

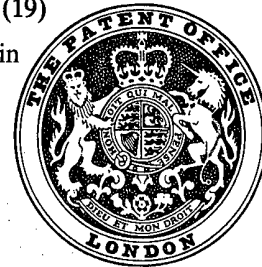
PATENT SPECIFICATION

(11)

1 582 338

1 582 338

- (21) Application No. 51461/76 (22) Filed 9 Dec. 1976 (19)
(31) Convention Application No. 645262 (32) Filed 29 Dec. 1975 in
(33) United States of America (US)
(44) Complete Specification Published 7 Jan. 1981
(51) INT. CL.³ G02B 5/28
(52) Index at Acceptance
G2J 28



(54) COLOUR ENHANCEMENT BY THIN FILM INTERFERENCE EFFECTS

(71) I, WILLIAM JAMES KING, a citizen of the United States of America of 9 Putnam Road, Reading, Massachusetts 01867, United States of America, do hereby declare the invention, for which I pray that a patent may be granted to me, and the method by which it is to be performed, to be particularly described in and by the following statement:-

The invention relates to the enhancement of colour by means of the optical interference effects which are produced by thin films. Interference phenomena in connection with thin films are well known. A summary of some of these phenomena is set forth in an article in the Scientific American entitled "Optical Interference Coatings", December 1970, pages 59-75. Although the article starts with a display of various colors in a colored illustration and includes references to certain color effects produced in nature by thin films such as oil slicks, soap films, oyster shells, and peacock feathers, the various scientific uses of optical interference coatings described in the article do not include the controlled production of visual color effects. A major use of optical coatings is the production of reflection or non-reflection across the visible spectrum. Thus anti-reflection coatings are used on lenses, and multiple reflective coatings are used in dielectric mirrors. Applications requiring enhancement at a particular wavelength have an analytical rather than a visual purpose and require the maximum reflectivity possible, such as the laser and the Fabry-Perot interferometer. Although the Plumbicon tube separates light into primary colors, these are not viewed, but produce signals for transmission to a receiver via megacycle carrier waves. Moreover, not only do these prior scientific uses of optical interference films have no visual purpose, but the way in which the films are used to achieve a particular effect is such that, once adjusted for this effect, the optical device in question can no longer be adjusted to control other parameters.

Various methods have also been used to alter the spectral transmission and other characteristics (such as absorption and color) of materials such as glasses or plastics in order to make them useful as sunglasses, either as light absorbers to reduce and/or control the amount and nature of light reaching the eye, or for cosmetic reasons. These methods have included coloring the basic materials, adding a colored layer over the surface, adding a neutral filter to one or more surfaces, and adding a polarizing material.

However, the application of interference films to provide interference colors has not normally been used for such purposes. Such colors, although observed by many investigators, have not been used in general for cosmetic purposes because of difficulties in obtaining "predetermined" colors and because the colors lacked "depth", particularly on the transparent or partly absorbing substrates that are used for sunglasses and similar purposes. It is one purpose of this specification to show how such colors can be obtained having "depth" or color "density" under controlled conditions. In addition, this specification shows that such "high depth" colors can be obtained under conditions which allow the user to control the amount and nature of light transmitted to and through the substrate. This specification will also show how the latter control of the transmitted light can also be obtained while having "low depth" coloring. In fact, any practical degree and/or combination of color depth and transmitted light control can be obtained by proper use of the teaching of the present specification.

In conventional optical techniques, interference films are commonly used to fabricate band-pass light filters and to "increase" (as distinct from the invention's effect, which is always to decrease the transmitted light, as in the case of sunglasses and other light reducing devices) the amount of transmitted light (for example for lenses and binoculars) through their use as so-called quarter-wavelength anti-reflection filters, the latter being a simple form of

the former. As discussed below, since any film of "optical" thickness $\lambda/4$ (λ being the wavelength of the radiation) is effective only around one value of λ (or specific functions thereof), the application of such films having λ values in the visible range causes the reflected and transmitted light components to be colored, even when the incident light is white, as is usually the case, for example, for sunglasses or windows.

By choosing film thicknesses properly, one can get a wide spectrum of reflected colors (the color of the transmitted light being the spectrum of the incident light, normally white, minus the reflected and absorbed components). This technique has not normally been used as a "coloring" mechanism primarily because of difficulties in controlling the color and very importantly because of the lack of intensity or color depth when used on transparent or partly absorbing substrates. In fact, such colors are normally observed only as a necessary adjunct to other factors such as the need for an anti-reflection filter on binoculars.

