the manufacturing process.

Example 7

A multilayered composite of alternating PEN and coPEN layers to form a reflective polarizer was coextruded with thick skin layers of coPEN to form a tear resistant reflective polarizer. A coextruded film containing 603 layers was made on a sequential flat-film extruder. A polyethylene naphthalate (PEN) with an intrinsic viscosity of 0.47 dl/g (as measured in a solution of 60 weight percent phenol/40 weight percent dichlorobenzene) was delivered by an extruder at a rate of 86 pounds per hour and the coPEN was delivered by another extruder at 78 pounds per hour. The coPEN was a copolymer of 70 mole percent, 2,6 naphthalene dicarboxylate methyl ester and 30 percent dimethyl terephthalate with ethylene glycol. The feedblock extruded 151 layers. The feedblock was designed to produce a stack of films having a thickness gradient from top to bottom, with a thickness ratio of 1.22 from the thinnest layers to the thickest layers. This optical stack was multiplied by two sequential multipliers. The nominal multiplication ratio of the multipliers was 1.2 and 1.27, respectively. Between the final multipliers and the die, composed of coPEN as described above, layers were added. These layers were charged and delivered by a third extruder at a total rate of 187 pounds per hour. The film with the additional coPEN outer layers was preheated to 160°C in about 40 seconds and drawn in the transverse direction to a draw ratio of approximately 6 at an initial rate of about 20 percent per second. The finished film had a thickness of approximately 100 µm including an inner multilayered optical stack of about 50 µm thickness and two exterior outer layers (one on each side of the film) of about 25 µm thickness, each. Tear resistance improved over the case without skins allowing the creation of wound rolls of tough reflective polarizer. Specifically, tear resistance was measured on films made according to this example and on film made under similar conditions but without coPEN skin layers using a trouser tear test along the principal draw direction, according to ASTM D-1938. Average film thicknesses were 100 µm and 48 µm, respectively. The average tear force values were 60.2 and 2.9 grams force, with standard deviations of 4.44 and 0.57 grams force, respectively. Analysis of the coPEN skin layers showed low orientation with indices of refraction of 1.63, 1.62, and 1.61 at 633 nm. Good interlayer adhesion was demonstrated by the difficulty of cleanly separating the construction. For further comparison a 48 µm optical stack having 3.8 µm outer layers of PEN was tested and found to have an average tear force of 2.8 grams with a standard deviation of 1.07.

The appearance and/or performance of a film may be altered by including a skin layer having a dye or pigment that absorbs in one or more selected regions of the spectrum. This can include portions or all of the visible spectrum as well as ultraviolet and infrared. Of course, if all of the visible spectrum is absorbed, the layer will be opaque. These can be selected in order to change the apparent color of light transmitted or reflected by the film and can include dyes and pigments with fluorescent properties. Fluorescent materials are often chosen to absorb electromagnetic energy in the ultraviolet region of the spectrum and reemit in the visible. They can also be used to compliment the properties of the film, particularly where the film transmits some frequencies while reflecting others. Thus, Figure 9 illustrates such a film with layer 316 representing a layer containing an electromagnetic absorbing material.

The use of an UV absorptive or protective material in a cover layer is particularly desirable because it may be used to protect the inner layers that may be unstable when exposed to UV radiation. Desirable protective materials include hindered amine light stabilizers (HALS), which could be incorporated in layer 316 of Figure 9 or one or both layers 416 and 418 of Figure 9, and are described in more detail in U.S. Patent No. 5,605,761.

Pressure sensitive adhesives form another desirable class of materials that may be applied to a multilayer stack as layer 316 of Figure 9 or one of layers 416 or 418 of Figure 10. Generally pressure sensitive adhesives may be applied when the optical stack is intended for later lamination to another material, such as a glass or metal substrate.

Another material that could be incorporated in a skin layer such as layer 316 or one of layers 416 or 418 would be a slip agent. A slip agent will make the film easier to handle during the manufacturing process. Typically a slip agent would be used with a mirror film rather than a film intended to transmit a portion of the light striking it. The side including the slip agent would typically be the side intended to be laminated to a supporting substrate in order to prevent the slip agent from increasing haze associated with the reflection.

Another type of additional layer that could be used is a protective layer. Such a layer could be abrasion resistant or resistant to weathering and/or chemical action. Such coatings would be particularly useful in situations where the multilayer film is to be exposed to a harsh or corrosive environment. Examples of abrasion-resistant or hard coatings include acrylic hardcoats such as Acryloid A-11 and Paraloid K-120N, available from Rohm & Haas; urethane acrylates, such as described in U.S. Patent No. 4,249,011 and those available from Sartomer Corp.; and urethane hardcoats such as those obtained from reacting an aliphatic polyisocyanate such as Desmodur N-3300, available from Miles, Inc. with a polyester such as Tone Polyol 0305, available from Union Carbide. Such layers could also provide protection against transmission of gases such as oxygen or carbon dioxide or water vapor through the film. Again this could be a single layer as shown in Figure 9 or layers on both sides as shown in Figure 10.

Figure 11 shows alternative multilayer film 500 having alternating layers 512 and 514 with protective layers 516, 518, and 520. Thus, multiple additional layers could be provided adjacent a single major surface of the multilayer optical stack. An example of a use for a structure of the type shown in Figure 11 would be one in which protective layers 516 and 518 were tear resistant structures, as described above, and layer 520 was abrasion resistant.

Other layers that could be added include layers containing holographic images, holographic diffusers, or other diffusing layers. Such layers could be in a hard polymer or in an adhesive. Preformed holographic materials, such as holographic hot stamping foil or holographic laminate film, could be attached to the outer surface of multilayer films. The holographic material could contain either a aluminum reflector for a metallized opaque effect or a high refractive index reflector for an essentially transparent effect. A holographic hot stamping foil could be applied using heat and pressure to the surface of the multilayer film. A typical transparent hologram hot stamping foil under the designation VC55-101G and a typical opaque holographic hot stamping foil under the designation BD68-100F are currently available from Crown Roll Leaf of Paterson, New Jersey. Alternately, a holographic film could be attached to the multilayer film using a hot melt or pressure sensitive adhesive. A typical transparent holographic film is currently available under the designation XLT-101W from Crown Roll Leaf. A typical pressure sensitive transfer adhesive on a liner under the designation 9458 is currently available from Minnesota Mining and Manufacturing Company, St. Paul, Minnesota (3M). The holographic image can either be viewed on the surface of the multilayer film or viewed through the multilayer film.

To those skilled in the art, the term "holographic images" can include holographic structures, diffraction gratings, electron beam generated structures, stereolithography generated structures, laser interferometric generated structures, holographic optical elements, and photopolymer volume holograms.

Such holographic images can be incorporated into multilayer optical films by embossing the holographic structure directly into the outer layer of the film, or by first coating an embossable resin onto the film, then embossing into it. In addition, the visibility and durability of the holographic structured surface can be enhanced by coating a high refractive index material on the structure. Further, an optional protective layer or adhesive can be added over the high refractive index coated structure, in order to attach the film to an article or protect the holographic structure from fingerprints and scratching. An alternative means for incorporating holographic images is to coat a suitable photopolymer onto a multilayer optical film, and then record a volume hologram in the photopolymer coating.

Also, the inherent reflectivity of polarizer, mirror, and color shifting mirror films can eliminate the need for an additional reflective layer that is typically added to holographic structures. Accordingly, another aspect of the present invention is the provision of a cost effective method to emboss holographic structures directly into the multilayer optical films and coat additional layers directly on the film to enhance the holographic images. Figures 12 through 20 illustrate, and Examples 8 through 17 describe, various embodiments of these aspects of the invention. In each of Figures 12 through 18, only a small number of layers are illustrated as being in the optical stack (the alternating layers of a first polymer and a second polymer), but this is simply for convenience. Multiple layers can be used as described herein.

Figure 12 illustrates a multilayer optical film 600 having alternating polymer layers 602 and 604, and polymeric skin layers 606 and 608. A holographic structure 610 that provides a holographic image is provided in one skin layer. In the embodiment illustrated in Figure 13, the holographic structure 610 is provided with a high refractive index layer 612 that may be applied by any appropriate method, including vacuum deposition. In the embodiment illustrated in Figure 14, an optional protective layer 614 is applied over the high refractive index layer 612, which helps to protect the holographic structure from damage, contaminants, and other environmental factors that may degrade the quality of the holographic image.

Figure 15 illustrates an embodiment of a multilayer optical film having a resin layer 616 applied to the film (preferably by coating, but potentially by lamination or other methods), in which the holographic structure 610 is embossed into the resin layer. Figure 16 illustrates an embodiment in which a resin layer 618 is cast onto the multilayer film and then cured (a "cast and cure" process), in which a holographic structure 610 is provided in the cast and cured layer.

In Figure 17, a holographic layer 620 is provided by a resin layer 622 having a holographic structure, a high refractive index reflector layer 624, and an adhesive layer 626 for applying the holographic layer 620 to the remainder of the multilayer film. The adhesive layer 626 may be a pressure sensitive adhesive, a hot-melt adhesive, or another suitable adhesive.

