350-405 SR

OR 3,647,278

United State

Makas

[15] **3,647,278**

[45] ***Mar. 7, 1972**

[54] LIGHT-TRANSMITTING ELEMENTS

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[73] Assignee: **Polaroid Corporation,** Cambridge, Mass.

[*] Notice: The portion of the term of this patent subsequent to Sept. 15, 1987, has been disclaimed.

[22] Filed: **Mar. 26, 1970**

[21] Appl. No.: **22,863**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 771,970, Oct. 30, 1968, Pat. No. 3,528,722, which is a continuation-in-part of Ser. No. 697,113, Jan. 11, 1968, abandoned.

[52] **U.S. Cl.** **350/157,** 350/149, 350/155, 350/158, 356/33

[51] **Int. Cl.** **G02b 5/30**

[58] **Field of Search** 350/147, 155, 157, 158, 166, 350/149; 356/33-35, 115

[56] **References Cited**

UNITED STATES PATENTS

3,528,722	9/1970	Makas	350/157
2,184,999	12/1939	Land et al.	350/158
2,604,817	7/1952	Schupp, Jr.	350/157
2,527,400	10/1950	Cooper, Jr.	350/155
2,323,059	6/1943	Land	350/158
3,377,118	4/1968	MacNeille	350/157

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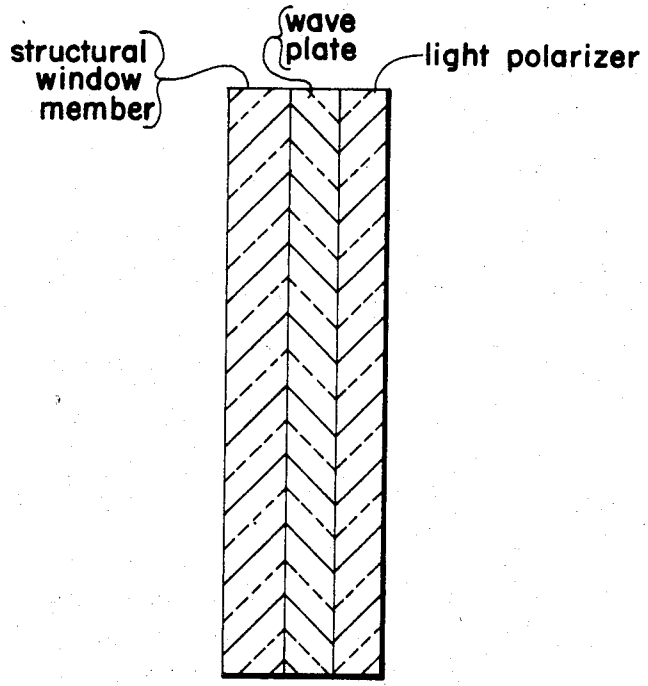
[57] **ABSTRACT**

A composite structure comprising a high-order wave plate and a light-polarizing element utilized in a light-transmitting window apparatus comprising a stressed plastic material to eliminate polariscopy.