The lack of color depth (pastel shading in general) is acceptable for some purposes (e.g. lightly tinted sunglasses) but is not adequate for others. Another reason why interference techniques have not been put to widespread commercial use is the need to put such films on the outside of the lens (or window) for the best cosmetic effect or function. In practice, this means the films themselves must be quite hard or must be covered with another harder (normally transparent) film or layer to prevent scratching or other attack, thereby complicating the manufacturing process. The use of interference films has therefore been primarily restricted to optical instruments (such as binoculars, and spectrometers) and techniques (such as band pass filters) where such factors are relatively unimportant because of the care which the optical components receive and/or the undesirability of or lack of need for coloration. In fact, in many scientific instruments which use interference effects for measurement purposes, monochromatic light must be used at some stage to provide the necessary operation. For most such purposes, conventional interference techniques are adequate.

However, in the case of plastic eyeglass (i.e. spectacle) lenses (both prescription and sunglass) there is a need for a coloring technique which can provide vivid cosmetic colors and also give protection to the soft plastic surface while providing the light reflection and/or absorption necessary to perform a worthwhile sunglass function. Similar applications exist in, (for example, plastic windows, plastic decorator panels or building materials) and also for other substrate materials (e.g. glass) in special applications (such as decorator panels or functional windows). Other applications will be obvious to those skilled in the art who become familiar with this invention. Some of such applications may simply require a color effect without the need to adjust other parameters such as light transmission. For example, such applications as plastic wall panels protected against scratching, costume jewelry, decorative dishes, and bottles, may incorporate the principles of the invention simply for a coloring effect.

In these applications, the interference coloring film must usually be extremely well bonded, to a degree not normally achieved with standard deposition techniques. Although any "appropriate" process capable of attaching the required materials in the "required" form to the substrate surface may be used in applying this invention, the invention itself has been demonstrated using ion beam sputtering and ion beam implantation sputtering techniques. The former is disclosed, for example, in U.S. Patent No. 3,472,751. The latter can be used to deposit very tightly bonded, durable films on plastics and other difficult substrates, the film of deposited material commonly, but not necessarily, being harder than the substrate material.

The invention deals with transparent solids such as windows and eyeglasses, (and, in certain embodiments, coloring effects on solids whether transparent or not, such as wall panels, and costume jewelry), and provides means for enhancing the color of light incident upon the transparent solid while at the same time permitting further control of the radiation transmitted and reflected over a wide spectrum. The invention makes use of the discovery that the color of the reflected or the transmitted light may be enhanced in a way which does not materially affect the bulk of the visible light passing through or reflected by the transparent solid. As will be clear from the specification color enhancement may be achieved by interference between light reflected from a semi-reflecting layer on the transparent solid and light reflected from the outer surface of a dielectric layer which is hermetically sealed over the semi-reflecting layer. The reflectivity at each of these surfaces need not be particularly large since color enhancement is achieved by a differential effect whereby the eye detects either the prominence of constructive interference at a particular band of wavelengths over the background radiation, or the color effect produced when a band-width of light is removed from the reflective light by destructive interference. In each case the bulk of the radiation is not affected by the interference phenomena, so that the light transmitted through, reflected by, or absorbed in the transparent solid may still be controlled by varying the thickness of the semi-reflecting layer and by other means.

The present invention provides a method of enhancing color effects produced by ambient light while controlling light intensity produced thereby, comprising: reflecting with a phase

change substantially equal to π radians between 1 and 25% of the ambient light at an interface while permitting substantially all of the remaining ambient light to continue as transmitted light, permitted said transmitted light to travel without reflection to an absorbing layer and then reflecting a portion of said transmitted light at said absorbing layer while permitting the remaining light to continue as retransmitted light, the distance between said first interface and said absorbing layer being such that a specific color effect is produced due to interference at one, or a limited number of, specific wavelength(s) in the visible spectrum between the light reflected from said interface and the light transmitted back through said interface after reflection at said absorbing layer.

The present invention also provides optical apparatus comprising in combination a dielectric substrate, a semireflecting layer intimately bonded to one surface of said substrate, and a dielectric layer having an outer surface and an inner surface, said inner surface being hermetically sealed to said semireflecting layer, said dielectric layer having a uniform thickness such that, when ambient light is incident on the outer surface, a specific colour effect is produced due to interference at one, or a limited number of, specific wavelength(s) in the visible spectrum between light reflected from said outer surface and light transmitted back through said outer surface after reflection at said semi-reflecting layer.