Figure 18 illustrates a holographic polarizing label 630 is provided, including a multilayer film of the type shown in Figure 12, for example, to which is bonded by, for example, adhesive 631 to label stock 632 that includes a label base film 634, a printed image 636 (alphanumeric or graphical, for example), and an adhesive layer 638 to bond the label to a substrate. A label or other laminate of this type may be bonded to articles of value such as, for example, software, boxes or cartons, documents of value, passports, consumer goods such as electronics and computers, and other such items. Figures 19 and 20 illustrate the use of the holographic polarizing label of the type illustrated in Figure 18. When the label is viewed by an observer through a verifying polarizer 640 held at one orientation, both the holographic image provided by the holographic structure and the printed image 636 are visible. When the verifying polarizer 640 is rotated with respect to the label (the verifying polarizer is "crossed" with the label), the printed image disappears, but the holographic image remains visible. This permits a user to verify the authenticity of the polarizing label, and accordingly to verify the authenticity of the item to which it is attached. This is further described with reference to Example 9, below.

Example 8

Polarizer film made from alternating layers of coPEN/PEN polymers had a half-silver reflective mirror appearance (available from Minnesota Mining and Manufacturing Company of St. Paul, Minnesota (3M) under the designation "Dual Brightness Enhancement Film, #98-0440-0037-4). The outer coPEN layer of the film was embossed with a holographic structure by the following method to provide a multilayer film of the kind shown in Figure 12. A nickel embossing plate was electroformed on a hologram master, creating a holographic structure in the image of a company logo, as is typically done in the holographic embossing industry. The plate was attached to a cylinder on an embossing machine, such as machines that are currently available from James River Holographics of Richmond, Virginia. The cylinder with the embossing plate was heated to 93°C. A roll of the polarizer film was threaded between the embossing cylinder and a metal back-up cylinder which was heated to 49°C. Pressure was applied to the cylinders to contact the polarizer film to the embossing plate, and a holographic structure was embossed into the surface of the polarizer film. Thereby, a roll of polarizer film was continuously embossed in an economical manner.

The holographic structure in the form of a company logo, which was embossed into the front surface of the polarizer film, was highly visible when viewed from the front of the film due to the reflective mirror appearance of the film. When the film was turned over, the holographic logos were not very visible when viewed through the back of the film, because the polarizing film reflected half of the light incident on the front of the film.

Example 9

The holographically embossed polarizer film from Example 8 was applied to a printed white label by applying the back of the film to the label using an adhesive, so that the holographic structure was exposed, as shown generally in Figure 18. The print on the label was visible through the half-silver polarizing film.

To verify the authenticity of the holographic image, another piece of polarizer film (without a hologram), called a verifying polarizer, was placed between the viewing person and the polarizing label with holographic image. When the verifying polarizer was rotated until it crossed the polarizer with holographic images, the underlying print on the label was substantially imperceptible due to the high reflectivity of the two crossed polarizer films, and the holographic images were visible, as shown in Figure 20. When the verifying polarizer was rotated 90 degrees so that it was parallel to the polarizer with holographic images, the underlying print on the label was again visible, and the holographic images were only faintly visible, as shown in Figure 19. Therefore, the authenticity of the holographic image could be verified by use of the verifying polarizer. Alternatively, viewing of the holographic polarizing label with a light source capable of transmitting light of at least two perpendicular polarization states could produce the same verification effect.

Example 10

A color-shifting polarizer film having an upper band edge of 590 nanometers made from 601 alternating layers of coPEN/PEN polymers had a color shift from orange to yellow when viewed at an increasing observation angle. The coPEN surface of the film was holographically embossed using the process described in Example 8. The film was applied to a printed white label as described in Example 9 with the holographic structure facing forward.

A verifying polarizer was used to verify the authenticity of the label, and the appearance changed from white to dark orange at normal incidence when the verifying polarizer was rotated to cross the polarizer with the holographic images. The unique, detectable color change under the verifying polarizer added to the security of the label.

Example 11

The structure surface of the holographic polarizer film from Example 8 was susceptible to scratches during some handling conditions. In addition, oil from fingerprints could fill in the holographic structure, decreasing the visibility of the holographic image. Finger oil and typical polymers have a refractive index similar to the surface coPEN polymer (approximately 1.6), so they closely match the refractive index of the film and tend to black out the holographic image. To avoid that effect, a material with a different refractive index was used to protect the structure, as generally shown in Figure 13. A high refractive index thin film of zinc sulfide, with 2.34 refractive index, was vapor coated using vacuum deposition onto the holographic structure of the polarizer material in Example 8 in a continuous roll to roll manner.

The visibility of the holographic image was comparable to Example 8. Oil from fingerprints did not significantly decrease the visibility of the holographic image, due to the high refractive index coating protecting the surface of the structure. Other high refractive index layers of the kinds disclosed in U.S. Patent No. 4,856,857 (Takeuchi et al.), could also be used for such an application.

Example 12

The holographic polarizer film from Example 11 was coated with an additional protective polymer layer over the structure bearing the high refractive index coating to provide a construction of the general type illustrated in Figure 14. A clear UV-cured acrylic varnish (currently available under the designation Flexographic UV Curable Varnish, UVF 02037, from Akzo Nobel Inks Corp., Langhorne, PA), having about 1.5 refractive index, was coated and cured using a flexographic printing press.

The varnish effectively protected the structure from scratches. The visibility of the holographic image was slightly less than that of Example 11, since the difference between the refractive index of zinc sulfide (2.34) and the varnish (1.5) in this Example 12 was less than the difference between the refractive index of zinc sulfide (2.34) and air (1.0) in Example 11. However, the visibility of the holographic image in this Example 12 was acceptable when viewed with a verifying polarizer as described in Example 9.

Example 13

A color shifting mirror film (available from 3M under the designation CM590 Radiant Light Film, #70-4000-0049-6) made from 224 alternating layers of PET/coPMMA polymers had a color change from cyan to blue to magenta as the film was viewed at an increasing observation angle, and had a reflective mirror appearance. The film was made as described in PCT Publication WO 99/36258 entitled "Color Shifting Film." Color shifting films are characterized by a change in color as a function of viewing angle. The outer PET layer was not as receptive to the heat and pressure of direct holographic embossing as the outer coPEN layer of the polarizer film in Example 8. Accordingly a clear PMMA resin was first solvent coated and dried onto the front surface of the color shifting film. Then the film was holographically embossed using the process from Example 8 with a decorative diffraction grating to provide a structure of the type generally illustrated in Figure 15.

The diffraction grating hologram was highly visible when viewed from the front surface of the film and enhanced by the reflectivity of the film. The color of the film changed from cyan to blue to magenta when viewed at increasing observation angles, giving a unique effect to the holographic image. This effect would be useful to authenticate the holographic images as genuine.

Example 14

A visible mirror film (available from 3M under the designation VM2000 Radiant Mirror Film, #70-4000-0069-4) from alternating layers of PEN and PMMA was coated with a 10% w/v PMMA (currently available from DuPont, of Wilmington, Delaware, under the designation Elvacite 2041) solution in toluene. The wet thickness was 175 micons, dried overnight at 95°C, yielded a 17-20 micron film of PMMA on the mirror film. A nickel embossing shim with the image of a US quarter coin was used at 115°C and 70 tons of pressure for 30 seconds. The image was very bright, due to the higher reflectivity of the multilayer polymer film (>99%) compared to the 95% reflectivity of aluminum vapor coating.

Example 15

The color shifting mirror film from Example 13 was vapor coated with zinc sulfide using the process described in Example 11 to protect the structure. The holographic images were still highly visible as in Example 13. The film could then be coated with an acrylic varnish, as in Example 12, to protect the structure from scratches. Other high refractive index reflectors such as those described in U.S. Patent No. 4,856,857 (Takeuchi et al.), could also be used for such a construction.

Example 16

A color shifting film made from 224 alternating layers of PEN/PMMA polymers with a lower band edge of 740 nanometers would exhibit a change from clear to cyan (generically a "clear-to-colored" film) when the film was viewed at increasing observations angles, as described in U.S. Patent No. 6,045,894 (Jonza et al.), entitled "Clear to Colored Security Film." To provide another exemplary film, a clear PMMA resin could be coated on the front surface of the film, as in Example 13, or the film could be produced with PMMA as the outer layer. Then the film could be holographically embossed using the process from Example 8.

The holographic images would be expected to be visible on the front surface of the film. The images would be expected to be visible when viewed through the film, with the structure facing the back surface of the film. The authenticity of the holographic images would be expected to be verified by increasing the observation angle of the film and viewing the color shift from clear to cyan. A zinc sulfide or other high refractive index coating of the type described in Example 11 could be added to the structured side. Then a protective varnish of the type described in Example 12 or an adhesive could be added over the structure, so the holographic color shifting film could be used as an overlaminate.

Example 17

To create other exemplary structures, a holographic structure could be added to the multilayer optical films described above by casting and curing the holographic structure directly onto the surface of the film, in a manner known in the holography art and described in, for example, U.S. Patent No. 5,948,199 (McGrew). A construction of this general type is illustrated in Figure 16 Additional high refractive index, protective, and adhesive layers could be provided as described above with reference to embossed holograms.