10 Claims, 7 Drawing Figures



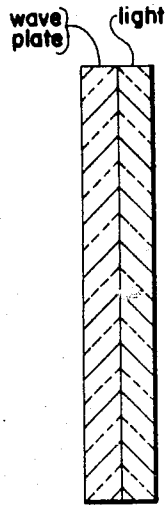


FIG. 1

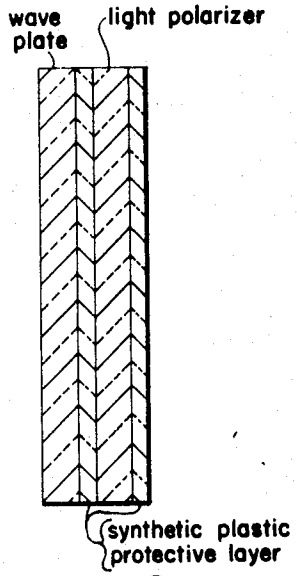


FIG. 2

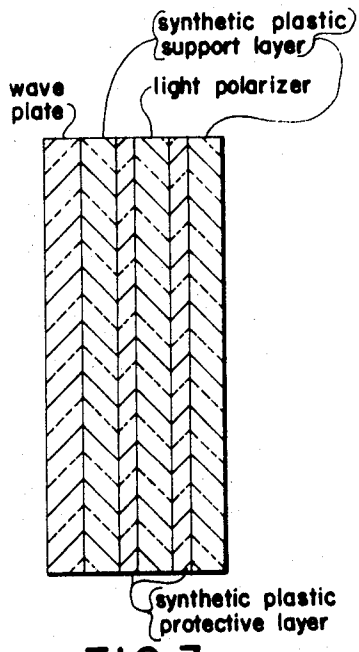


FIG. 3

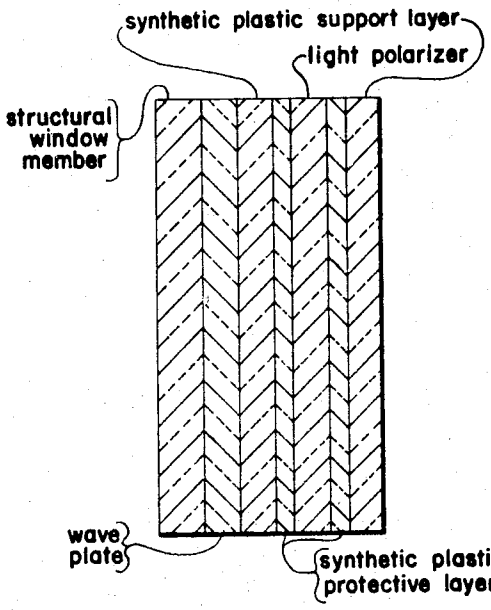


FIG. 4

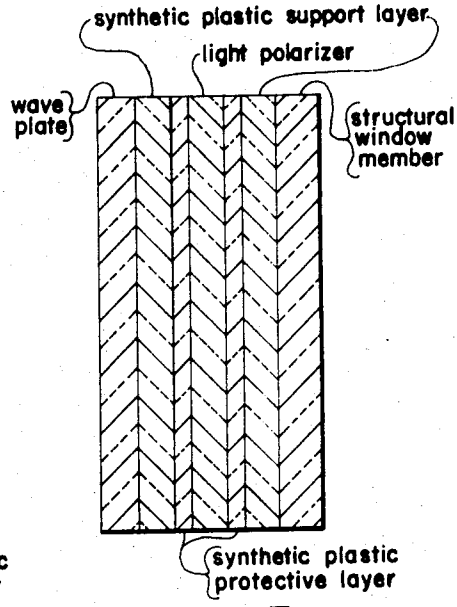


FIG 5

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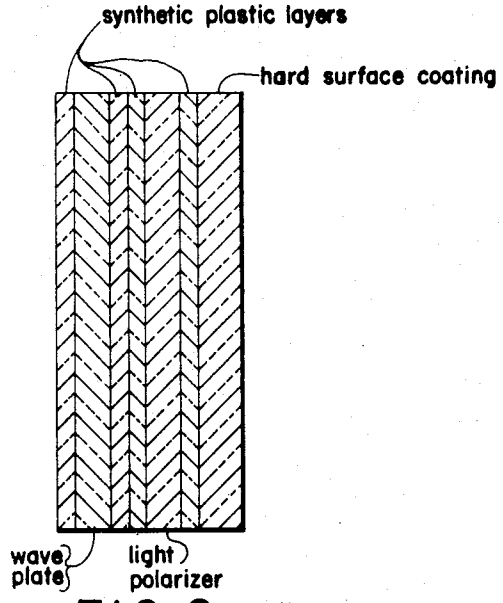

FIG. 6

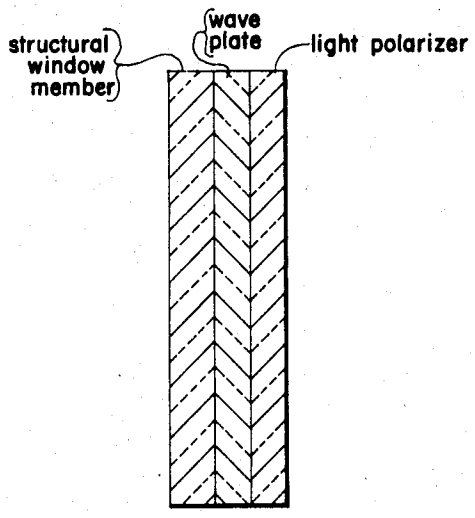

FIG. 7

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LIGHT-TRANSMITTING ELEMENTS

This application is a continuation-in-part of copending U.S. application Ser. No. 771,970, filed on Oct. 30, 1968, now U.S. Pat. No. 3,528,722, which is in turn a continuation-in-part of U.S. application Ser. No. 697,113, filed on Jan. 11, 1968, now abandoned.