The invention may best be understood from the following detailed description thereof, having reference to the accompanying drawings, in which:

Fig. 1 is a diagrammatic sectional view of a series of layers arranged in accordance with one aspect of the invention;

Fig. 2 is a diagrammatic view showing the transmission and reflection of light rays incident upon a glass layer in air according to the prior art;

Fig. 3 is a series of graphs showing the effect of superimposition of waves;

Fig. 4 is a view similar to that of Fig. 2 wherein the glass layer is supported upon a plastic substrate according to the prior art;

Fig. 5 is two views similar to that of Fig. 2 showing the reflection of light rays incident upon a highly reflecting layer according to the prior art;

Fig. 6 is two views similar to those of Fig. 5 showing the reflection of light rays incident upon a semireflecting layer in accordance with the invention; and

Fig. 7 is a view similar to those of Fig. 6 wherein glass of a relatively high index of refraction is used.

The primary object of the described embodiments of the invention is the means of obtaining on suitable substrates, optical layers which with reflected light, i.e. to the viewer on the side of the incident light, have a "colored" metallic appearance as opposed to the conventional neutral metallic appearance normally used in, for example, sunglasses and mirrors.

A second object is the means to obtain optical layers which control the characteristics of the visible light and/or other radiation reaching a viewer on the opposite side of the substrate from the incident visible light and/or other radiation (hereinafter collectively referred to as radiation), while simultaneously controlling the "color" of the composite structure as viewed by an observer on the side of the substrate upon which the radiation is originally incident.

A third object is to "control" the transmitted radiation and colors as in the second object above while simultaneously controlling the amount and type of incident radiation which is absorbed in the original substrate, by controlling the amount of incident radiation which is reflected away from the substrate.

A fourth object is to obtain the functions above while simultaneously protecting the underlying substrate and deposited material from mechanical and/or chemical attack.

The physical arrangement required in accordance with the invention to obtain all of the above functions is shown in Figure 1. The important feature of this arrangement is the combination of a partially-reflecting or so called semi-reflecting (reflectivity being less than a highly polished or deposited "opaque" metal layer and more than a low reflectivity substrate such as clear glass or plastic) layer 1 and a layer 2 of transparent or "partially" absorbing material (such as clear or colored glass, respectively) with index of refraction and thickness appropriate to obtain the desired features of the invention. How this combination differs from conventional interference methods and how it works in practice are described below. If necessary, a second layer 3 of transparent or partially absorbing material can be put over the interference layer 2 to provide additional protection and/or coloring effects in conjunction with those due to the interference layer. The semi-reflecting layer 1 is itself supported on a suitable underlying substrate 4.

The operation of this invention and the differences with respect to previous methods can best be understood by comparison with classical optical theory and practices related to interference effects due to thin films. This can be done in stages as shown in Figures 2-6.

The incident light may be incident at any angle θ from 0 to 90°. However, in the following discussion, unless stated otherwise the light is considered to be incident normal to the surface

(i.e. $\theta = 0^\circ$) to simplify and clarify the description of the invention. The light rays in Figures 2, 4, 5, and 6 are shown at an angle $\theta \neq 0^\circ$ for purposes of ray identification and only the reflected rays of interest are shown. The corresponding transmitted rays are the incident rays minus the reflected component. If the substrate medium is absorbing (e.g. colored glass) the final transmitted ray would also be minus the absorbed component. Unless otherwise stated, all dielectric materials shown are non-absorbing and are assumed to have indices of refraction that are constant across the visible spectrum.

The first element in defining the invention is a simple very thin (e.g. $< 10,000 \text{ \AA}$ thick) film 5 of glass suspended in an air medium as shown in Figure 2. This is analogous to the classical soap film in which interference colors are observed corresponding to discrete film thicknesses 10 t.

In general, there is a phase change of $\pm \pi$ if a light wave travelling in a medium with a given index of refraction is reflected at the interface with a medium having a higher index of refraction and the phase change is 0 if the reflecting medium has a lower index of refraction than the original medium. This assumption is not rigorously true for many cases of reflection at the boundary of two different media, for example at many air-metal interfaces, but is adequate and convenient for purposes of explanation. It is valid for the air-glass-air case shown in Figure 2. Exact phase changes of 0 or changes of $\pm \pi$ are used below in discussing all of the interfaces in Figures 2, 4, 5 and 6 and where this can lead to appreciable difference in operation of the invention, it is discussed. In no event does the divergence from a rigorous treatment alter the basic concepts of the invention.