The multilayer optical films described herein, and particularly those with holographic images, may be used for one or more of a variety of uses, including as a label, as polymeric currency, as a component of a document of value (such as a passport, title document, certificate of authenticity, or the like), as a component of a card (such as an identification card, a drivers' license, a credit card, or the like), or as a component of a consumer product (such as a toy, packaging for another product, or any other product available to consumers in a store).

We claim:

1. A multilayer layer film including an optical stack comprising layers of a semi-crystalline polymer having an average thickness of not more than 0.5 microns and layers of a second polymer having an average thickness of not more than 0.5 microns wherein said optical stack has been stretched in at least one direction to at least twice that direction's unstretched dimension, said optical stack having first and second major surfaces, each of said layers having indices of refraction n_x and n_y in a plane of said layer and n_z normal to a plane of said layer all of said indices of refraction being selected to provide desired optical properties, said film further comprising a first additional layer adhered to said first major surface, said additional layer being of a material selected for its mechanical properties, said mechanical properties differing from mechanical properties of said layers of said optical stack.

2. The multilayer film of Claim 1 further comprising a second additional layer adhered to said second major surface.

3. A multilayer optical film having layers of first and second polymers, said first and second polymers differing in composition, each of said layers having a thickness of no more than 0.5 microns, said layers of said first polymer having indices of refraction of n_{1x} and n_{1y} in planes of said layers of said first polymer and n_{1z} normal to said planes of said layers of said first polymer and said layers of said second polymer having indices of refraction of n_{2x} and n_{2y} in planes of said layers of said second polymer and n_{2z} normal to said planes of said layers of said second polymer layer all of said indices of refraction being selected to provide desired optical properties, said optical stack having first and second major surfaces, said first major surface having adhered thereto a first tear resistant layer.

4. The multilayer optical film of Claim 3 wherein said second major surface has adhered thereto a second tear resistant layer.

5. The multilayer optical film of Claim 4 wherein each of said tear resistant layers has a thickness greater than 5 percent of the thickness of said optical stack.

6. The multilayer optical film of Claim 5 wherein each of said tear resistant layers has a thickness in the range of 5 percent to 60 percent of the thickness of said optical stack.

7. The multilayer optical film of Claim 6 wherein each of said tear resistant layers has a thickness in the range of 30 percent to 50 percent of the thickness of said optical stack.

8. The multilayer optical film of Claim 5 wherein said tear resistant layers have a composition that is substantially the same as the composition of said second polymers.

9. The multilayer optical film of Claim 8 wherein said first polymer is polyethylene naphthalate and said second polymer is a copolyester comprising naphthalate and terephthalate units.

10. The multilayer optical film of Claim 3 wherein said first polymer has a positive stress coefficient.

11. A multilayer film including an optical stack comprising layers of a semi-crystalline polymer having an average thickness of not more than 0.5 microns and layers of a second polymer having an average thickness of not more than 0.5 microns wherein said optical stack has been stretched in at least one direction to at least twice that direction's unstretched dimension, said optical stack having first and second major surfaces, each of said layers having indices of refraction n_x and n_y in a plane of said layer and n_z normal to a plane of said layer all of said indices of refraction being selected to provide desired optical properties, said film further comprising a first additional layer adhered to said first major surface, said additional layer being of a material selected for its

chemical properties, said chemical properties differing from chemical properties of said layers of said optical stack.

12. The multilayer film of Claim 11 further comprising a second additional layer adhered.

13. A multilayer film including an optical stack comprising layers of a semi-crystalline polymer having an average thickness of not more than 0.5 microns and layers of a second polymer having an average thickness of not more than 0.5 microns wherein said optical stack has been stretched in at least one direction to at least twice that direction's unstretched dimension, said optical stack having first and second major surfaces, each of said layers having indices of refraction n_x and n_y in a plane of said layer and n_z normal to a plane of said layer all of said indices of refraction being selected to provide desired optical properties, said film further comprising a first additional layer adhered to said first major surface, said additional layer being of a material selected for its optical properties, said optical properties differing from optical properties of said layers of said optical stack.

14. The multilayer film of Claim 13 further comprising a second additional layer adhered.

15. The multilayer film of Claim 1 further having a second additional layer adhered to said first additional layer, said second additional layer having mechanical properties differing from those of said layers of said optical stack and those of said first additional layer.

16 The multilayer film of Claim 15 wherein said first additional layer is a tear resistant layer and said second additional layer is an abrasion resistant layer.

17. The multilayer film of Claim 1 wherein said second additional layer is an abrasion resistant layer.

18. The multilayer film of Claim 1 wherein said first additional layer includes a slip agent.

19. The multilayer film of Claim 13 wherein said first additional layer includes an electromagnetic absorbing material.

20. The multilayer film of Claim 19 wherein said electromagnetic absorbing material absorbs ultraviolet radiation.

21. The multilayer film of Claim 13 wherein said first additional layer includes a fluorescent material.

22. The multilayer film of Claim 13 wherein said first additional layer includes a holographic image.

23. The multilayer film of Claim 13 wherein said first additional layer includes a holographic diffuser.

24. A multilayer film including an optical stack comprising layers of a semi-crystalline polymer having an average thickness of not more than 0.5 microns and layers of a second polymer having an average thickness of not more than 0.5 microns wherein said optical stack has been stretched in at least one direction to at least twice that direction's unstretched dimension, said optical stack having first and second major surfaces, each of said layers having indices of refraction n_x and n_y in a plane of said layer and n_z normal to a plane of said layer all of said indices of refraction being selected to provide desired optical properties, said film further comprising a first additional layer adhered to said first major surface, said additional layer being of a pressure sensitive adhesive.

25. A multilayer film including an optical stack comprising layers of a semi-crystalline polymer having an average thickness of not more than 0.5 microns and layers of a second polymer having an average thickness of not more than 0.5 microns wherein

said optical stack has been stretched in at least one direction to at least twice that direction's unstretched dimension, said optical stack having first and second major surfaces, each of said layers having indices of refraction n_x and n_y in a plane of said layer and n_z normal to a plane of said layer all of said indices of refraction being selected to provide desired optical properties, said film further comprising a first additional layer adhered to said first major surface, said additional layer being of a material selected for its mechanical properties, said mechanical properties differing from mechanical properties of said layers of said optical stack wherein said additional layer is a tear resistant layer in the range of 5 percent to 60 percent of the thickness of said optical stack has a composition that is substantially the same as the composition of said second polymers.

26. The multilayer optical film of Claim 25 wherein said first polymer is polyethylene naphthalate and said second polymer is a copolyester comprising naphthalate and terephthalate units.

27. A multilayer film including an optical stack comprising layers of a semi-crystalline polymer having an average thickness of not more than 0.5 microns and layers of a second polymer having an average thickness of not more than 0.5 microns wherein said optical stack has been stretched in at least one direction to at least twice that direction's unstretched dimension, said optical stack having first and second major surfaces, each of said layers having indices of refraction n_x and n_y in a plane of said layer and n_z normal to a plane of said layer all of said indices of refraction being selected to provide desired optical properties, said film further comprising a first additional layer adhered to said first major surface, said additional layer being of a material selected for its mechanical properties, said mechanical properties differing from mechanical properties of said layers of said optical stack wherein said additional layer is glass.

28. A multilayer optical film comprising:

(a) an optical stack including alternating layers of at least a first polymer and a second polymer; and

(b) a holographic image.

29. The multilayer optical film of claim 28, wherein the holographic image is provided in one of the layers of the optical stack.

30. The multilayer optical film of claim 28, wherein the holographic image is provided in a skin layer.

31. The multilayer optical film of claim 28, wherein the holographic image is provided in a hard polymer.

32. The multilayer optical film of claim 28, wherein the holographic image is provided in an adhesive.

33. The multilayer optical film of claim 28, wherein the holographic image layer is the outermost layer of the film.

34. The multilayer optical film of claim 28, wherein the holographic image layer is not the outermost layer of the film.

35. The multilayer optical film of claim 28, wherein the film is reflective.

36. The multilayer optical film of claim 28, wherein the film is a polarizer.

37. The multilayer optical film of claim 36, in combination with a verifying polarizer.

38. The multilayer optical film of claim 28, wherein the film is a color shifting film.

39. The multilayer optical film of claim 28, wherein the film is a clear-to-colored film.

40. The multilayer optical film of claim 28, wherein the holographic image is a holographic hot stamping foil applied with heat and pressure to a surface of the multilayer film.

41. The multilayer optical film of claim 28, wherein the holographic image is a holographic film applied with an adhesive to the outer surface of the multilayer film.

42. The multilayer optical film of claim 28, wherein the holographic image is provided in an embossable resin layer.

43. The multilayer optical film of claim 28, wherein the holographic image comprises a metallized layer.

44. The multilayer optical film of claim 28, wherein the holographic image comprises a high refractive index reflector.

45. The multilayer optical film of claim 28, wherein the film further comprises a protective layer.

46. The multilayer optical film of any one of claims 28 through 45, wherein the film is a component of a label.

47. The multilayer optical film of any one of claims 28 through 45, wherein the film is a component of currency.

48. The multilayer optical film of any one of claims 28 through 45, in combination with a document of value.

49. The multilayer optical film of any one of claims 28 through 45, wherein the film is a component of a card.

50. The multilayer optical film of any one of claims 28 through 45, wherein the

film is a component of a consumer product.