This invention relates to the utilization of light polarizers in conjunction with stressed synthetic plastic materials in a composite window environment. More particularly, this invention relates to the utilization of high-order wave plates to eliminate interference spectra which result from the polariscopic effect produced when a stressed transparent material is viewed between two light-polarizers.

It is a primary object of the present invention to eliminate undesirable interference spectra associated with the polariscopic effect produced when a stressed transparent material is viewed between sources of polarized light.

It is another object of the present invention to provide a composite structure which comprises a high-order wave plate and a light-polarizer, wherein light passing therethrough is substantially free of chromatic aberration associated with the polariscopic effect.

It is an additional object of the present invention to provide a synthetic plastic wave plate capable of at least seven wavelengths of retardation.

Other objects of the invention will in part be obvious and will in part appear hereinafter.

The invention accordingly comprises the product possessing the features, properties and the relation of components which are exemplified in the following detailed disclosure, and the scope of the application of which will be indicated in the claims.

For a fuller understanding of the nature and objects of the invention, reference should be had to the following detailed description taken in conjunction with the accompanying drawings wherein FIGS. 1 through 7 are alternative embodiments of the composite structure of the present invention.

It is very often desirable to attenuate light entering a room of a transportation vehicle by the utilization of light-polarizing material. It may be additionally desired, and in fact is well known, to utilize a technique which comprises rotating one light-polarizer relative to another in order to achieve substantially complete extinction of and light incident thereto at the option of the operator. The need for such attenuation is generally most profound with respect to transportation vehicles and particularly airplanes which are often exposed to direct skylight without benefit of natural attenuation provided by cloud formations.

Skylight, by its nature, is rather highly polarized; that is, there is preferential alignment of the vibrating light waves due to particle scattering, etc., which produces a more or less ordered, rather than random, wave configuration. This effect may easily be experienced by rotating a polarizer against skylight and noting the differences in intensity of the light passing therethrough. When the absorption axis of the polarizer is parallel to the primary plane of vibration of incident light, partial extinction occurs to a greater extent than would be achieved were the transmission axis of the polarizer aligned therewith.

In order to achieve a high degree of pressurization and safety for the interior of modern aircraft, the outer structural window members thereof are made of very highly stressed synthetic plastic material, usually polymethyl methacrylate (Plexiglas, Lucite), although polycarbonates such as Lexan, the condensation product resultant from the reaction of bisphenol A and phosgene, and diethylene glycol bis allyl carbonate, sold by Pittsburg Plate Glass Company under the trade name CR-39, or any other suitable transparent material may be used. As a backup or fail-safe procedure, a second synthetic plastic structural window member, comprising a stressed or unstressed material, at the option of the operator, is inserted inboard of the outer stressed member. In the event that a light-polarizer is placed inboard of said stressed member

or members, a polariscopic effect is noted; that is, the polarized light outboard of the window and the polarizer inboard of the window form an analyzer which vividly and chromatically portrays the stress pattern of the synthetic plastic window members. The maximum effect occurs when the polarizer absorption axis of 90° to the axis of the incoming polarized light. This polariscopic phenomenon is quite undesirable aesthetically and often causes passengers on an airplane needless worry since the pattern changes with changes in pressure.

The stress pattern observed in airplane windows comprising a light-polarizing element, is due to birefringence, generally random, occurring in the stressed material. In polymethyl methacrylate and similar type windows the maximum retardation produced by this birefringence is up to approximately three wavelengths, which is in a vividly colored area.

Retardation may be regarded as the product of birefringence and the thickness of a given material. Thus, if the two refractive indices of a given birefringent material are denoted as n and n_1, the birefringence as $(n-n_1)=\Delta n$, and the thickness of the material is denoted as t, the retardation may be visualized as $\Gamma=(\Delta n)t$. Since the thickness range and the birefringence of the members utilized in window configurations anticipated by the present invention are such that the retardations which result are of the order of magnitude of approximately three wavelengths, some method must be devised for causing a depolarization effect to thereby produce substantially white light.