Since there is a phase change of $\pm \pi$ at the first interface in Figure 2 and 0 at the second, it can be shown that the first ray reflected from the air-glass interface is reinforced through constructive interference effects at wavelength λ_c given by

$$t = \frac{(2m+1)\lambda_c}{4n_g \cos\theta} \quad m = 0, 1, 2, 3, \text{ etc.} \quad (1)$$

where t = thickness of glass
 n_g = index of refraction of glass
 θ = angle of incidence

For $\theta = 0$, $\cos \theta = 1$ and equation (1) becomes

$$t = \frac{(2m+1)\lambda_c}{4n_g} \quad (2)$$

(All subsequent formulae and discussions assume $\theta = 0$)

Reflectivity at the interface between two non-absorbing media is given by the formula

$$R = \left[\frac{n_g - n_o}{n_g + n_o} \right]^2 \quad \text{for normal incidence} \quad (3)$$

where

n_o = index of refraction of first medium; in this case, air.
 n_g = index of refraction of second medium; in this case, glass.
 For $n_o = 1$ (air) and $n_g = 1.46$ (fused silica)

$R = 3.5\%$

Unless otherwise noted it is assumed for purposes of discussion that the reflectivity is the same at all λ 's of interest, i.e. n_g is constant across the spectrum of interest.

From Figure 2 it is seen that the component (R_1) reflected from the first air-glass interface has an intensity of 3.5% of the original ray. The remaining 96.5% of the original ray is reflected from the rear glass-air interface with an intensity relative to the original ray of $96.5\% \times 3.5\% = 3.38\%$. At the front surface this internal ray is again reflected (reflectivity = 3.5%) with an intensity relative to the original ray of $3.38\% \times 3.5\% = .118\%$ and the remaining $3.38\% \times 96.5\% = 3.26\%$ emerges as the second component (R_2).

The part of the first internal ray (.118% of original intensity) which is rereflected at the

front surface, will be rereflected from the back surface with an intensity of $0.118\% \times 3.5\% = .00413\%$ and will emerge through the front surface as R_3 having an intensity of $.00413\% \times 96.5\% = .0040\%$ after an additional 3.5% loss through reflection at the front surface. The internal reflections continue with corresponding decreases in the intensity of the rays $R_4, R_5, \dots$ emerging through the front surface. If the first internally reflected ray R_2 is in phase with the originally reflected ray R_1 upon emerging as given by equation (3), the second internally reflected ray (R_3 after emerging) is out of phase since the total additional path length is a $1/2$ integral number of wavelengths long and there is no additional phase change at either the front or rear internal reflections. The third internally reflected ray (R_4 after emerging) is thus in phase, and so on.

R_1 and R_2 are in phase and of much larger magnitude than the other rays, resulting in an enhancement of the color at the particular wavelength involved (assuming glass thickness t corresponding to constructive interference at visible wavelengths λ_c). A rough approximation is a doubling of the energy reflected at λ_c as given by equation (3) and shown (for the first two rays R_1 and R_2) in Figure 3(a). At other wavelengths near the coherent wavelength, the amplitudes can be partially reinforced as in Figure 3(b) where it is assumed that R_2 is roughly 36° (for example 30°) out of phase with R_1 . If, however, R_1 and R_2 are π or near π out of phase as in Figure 3(c), there can be almost complete annihilation of the reflected components at that wavelength. The wavelengths λ_D for maximum out of phase destructive interference is given by:

$$t = \frac{m\lambda_D}{2n_g} \quad m = 1, 2, 3 \text{ etc.} \quad (4)$$

Whether major constructive and destructive interference effects can occur simultaneously in the same film and to what extent is primarily a function of the film thickness and is discussed below.

The net result with respect to the film is an apparent color corresponding to wavelengths around λ_c (if constructive interference dominates) or at that color that remains after than corresponding to wavelengths around λ_D are removed (if destructive interference dominates). These colors for this type of film can be reasonably intense if the film is not exposed to a lot of white light incident on the rear surface. Since the transmitted light is the complement of the reflected light, if there were white light incident on the rear surface of intensity level 100% of that incident on the front surface, the two wave trains would tend to complement each other and produce white light as viewed from either side.