51. A method of providing an optical film, comprising the steps of:

(a) providing an optical stack including alternating layers of at least a first polymer and a second polymer; and

(b) providing a holographic image on a polymeric layer associated with the optical film.

52. The method of claim 51, wherein the method includes the step of (c) coating an embossable resin onto the optical stack or skin layer, and step (b) comprises embossing a holographic image into the embossable resin.

53. The method of claim 51, wherein step (b) comprises casting and curing a resin to form the holographic image.

54. The method of claim 51, wherein step (b) comprises embossing a holographic image into the polymeric layer.

55. The method of any one of claims 51 through 54, in which the method further comprises the step of providing a high refractive index layer on the holographic image.

56. The method of claim 55, wherein the high refractive index layer comprises zinc sulfide.

57. The method of any one of claims 51 through 54, in which the method further comprises the step of providing a metallized layer on the holographic image.

58. The method of any one of claims 51 through 54, in which the method further comprises the step of providing a protective layer over the holographic image.

59. The method of claim 58, wherein the protective layer is a coating that is

cured.

60. The method of claim 58, wherein the protective layer is a thermoplastic layer.

61. The method of claim 58, wherein the protective layer comprises a pressure sensitive layer in contact with the hologram and a polymeric layer overlying the pressure sensitive adhesive.

62. In combination:

(a) a multilayer polarizer film having alternating layers of at least a first polymer and a second polymer and a holographic image, the multilayer polarizer film overlying a printed image; and

(b) a verifying polarizer film, whereby when the two polarizer films are aligned in at least one orientation the printed image is substantially imperceptible and the holographic image is perceptible.

63. A multilayer optical film comprising:

(a) an optical stack including alternating layers of at least a first polymer and a second polymer, wherein at least one of the polymers has a stress-induced birefringence; and

(b) a holographic image.

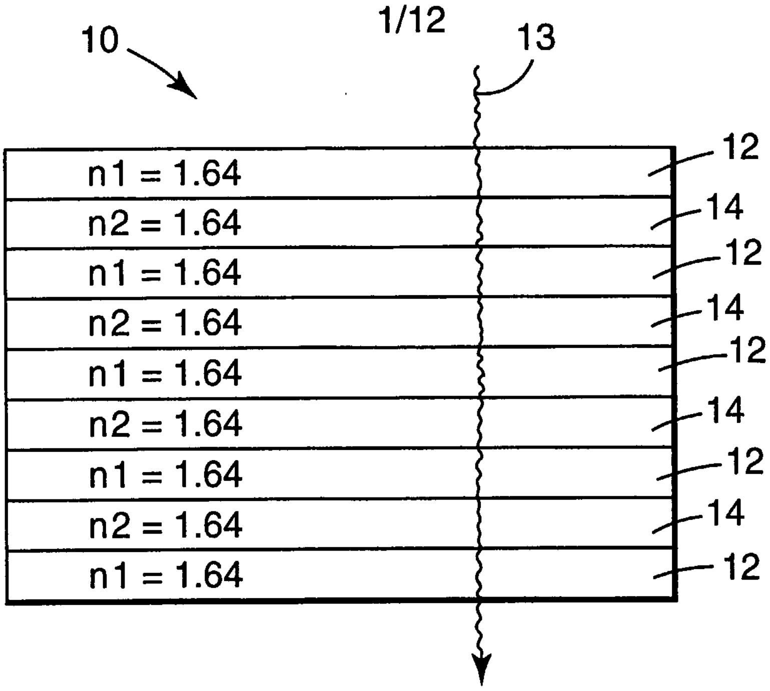

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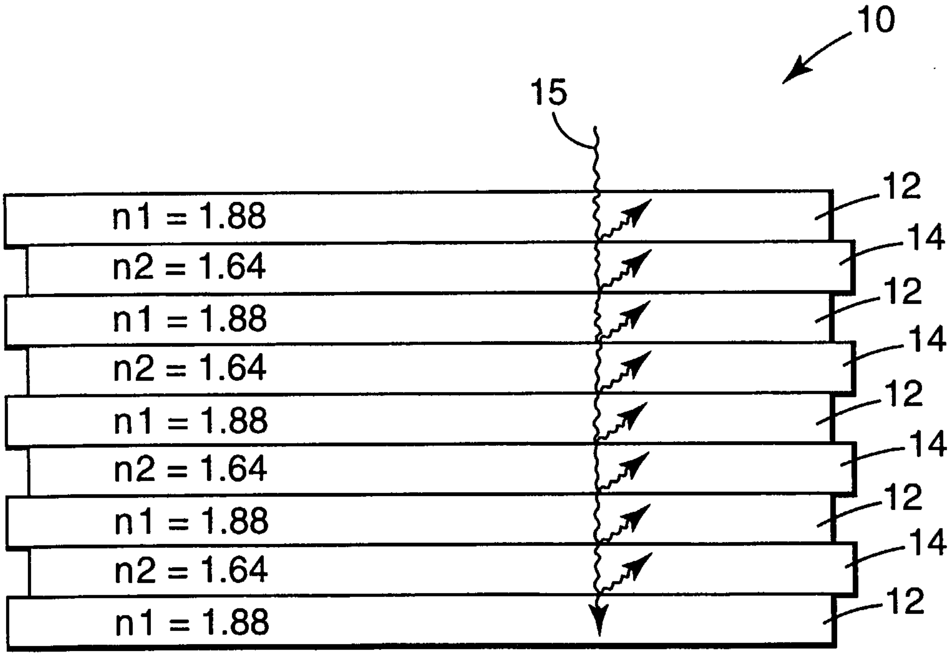
Fig. 1a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12