It may be beneficial at this time to briefly mention the theory producing the various chromatic effects achieved with stressed synthetic plastic material of the type discussed hereinabove in a polariscopic environment. Let us assume, for example, that at one point in said material the stress produces a birefringence which causes approximately one-quarter wavelength of retardation relative to 575 mμ light, which is in about the center of the visible spectrum, thus producing a 144 mμ retardation. If an inboard polarizer is positioned to produce maximum extinction with incoming skylight, i.e., the absorption axis of the polarizer is parallel to the primary plane of vibration of the entering light, it will be appreciated that for midspectrum light there will be an effect on transmission of a one-quarter wavelength retardation; for 400 mμ light there will be 144/400 or approximately one-third wave length retardation; and for 750 mμ light there will be approximately one-fifth wavelength retardation. It is evident that the resultant light will be slightly blue colored. If approximately three-fourths wavelength of retardation is produced relative to 575 mμ light, it will be seen that the resultant light would be approximately amber; while one-half wavelength retardation relative to 575mμ light produces greenish-yellow light. For orders up until approximately 3.5 wavelengths retardation is achieved, very vivid simple colors are progressively evident. Over 3.5 wavelengths the colors are so profuse that they cannot be distinguished individually and are viewed as a less colorful mixture, or as white light. Graphically, they may be visualized as curves containing many maxima and minima.

It is known that one light-polarizing member will not cause substantial extinction of polarized light when its absorption axis is parallel to the plane of vibration of said light if a birefringent material is placed between said polarizer and said polarized light because the birefringent material changes the linearity of the penetrating polarized light waves and causes the emission of waves which may be helical or elliptical in nature. It has additionally been found that when an axis of stress of 45° to either transmission or absorption axes of the crossed polarizers a maximum intensity of the interference spectra is reached. Where the axis of stress coincides with either transmission or absorption polarizer axis no effect is seen. The resultant pattern, therefore, evident to a viewer, appears a four distinct quadrants with maximum intensity at the center of each sector and minimum intensity along the polarizer axes.

It has been found that if a wave plate with approximaterial 10 to 15 wavelengths of retardation is inserted in a stressed

window—-light polarizer combination, outboard of the polarizer, effective depolarization of penetrating light is achieved, i.e., the polariscopic effect is obviated. Assuming that the retardation of the wave plate and window material are additive, it is evident that a wave plate with about four wavelengths retardation would be adequate to produce substantially white light. However, if the wavelengths of retardation capable of being provided by the wave plate, in relation to those of the stressed window, are subtractive, about seven or eight wavelengths of retardation would be required. In order to provide maximum effectiveness and account for retardation which may be imparted to the system by imperfect laminations, utilization of retarders on the order of 10 to 15 wavelengths of retardation is considered ideal. However, practically speaking, any material which will provide approximately seven or more wavelengths of retardation may be utilized as, for example, oriented polyvinyl alcohol, various oriented polyesters, etc. It has been unexpectedly found that the best results are obtained when polyethylene terephthalate (Mylar, Melinex) is utilized, it having been uniaxially oriented. With material of this type up to 20 wavelengths of retardation, and perhaps more, may be achieved. An additional advantage is gained with uniaxially oriented polyethylene terephthalate over other materials since the optical axes of this material are not evident to the viewer no matter what position is assumed, the critical angle being internal. Thus, there is no possibility of the viewer looking down an optical axis of the material and seeing only a black area surrounded by a chromatic environment.

In all embodiments of the instant invention, greatest efficiency will be achieved when the optic axis of the wave plate is at a 45° angle to either the transmission or absorption axis of the light-polarizing element. As an optical axis of the wave plate approaches an axis of the light-polarizing element, efficiency is lost until the polarizer axis and wave plate axis coincide—at which point the wave plate fails to produce the intended results.

Any suitable material which will produce the desired light-polarization effect may be utilized in the present invention. It has been found, however, that polymeric light-polarizing sheet materials lends itself most readily to function. The preferred material is a transparent sheet of polyvinyl alcohol containing substantially oriented molecules of dehydrated polyvinyl alcohol and deriving its light-polarizing properties essentially from said dehydrated molecules. The manufacture and utilization of such sheet material may be appreciated with reference of U.S. Pat. Nos. 2,173,304; 2,255,940; 2,306,108; 2,397,231; 2,445,555; 2,453,168 and 2,674,159, all incorporated herein by reference.