However, if most of the light is incident on the front surface, the "differential" effect on the reflected light can be quite significant leading to relatively intense coloring. For example, if only constructive interference occurs, those wavelengths near λ_c will have an intensity level of $R_1 + R_2 - R_3 + R_4 \text{ etc.} \approx I_c \approx R_1 + R_2 = 3.5 + 3.26 = 6.76\%$ while those at wavelengths far removed from λ_c , where R_2 is half in phase and half out of phase with R_1 will have an intensity I_B roughly equal to that of R_1 , i.e. approximately 3.5% . A convenient measure of the differential level of the constructive color component above the background is the difference between the enhanced intensity I_c and the random background intensity I_B , divided by the random background intensity I_B . For the case under consideration this is approximately

$$\text{Differential level} = \frac{I_c - I_B}{I_B} = \frac{6.76 - 3.5}{3.5} = .93 \text{ or } 93\%$$

if only the reflected components are considered. In practice, some white light is incident on the rear surface and the differential effect is much less than this.

It should be noted that the structure shown in Figure 2, although producing vivid coloring, is not adequate for most practical purposes because of the thinness of the glass layer involved.

It should also be noted that the coloring effects are due to the ability of the eye to observe and evaluate the "relative" amplitudes of the various components of the light entering the eye, so that the greater the differential height of the coherent λ_c (for example above) "above background", the deeper or more vivid will be the apparent color.

Although the above discussion consists primarily of an analysis of observed facts and in that sense is trivial, it is important to a clear understanding of the present invention as discussed below.

Figure 4 gives the next stage in understanding the invention and shows a glass film 5 of

index of refraction n_g intimately attached by some method to a plastic substrate material 6 having index of refraction n_p where $n_p > n_g$ and both media are non-absorbing. (The materials chosen here and in subsequent stages of the development are arbitrary and could be replaced with other "suitable" materials without altering the basic explanation.) In this case there is a phase change of $\pm \pi$ upon reflection at the front surface and "another" phase change of $\pm \pi$ upon reflection at the glass-plastic interface.

The condition for constructive interference of the first internally reflected ray R_2 with the initial reflected ray R_1 , in this case is given by;

$$t = \frac{m\lambda_c}{2n_g} \quad m = 1, 2, 3 \text{ etc.} \quad (5)$$

The condition for destructive interference is given by;

$$t = \frac{(2m+1)\lambda_D}{4n_g} \quad m = 0, 1, 2, \text{ etc.} \quad (6)$$

However, in this case the amount of light reflected from the glass-plastic interface, as given by equation (3) for $n_g = 1.46$ and $n_p = 1.54$ (plastic) is only $.071\% \times 96.5\% = .0686\%$ of the incident light with the emerging component R_2 only $.0686\% \times 96.5\% = .0662\%$. The plastic substrate 6 is assumed to be very thick since it must provide support, and so there are no interference effects due to reflection at the rear plastic-air interface. This additional light of R_2 , even if satisfying equation (5), will therefore produce a differential effect of only $.066/3.5 = .019$ or 1.9% above background. Such combinations of materials therefore have only a very slightly observable coloring. In such a case white light penetrating from the back surface also tends strongly to wash out any net coloration since almost all of the white light incident on the back surface will emerge from the front as white light, raising the background level to approximately 100%.

It should be noted that in this case, if R_1 and R_2 are in phase, R_3 will be out of phase; i.e. will destructively interfere with R_1 and R_2 because of the additional $\pm \pi$ phase change at the second reflection at the glass-plastic interface. The additional path length in the glass is, of course, an integral number of wavelengths since that is the condition for the first internally reflected ray R_2 to be in phase with R_1 . The third internally reflected ray R_4 is in phase, and the fourth R_5 out of phase etc. This factor is unimportant for the case shown in Figure 4 because of the small reflectivities and intensities involved, but is important in the new elements involved in the present invention.

Next consider a simple highly polished opaque reflecting metal layer 7 as in Figure 5(a) (e.g. vacuum deposited Al on glass or plastic) with a reflectivity assumed for discussion to be 90% (normally higher) and flat across the visible spectrum. The reflectivity for such an opaque absorbing medium with light incident from a dielectric of index of refraction n_o is given by:

$$R = \frac{(n_o - n_m)^2 + k_m^2}{(n_o + n_m)^2 + k_m^2} \quad (7)$$

where

n_m = index of refraction of metal

k_m = extinction coefficient for metal

which reduces to

$$R = \frac{(1 - n_m)^2 + k_m^2}{(1 + n_m)^2 + k_m^2} \quad \text{for } n_o = 1(\text{air}) \quad (8)$$

For some metals such as Al where the relative values of n_m and k_m are appropriate across the spectrum (visible) the reflectivity remains fairly flat and the reflected light has a neutral gray pure metallic appearance. For other metals such as Cu, the relative values of n_m and k_m are such that R varies across the visible spectrum (e.g. for evaporated Cu, $R \approx 58\%$ at $4,500 \text{ \AA}$ and $R \approx 96\%$ at $7,000 \text{ \AA}$). For the example given, the Cu therefore appears by reflected light to be reddish since more of the red end of the spectrum is reflected. As discussed later, this factor is also used in controlling coloration using the present invention.