Fig. 1b

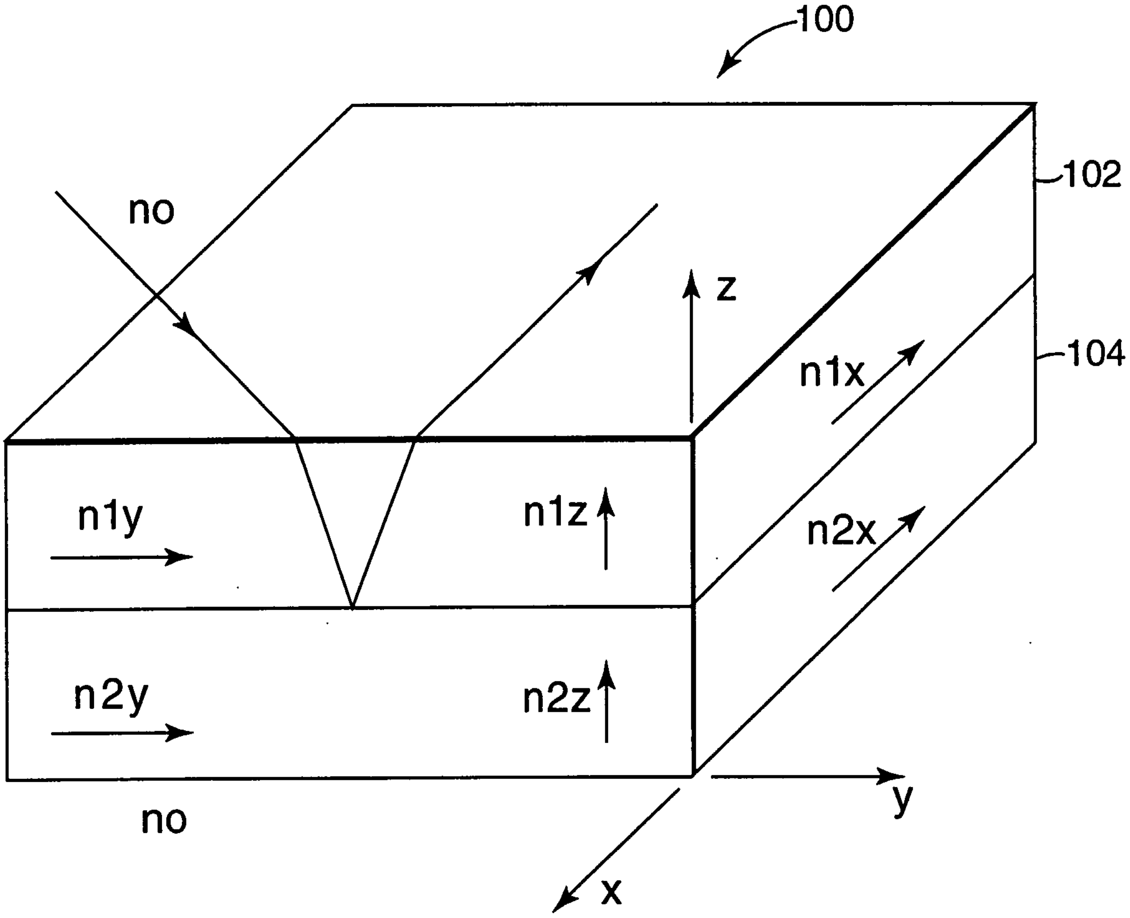

Fig. 2

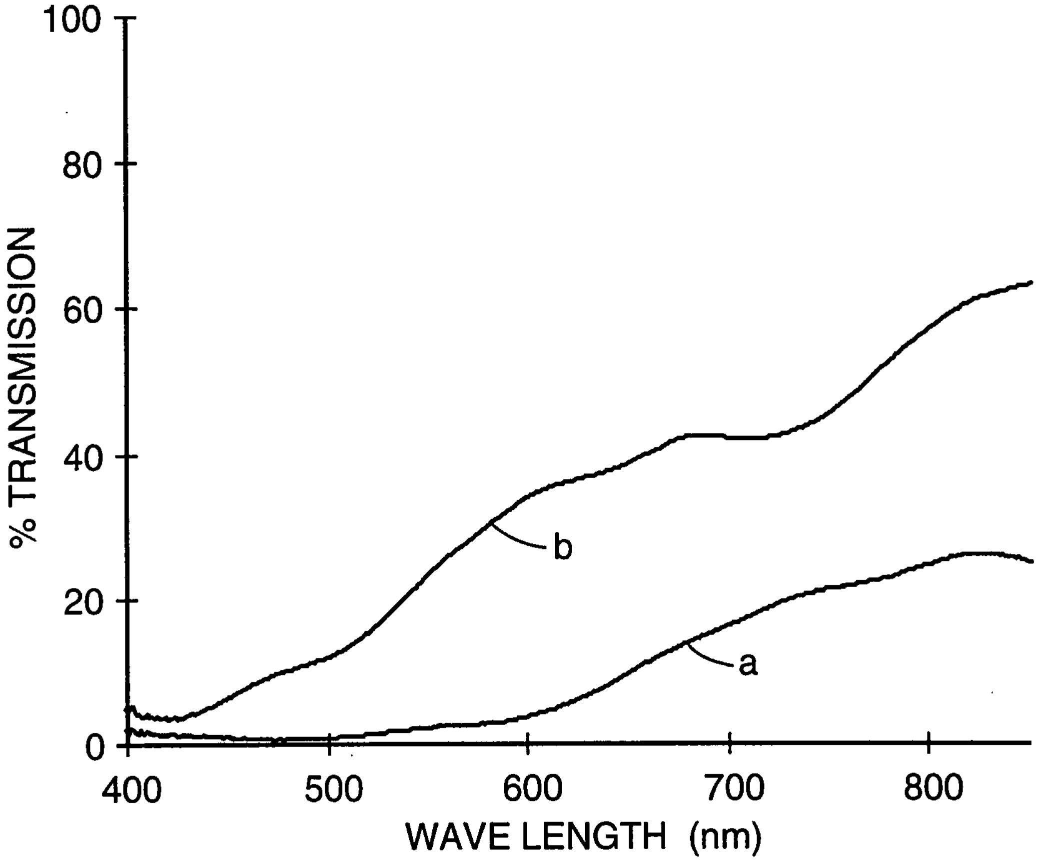
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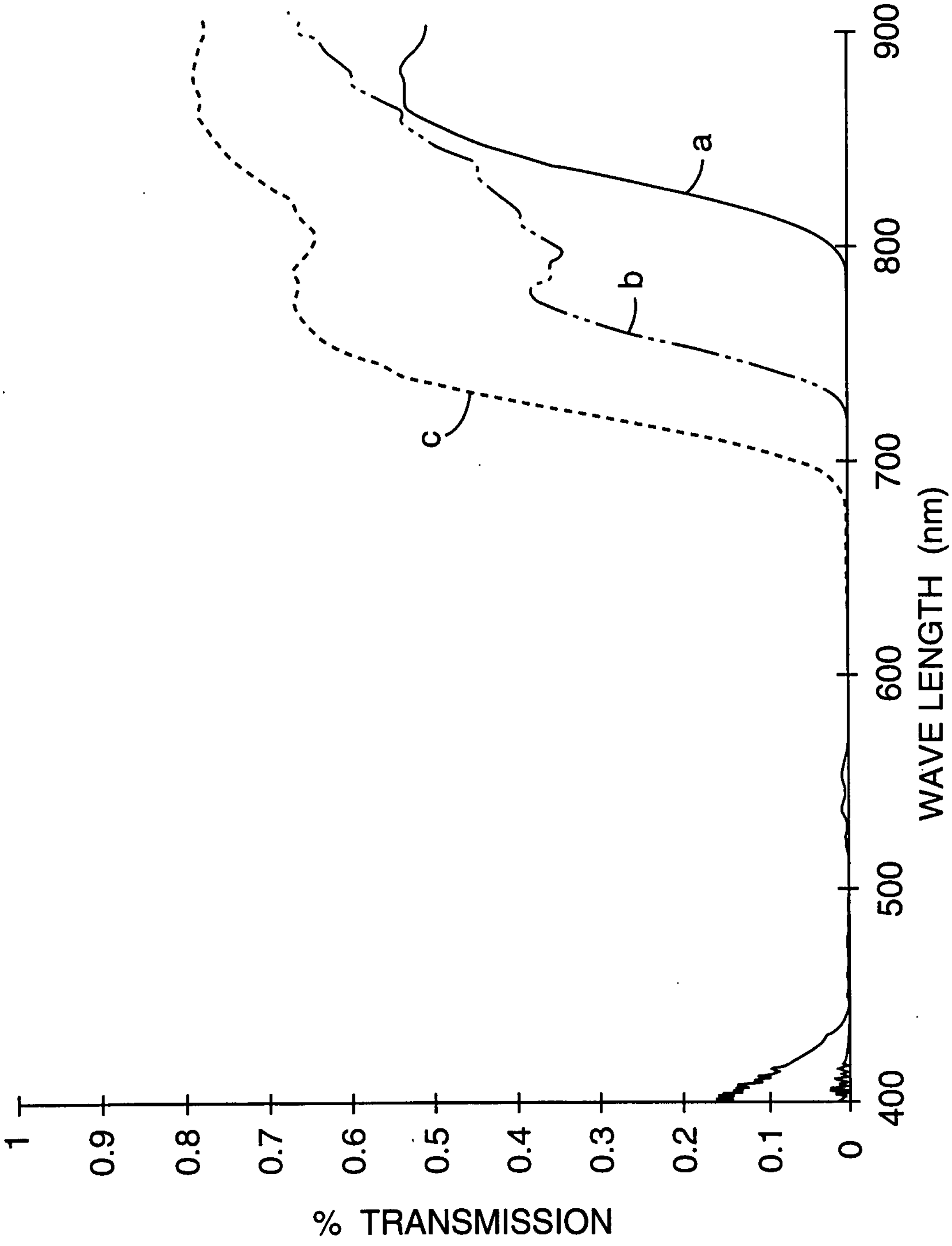
Fig. 3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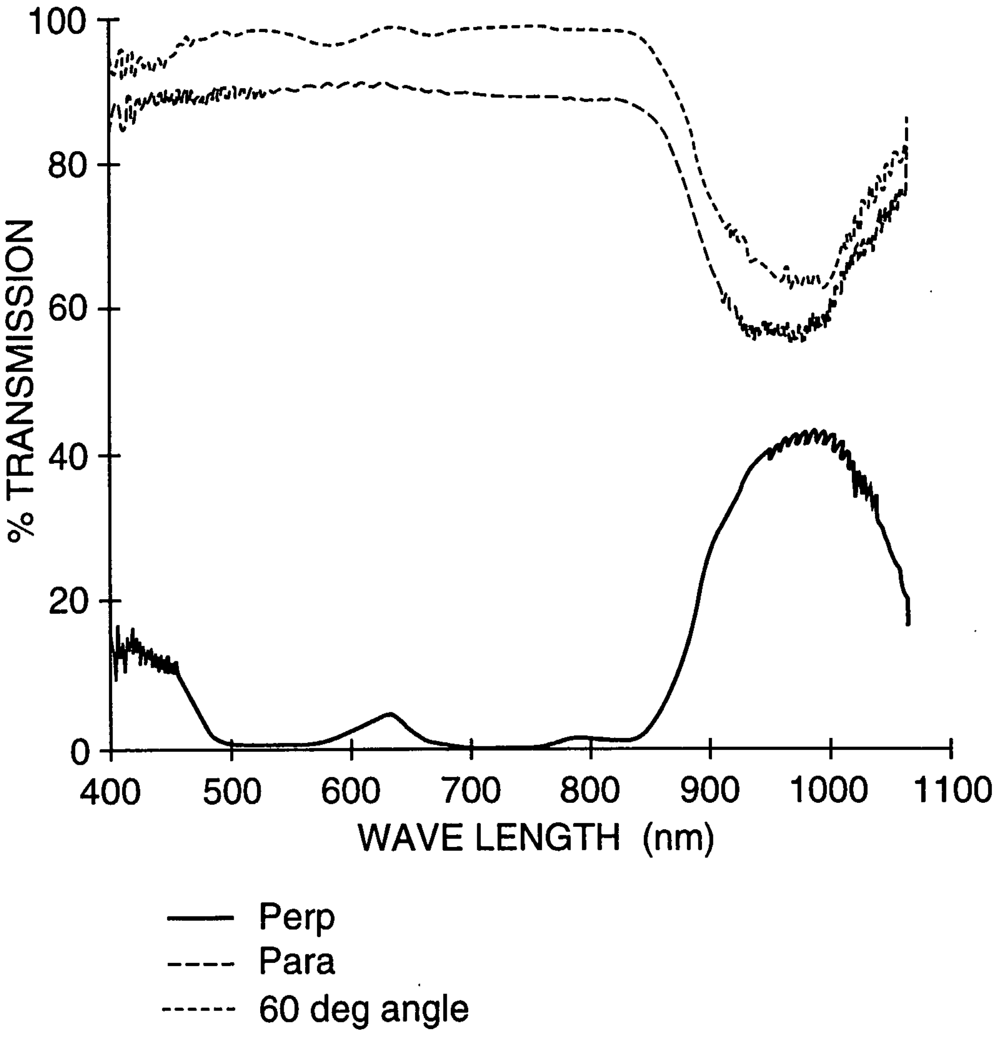
WAVE LENGTH (nm)
a
b
c