As a general rule, it may be stated that neither the polarizer nor the wave plate are structurally sufficiently rigid to be used by themselves. Therefore, in certain embodiments of the present invention, both the polarizer and wave plate may be laminated to a rigid synthetic plastic material such as, for example, polymethyl methacrylate, for support.

Any adhesive materials suitable for bonding the wave plate-polarizer composite structure, with or without support and/or protective layers, may be utilized as long as said adhesive does not hinder the transmission of light. Adhesives which may be used in the environment of the present invention generally comprise low molecular weight polyesters which are cross-linked in situ with a suitable cross-linking agent. Exemplary of such materials is Adcote 1069, sold by Morton Chemical Company, which is a low molecular weight polyethylene terephthalate material, probably hydroxyl terminated, in conjunction with a polyisocyanate cross-linking agent. Other polyester materials found suitable for this purpose are duPont Adhesive No. 46960 and National Starch Adhesives Nos. 76-2575, 30-9057 and 30-9066. These adhesives are, typically, polyesters utilized in conjunction with a suitable cross-linking agent, such as a polyisocyanate. The adhesives may be used alone or applied in conjunction with other adhesives. The most preferred embodiment of the instant invention utilizes a uniaxially oriented polyethylene terephthalate wave plate bonded directly, on each face, to layers of cellulose acetate butyrate with, preferably, one of the above-denoted National Starch adhesives using a standard pressure roll technique. The wave plate—cellulose acetate butyrate sandwich—and a polarizer—cellulose acetate butyrate sandwich—are then laminated, to one another, preferably using an adhesive which comprises approximately 4% cellulose nitrate whose viscosity is approximately 600 to 1,000 seconds^{-1} dissolved in methyl methacrylate monomer and utilized with a diisopropyl percarbonate catalyst present in an amount of about 1 percent, by weight. This latter defined adhesive is further described in copending application Ser. No. 697,019, filed in the name of Harold O. Buzzell on Jan. 11, 1968 and assigned to Polaroid Corporation.

In this preferred embodiment, as will be discussed more fully below, as regard to FIG. 6 and in any other inclusive embodiment of the present invention, a hard surface coating may be utilized on any or all external surfaces thereof to provide a hard marresistant surface. Preferred materials comprise melamine-formaldehyde condensation polymers, a polyalkylene glycol diester of an α,β-unsaturated carboxylic acid, etc., which materials and techniques of application are disclosed in U.S. Pat. Nos. 2,397,242; 2,481,809; 3,019,131; 3,081,192; and 3,097,106, incorporated herein by reference.

The stressed and/or unstressed window members which may be utilized with the present invention are generally between about 0.25 and 0.5 inch in thickness. The wave plate utilized in the composite structure of the present invention is approximately 1.5 to 5 mils in thickness and preferably about 3 mils thick. If transparent synthetic plastic support materials are utilized in the composite structure, they will generally comprise methyl methacrylate approximately 30 to 125 mils in thickness and preferably about 60 mils thick. The transparent synthetic plastic protective layers of the instant invention will generally comprise cellulose acetate butyrate from 4 to 30 mils in thickness and preferably about 5 mils thick, and the light-polarizing element of the composite structure of the present invention will generally be from about 0.75 to 1.5 mils in thickness and preferably about 0.75 mils thick.

As has been denoted hereinabove, the composite structures of the present invention, including all embodiments comprising a wave plate-polarizer composite unit are designed to be utilized in conjunction with a stressed light-transmitting window element comprising stress-induced birefringent areas. In composite embodiments wherein the wave plate may be laminated to the stressed light-transmitting window element, it will preferably be on the inboard side thereof, as denoted in FIG. 7; however, technically speaking, it will be operative for its intended purpose if laminated outboard thereof. The prime criterion for determining the purpose of the wave plate within the total light-transmitting window apparatus which is considered to be inclusive of the invention claimed herein, is that it must be located between the source of polarized light, e.g., skylight, and the light-polarizing element inboard of the light-transmitting element having stress-induced birefringent areas.