Returning to Figure 5(a) the situation is quite simple with only those rays reflected from the first surface being viewed by the observer (i.e. a simple front surface mirror). If, however, the metal is covered by a thin layer (such as that shown at 8 in Fig. 5(b)) of glass, or other appropriate medium, the situation changes to that shown in Figure 5(b) where again the

"initial" reflected ray is only 3.5% of the incident energy. A phase change of $\pm \pi$ is assumed at the glass-metal interface. In a more rigorous treatment the phase change ρ is given by:

$$\rho = \tan^{-1} \frac{2n_g k_m}{n_g^2 - n_m^2 - k_m^2} \quad (9)$$

where the symbols have the meanings previously given. For many glass-metal combinations ρ is near π , while for others it can vary by significant factors. This divergence from an exact π phase change on reflection has little effect on the present invention since its effect is to slightly shift the value of the thickness t required for constructive or destructive interference at a given wavelength, through the addition of an error factor viz. (for constructive interference)

$$t = \frac{m\lambda_c}{2n_g} + \Delta t_p \quad (10)$$

In practising the invention, as discussed below, one simply adjusts t to compensate for the Δt_p error (if significant). A similar correction exists for variations in reflectivity but is of no consequence to the present invention since it is basically an angle of incidence correction to reflectivity and we are primarily concerned with normal incidence. As shown by equation (1) and similar formulae, constructive and destructive interference coloring effects will be apparent at non-normal angles of incidence which will vary from those at normal incidence, but this has no effect on the practice of the invention since the contemplated uses of the invention do not require that the color effect should be the same for all angles of view.

Referring to Fig. 5(b), for a phase change of $\pm \pi$, the first internally reflected ray R_2 is in phase with R_1 at λ_c given by equation (5) and has an intensity of $(100 - 3.5)\% \times 90\% \times (100 - 3.5)\% = 96.5\% \times 90\% \times 96.5\% = 83.81\%$ of the original intensity. R_3 is out of phase with R_1 and R_2 and has an intensity of $96.5\% \times 90\% \times 3.5\% \times 90\% \times 96.5\% = 2.64\%$. R_4 is in phase with an intensity of $96.5\% \times 90\% \times 3.5\% \times 90\% \times 3.5\% \times 90\% \times 96.5\% = .083\%$. The sum of R_1 , R_2 , R_3 and R_4 (ignoring higher components) is therefore

$$3.5 + 83.81 - 2.64 + .083 = 84.75\%$$

One cannot readily state what the reflected amplitudes are for wavelengths other than the coherent value since they depend critically on, for example, wavelength, and materials. However, in general, considering R_2 as the primary ray because of its intensity, ($R_1 + R_4$) and R_3 will tend to cancel because of the corresponding phase differences so that the intensity variation cannot be greater than approximately

$$83.81 \pm [(3.50 + .083) - 2.64] = 84.75 \text{ to } 82.87$$

As a rough approximation, the maximum "differential effect is given by the value for λ_c minus the lowest value above, i.e. $I_c = 84.75$, $I_B = 82.87$ and

$$\text{Differential level} = \frac{I_c - I_B}{I_B} = \frac{84.75 - 82.87}{82.87} = .023 \text{ or } 2.3\%$$

A special case can occur if the thickness t is such (see later discussion) that destructive interference at λ_D can occur simultaneously with constructive interference at λ_c . Should such occur, R_2 , R_3 and R_4 for λ_D are all in phase with each other and out of phase with R_1 since each additional internal reflection traversal adds 2π to the phase (additional half wavelength due to path length plus π phase change at glass-metal interface). The amplitude for this value of λ_D is given by

$$(83.81 + 2.64 + .083) - 3.5 = 83.03\%$$

which gives less than the maximum differential effect calculated above for "random" wavelengths. Interference colors on such highly reflecting metal surfaces therefore tend to be weak or washed out to the eye because of the small differential intensities involved.