Fig. 4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1100
WAVE LENGTH (nm)
——— Perp
---- Para
------ 60 deg angle

Fig. 5

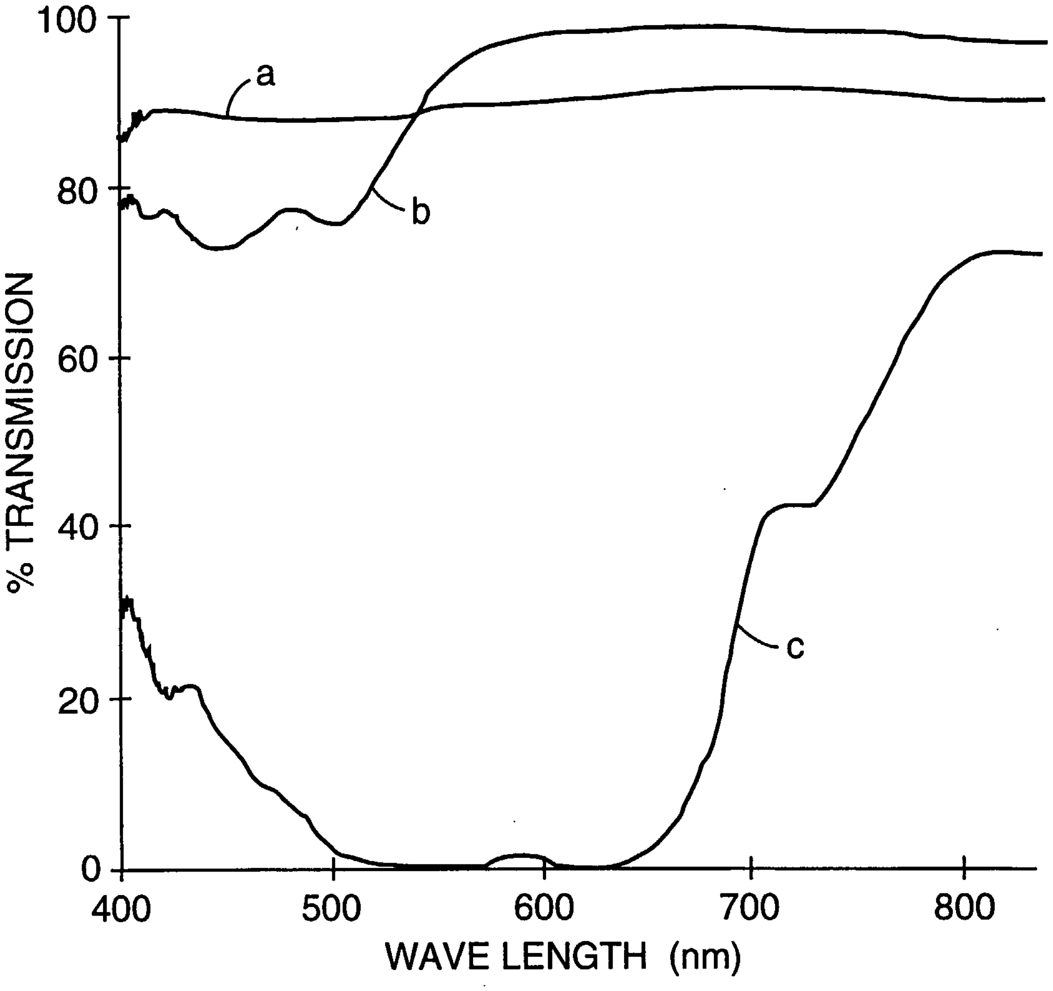
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Fig. 6

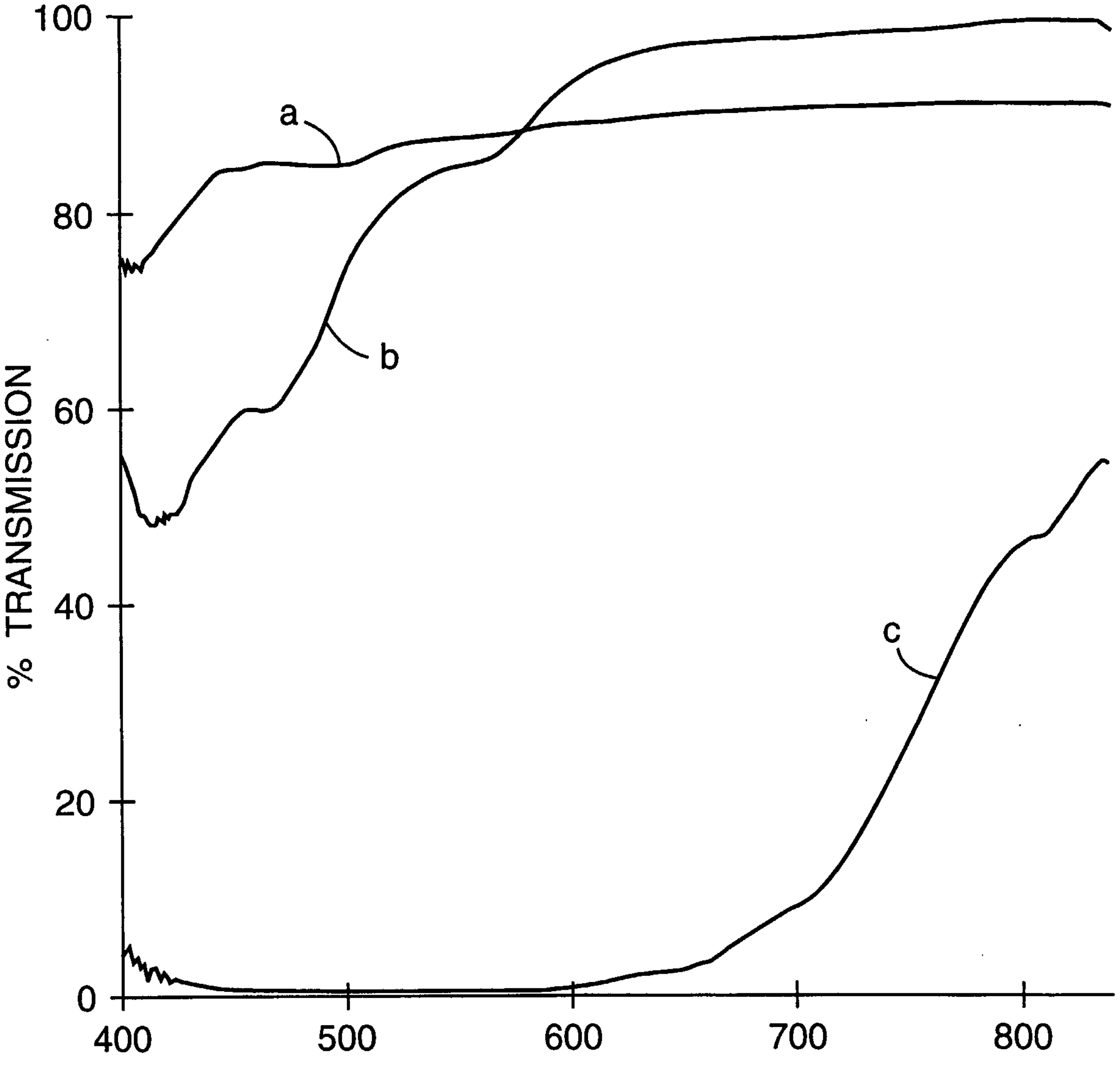
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Fig. 7