FIG. 1 depicts the present invention in elemental form and illustrates a composite structure comprising a wave plate and light-polarizing element. As has been indicated hereinabove, the wave plate will comprise at least four wavelengths of retardation and preferably seven or more wavelengths of retardation and will further comprise polyethylene terephthalate which, in the most preferred embodiment, is uniaxially oriented.

FIG. 2 depicts the structure of FIG. 1 which additionally comprises synthetic plastic protective layers which, as above denoted, are preferably cellulose acetate butyrate.

FIG. 3 depicts the structure of FIG. 2 which additionally contains synthetic plastic support layers to aid in providing dimensional stability to the unit which preferably will comprise polymethyl methacrylate. FIGS. 4 and 5 generally depict the unit illustrated in FIG. 3 laminated to a structural window member which may or may not be a stressed member and is

preferably laminated thereto according to the thicknesses disclosed hereinabove and utilizing the appropriate adhesive materials. As denoted above, in the event the depicted structural window member comprises birefringent areas, the light-polarizing element will be inboard thereof.

The most preferred embodiment of the present invention is depicted in FIG. 6 and comprises a composite structure comprising the above-denoted wave plate and light-polarizing element, each sandwiched in synthetic plastic layers preferably comprising cellulose acetate butyrate and bonded to one another, and including a hard surface coating on the face of the structure most proximal the light-polarizing element. Obviously, according to the wishes of the operator, a hard-surface coating may be applied to the wave plate face of the structure. In this embodiment, the hard-surface coating preferably comprises a melamine-formaldehyde condensation polymer such as is disclosed, for example, in above-denoted U.S. Pat. No. 2,481,809.

FIG. 7 is another embodiment of the present invention and generally depicts the structure of FIG. 1 laminated to a light-transmitting window member.

It will be appreciated that the present invention additionally contemplates the utilization of a subcombination comprising the wave plate element laminated to a structural light-transmitting window member containing random birefringent areas, which is considered to be the heart of decolorization in systems of the type discussed herein.

The discussions of adhesives and bonding techniques throughout the specification are considered to denote systems preferred for utilization in the invention disclosed herein and are not considered limited specific adhesives, by any means, since numerous adhesive systems will be obvious to those of ordinary skill in the art. In particular, various epoxy adhesives such as the Epon adhesives sold by Shell Chemical Company may be successfully utilized in laminating any of the structures herein disclosed, and particularly such structures as disclosed in FIGS. 1 through 7.

Throughout the specification the terms "inboard" and "outboard" have been extensively used. "Outboard" is considered to be the side through which light may enter the apparatus of the present invention, while "inboard" relates to the side through which transmitted light exits from said apparatus.

In addition, the term "structural," when applied to component elements of the herein claimed apparatus, defines such elements as being capable of maintaining the structural integrity of the article in which it is used, e.g., an aircraft, train, boat, etc., in conjunction with the body of said article.

Since certain changes may be made in the above product without departing from the scope of the invention herein involved, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. A light-transmitting window apparatus which comprises a stressed synthetic plastic light-transmitting element having random stress-induced birefringent areas and a wave plate of at least four wavelengths of retardation.

2. The invention of claim 1 wherein said wave plate is bonded to said light-transmitting element.

3. The invention of claim 1 wherein said wave plate comprises at least seven wavelengths of retardation.

4. The invention of claim 3 wherein said wave plate comprises uniaxially oriented polyethylene terephthalate.

5. A light-transmitting window apparatus which comprises a composite structure comprising a light-polarizing element and a wave plate of at least four wavelengths of retardation comprising uniaxially oriented polyethylene teraphthalate bonded thereto wherein the optic axis of said wave plate is at a 45° angle to the axis of said light-polarizing element.

6. The invention of claim 5 wherein said wave plate comprises at least seven wavelengths of retardation.

7. The invention of claim 6 wherein said wave plate and said light-polarizing element are each interposed between synthetic plastic protective layers.

8. The invention of claim 7 wherein said synthetic plastic protective layers comprise cellulose acetate butyrate.

9. The invention of claim 8 wherein at least one surface of said composite structure has coated thereon a marresistant coating.

10. The invention of claim 9 wherein said marresistant coating is a melamine-formaldehyde condensation polymer.

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