With the foregoing as background, the operation of the present invention may be readily understood. Consider the situation shown in Figure 6(a) where the arrangement is the same as that in Fig. 5(b) except that the metal layer 9 is only 20% reflecting (again assumed flat across the visible spectrum). For a thickness t corresponding to constructive interference at

λ_c , the intensities and phases of the reflected rays are $R_1 = 3.5\%$ (initial), $R_2 = 18.62\%$ (constructive), $R_3 = 0.13\%$ (destructive) with the higher orders being insignificant. The total reflected intensity at λ_c is therefore

$$5 \qquad 3.5 + 18.62 - .13 = 22\% \qquad 5$$

In general, for other "normal" wavelengths the effects of R_1 and R_3 may be approximated (considering R_2 as the main reflected ray) by assuming that they will add half their difference in intensity to R_2 (i.e. $1/2(3.5 - .13) = 1.69\%$) so that the total intensity $R_1 + R_2 + R_3$ may be estimated as $18.62 + 1.69 = 20.31$. The differential effect for λ_c above these wavelengths is therefore

$$15 \qquad \frac{22.0 - 20.31}{20.31} = .083 = 8.3\% \qquad 15$$

compared to the $\sim 2.2\%$ found for the opaque reflecting metal case shown in Figure 5(b). More importantly, if a simultaneous destructive interference occurs at λ_D at the same value of t , the minimum amplitude is given by $(R_2 + R_3) - R_1$ or

$$20 \qquad (18.62 + .13) - 3.50 = 15.25\% \qquad 20$$

In this case the differential effect = $\frac{22 - 15.25}{15.25} = .44$ or 44% above background which is roughly 20 times that found for the opaque reflecting metal (90%) situation in Figure 5(b).

For comparison, Figure 6(b) shows the values for a 30% reflecting layer 10. In this case the intensity at λ_c is given by $(R_1 + R_2) - R_3$. Since $R_1 = 3.5\%$, $R_2 = 96.5\% \times 30\% \times 96.5\% = 27.94\%$ and $R_3 = 96.5\% \times 30\% \times 3.5\% \times 30\% \times 96.5\% = 0.293\%$, then the intensity is

$$30 \qquad 3.50 + 27.94 - .29 = 31.15\% \text{ at } \lambda_c; \\ 27.94 + 1/2(3.5 - .29) = 29.54\% \text{ for an average noncoherent } \lambda_A; \text{ and} \\ (27.94 + .29) - 3.50 = 24.73\% \text{ for a destructively interfering } \lambda_D. \qquad 30$$

The differential effects are therefore

$$40 \qquad \approx \frac{31.15 - 29.54}{29.54} \times 100 = 5.45\% \text{ for } \lambda_c \text{ greater than } \lambda_A \text{ and} \\ 40 \qquad \approx \frac{31.15 - 24.73}{24.73} \times 100 = 25.96\% \text{ for } \lambda_c \text{ greater than } \lambda_D \qquad 40$$

These are considerably smaller than for the 20% reflecting layer case but are still much larger than the $\approx 2.2\%$ found for the 90% reflecting case or for the simple glass on plastic case.

One of the basic elements of this invention is therefore the adjustment of the thickness of the dielectric medium (glass in examples) used as an interference layer, and the reflectivity of the semi-reflecting metal layer to enhance and/or optimize the differential coloring effect. If one goes to reflectivities less than 20% the effect is enhanced still more, with, for example, the differential effect (both λ_c and λ_D occurring simultaneously), being > 100 at 10% reflectivity. At higher reflectivities than 30%, the effect, of course, decreases in intensity.

In examples given, SiO_2 ($n = 1.46$) has been used as the interference dielectric since this material has been extensively used in demonstrating the invention. The differential effect can be increased still further, however, by using other dielectrics having higher values of n , thereby affecting the reflectivities (particularly at the front surface) and ultimately the differential effect. Consider Figure 7 which gives the situation comparable to that shown in Figure 6(a) (20% reflecting metal) but with TiO_2 having $n = 2.60$ replacing the SiO_2 as the interference medium. In such a case $R_1 = 19.753\%$ by equation (3), $R_2 = 80.247\% \times 20\% \times 80.247\% = 12.8792\%$, and $R_3 = 80.247\% \times 20\% \times 19.753\% \times 20\% \times 80.247\% = .5088\%$. Considering only R_1 , R_2 and R_3 the enhanced intensity $I_c = (R_1 + R_2) - R_3 = (19.753 + 12.8792) - .5088 = 32.1234$ and the background intensity $I_B = R_1 - (R_2 + R_3) = 19.753 - (12.8792 + .5088) = 6.3650$. The maximum differential effect is given by