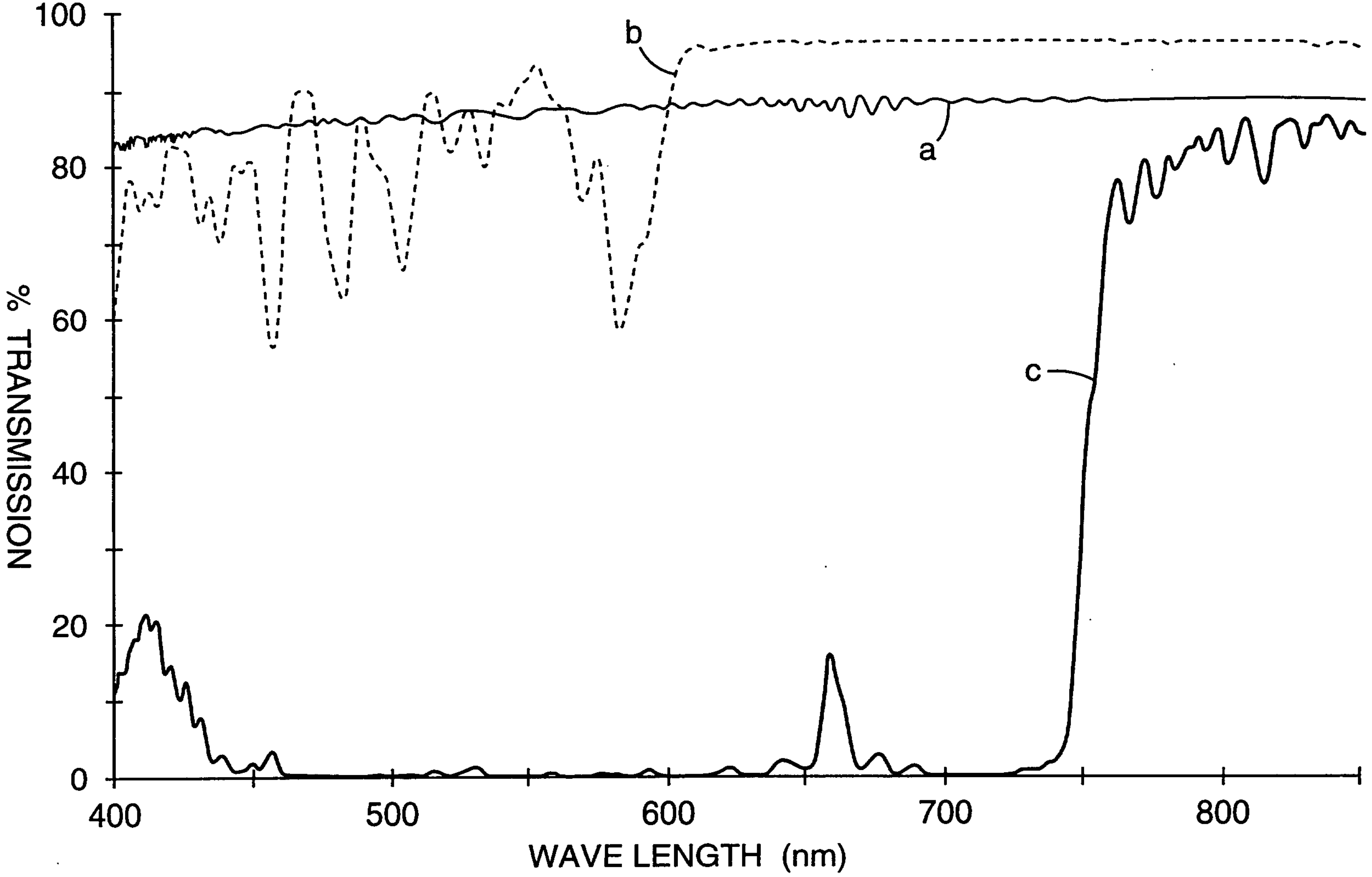
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Fig. 8

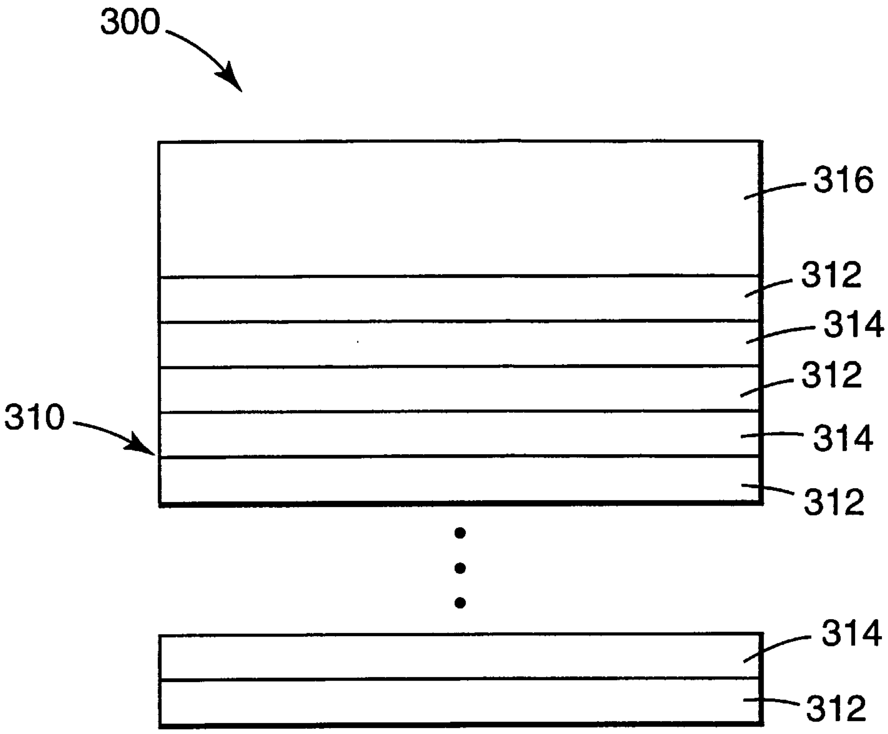
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Fig. 9

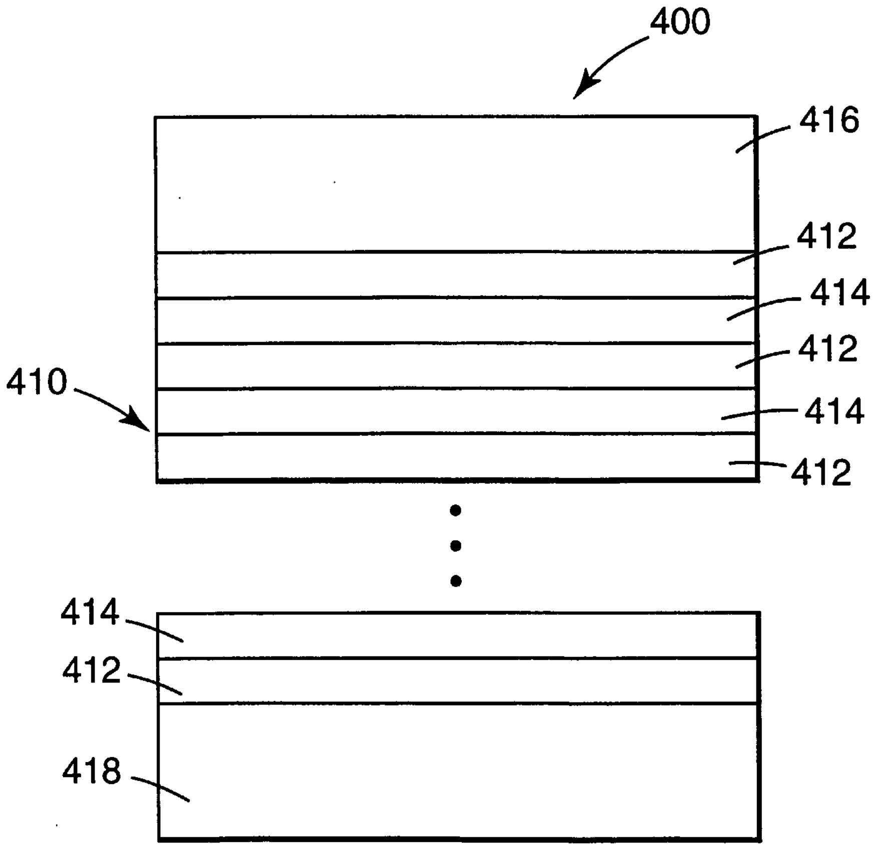
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Fig. 10

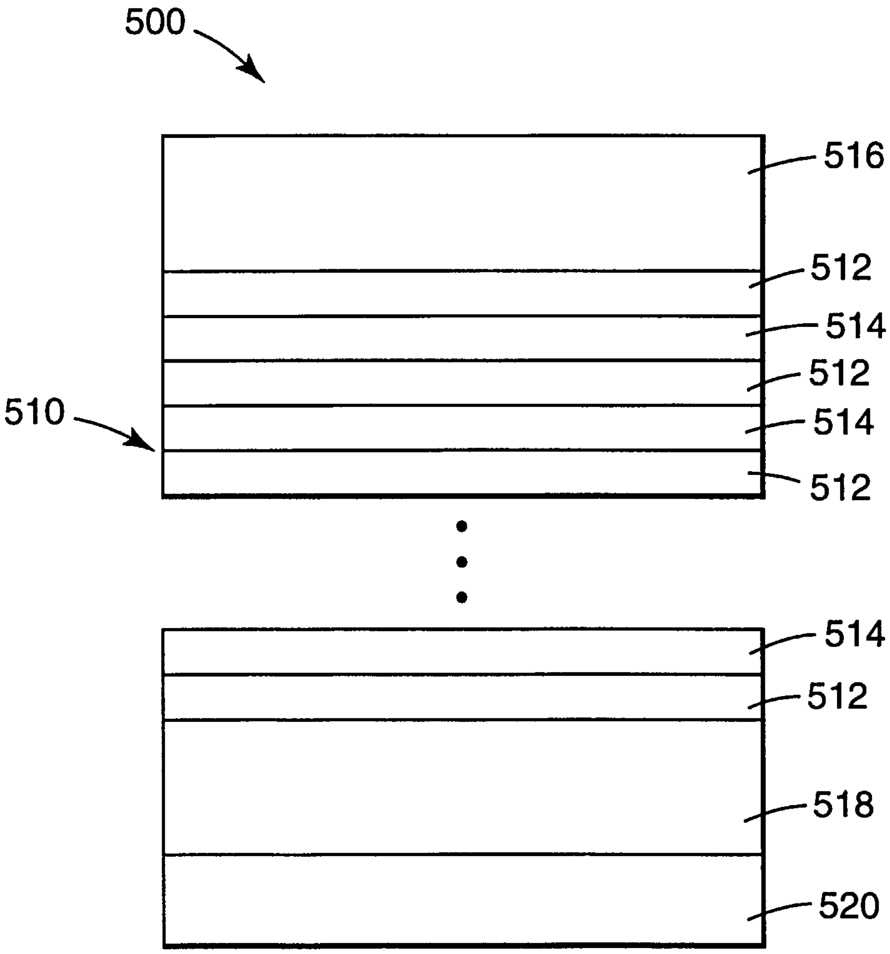

Fig. 11

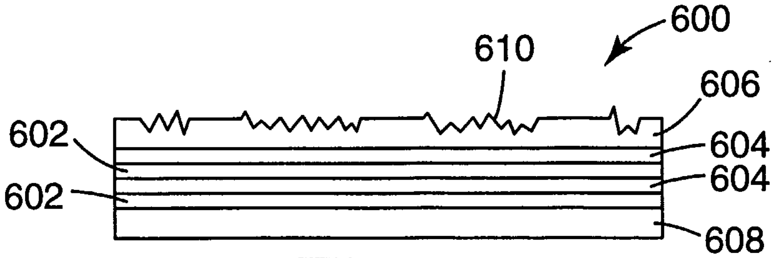

Fig. 12

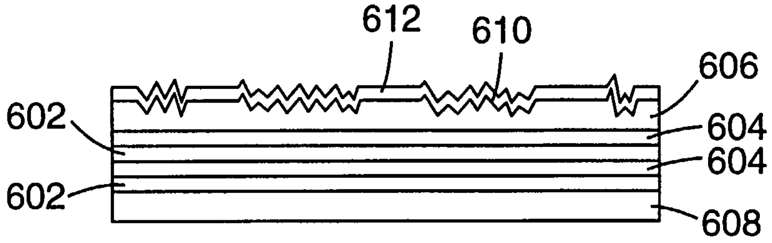

Fig. 13

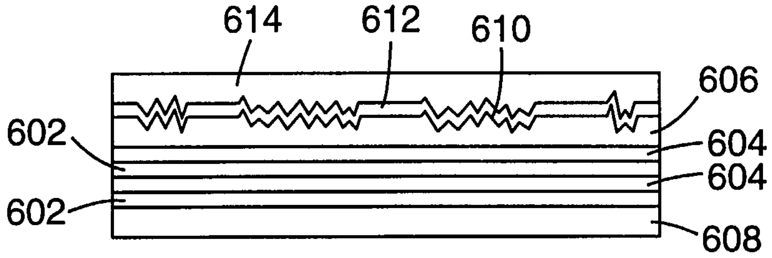

Fig. 14

Fig. 15

Fig. 16

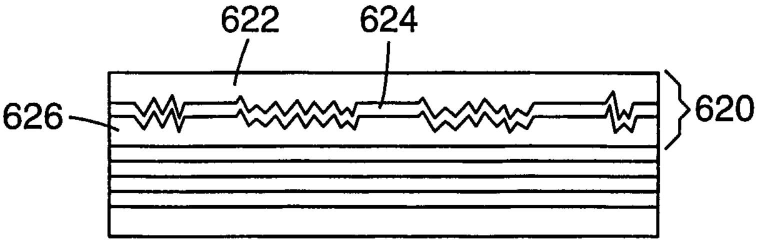

Fig. 17

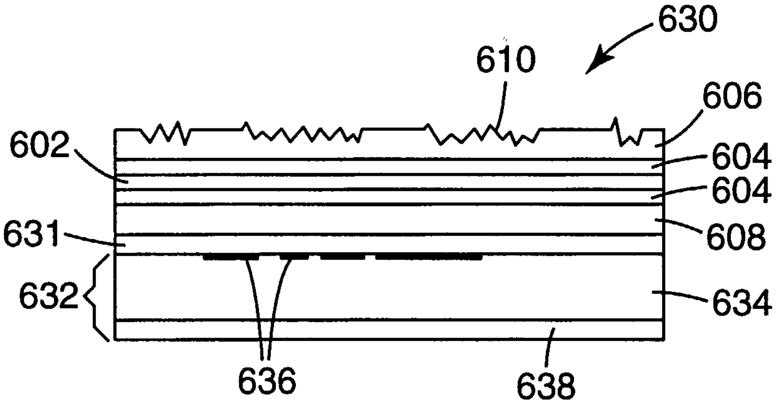

Fig. 18

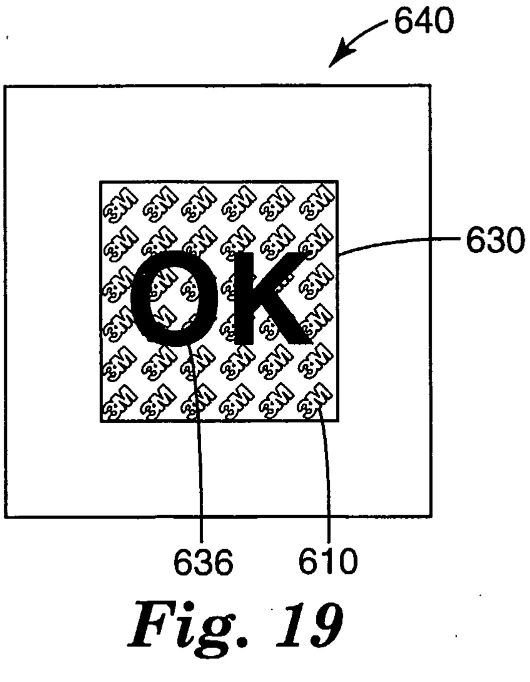

Fig. 19

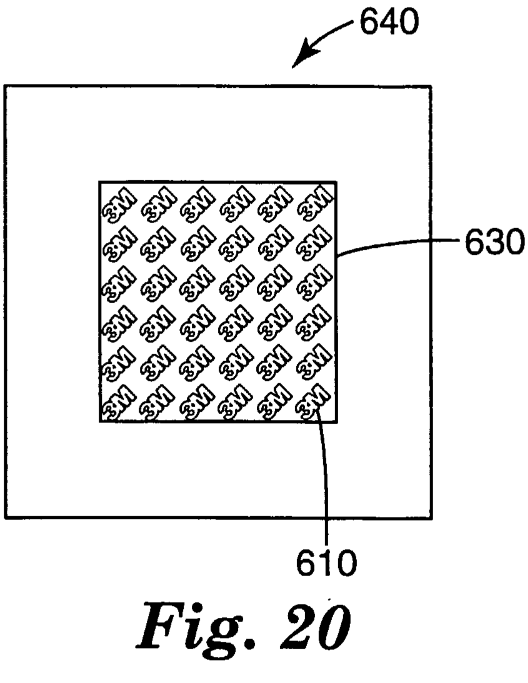

Fig. 20

INTERNATIONAL SEARCH REPORT

Ir ial Application No
PCT/US 02/07508

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G02B5/30 B32B27/36 G02B5/32

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G02B B32B G06K B42D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 97 01440 A (MINNESOTA MINING & MFG) 16 January 1997 (1997-01-16) page 2, line 27 -page 4, line 9 page 8, line 1 - line 12 page 17, line 11 -page 18, line 25 page 21, line 16 -page 23, line 10; claims 1-14; figures 1,2,9-11	1-36,45, 46,51, 57-61,63
Y		28-37, 45-50,62
Y		38,39

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☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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

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

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

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"&" document member of the same patent family

Date of the actual completion of the international search 4 July 2002	Date of mailing of the international search report 12/07/2002
Name and mailing address of the ISA European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Authorized officer Besser, V

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INTERNATIONAL SEARCH REPORT

Ir nal Application No
PCT/US 02/07508

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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Y		38,39

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