$$\frac{I_c - I_B}{I_B} = \frac{32.1234 - 6.3650}{6.3650} = 405\%$$

5 which is nearly a factor of 10 greater than in the 20% reflecting SiO₂ dielectric case. One 5
 could therefore reduce the reflectivity of the metal even more to allow much more of the light
 to penetrate to the inside while still maintaining a very strong coloring effect. (With a dense
 layer of metal, there is a glass-metal interface at the top of the layer and a metal-plastic
 10 interface at the bottom. However, as the density of the metal is decreased, there will be an 10
 increasing number of areas where (on a molecular scale) there will be no metal and therefore
 a glass-plastic interface. The limiting factor will be the increased reflectivity at the glass-
 plastic interface as the metal is made less dense and the relative index of the glass and plastic
 becomes larger leading to increased reflectivity. Exact values depend on a given application
 15 and materials). The maximum effects, of course, exist when the sum of R₁ and R₂ is much 15
 greater than their difference as in the above TiO₂ case. In general, this occurs when the index
 of refraction of the dielectric has a relatively (compared to SiO₂) high value. Another
 example is Si₃N₄ which has n = 2.03 resulting in a maximum differential effect of 503%.
 Other materials such as SiO (n = 1.95) and Al₂O₃ (n = 1.76) will have coloring effects which
 20 are more pronounced than those of SiO₂ and others will be apparent to those skilled in the art. 20
 The choice of material depends on the particular application. In the discussions which follow,
 the SiO₂ situation is the one which is considered in all cases.

For the non-opaque, semi-reflecting metal cases, white light incident upon and penetrating
 through the rear surface and emerging through the front tends to decrease the effect. The
 major decrease is due to an increase in the background level since interference effects that
 25 occur in the thin glass layer (i.e. interference effects between light reflected at plastic-metal 25
 interface and that reflected at glass-air interface) will be non-coherent with those occurring
 due to light incident on the front and even if occurring will have a much smaller effect due to
 the much higher background. The latter results because the transmitted light differential
 effect is the complement of the reflected light effect and is superimposed on a much higher
 30 background (80% of light reaching plastic-metal interface minus 3.5% reflected at glass-air 30
 interface).

Considering only the increase in background, if white light of intensity 100% of I (intensity
 of white light on front surface) is incident on the rear surface in the 20% reflectivity (metal)
 case, approximately 74.5% (after three reflective losses at various interfaces) will exit
 35 through the front surface. The effect in the maximum differential case ($\lambda_c + \lambda_D$ simultane- 35
 ously) is a reduction from 44% to a value of

$$\frac{22.0 - 15.24}{15.24 + 74.5} = .075 \text{ or } 7.5\%$$

40 Although in a practical embodiment of the invention (e.g. use as sunglasses) there is much 40
 less than 100% of I coming through the rear surface, even in the worst case of 100% of I the
 differential effect is much greater than that obtained (~2.2%) for a 90% reflecting layer case.
 This negative effect of white light penetrating through the rear surface can be partly negated
 45 by having the substrate (plastic in example) made of visible light absorbing material. If, for 45
 example, the plastic in the 20% reflecting case were of a thickness and absorptivity A to be
 50% absorbing in the visible, white light of intensity I entering through the rear surface would
 have an intensity of $(1 \times .965 \times .5 \times .8 \times .965) = 0.371$ on exiting through the front surface and
 the maximum differential effect ($\lambda_c + \lambda_D$ simultaneously) would be

$$\approx \frac{22.0 - 15.24}{15.24 + 37} = .129 \text{ or } 12.9\%$$

55 In the real case of sunglass use, the light entering through the rear is much less, say 20% of I 55
 maximum, being only that going around the frames and reflected off the skin. For this value
 the maximum differential effect equals approximately 22% for the non-absorbing substrate
 use and 29.8% for the 50% absorbing substrate case.

Since the thickness t of the interference medium (glass in example), the reflectivity R of the
 reflecting metal, the absorptivity A of the substrate material and the ratios thereof are
 60 infinitely variable, within the limits of minimal reflectivity (no metal) and no absorption 60
 (clear substrates) and maximum reflection (opaque polished or evaporated metal) and
 maximum absorption (highly absorbing substrate), the color and/or intensity of the structure
 as viewed by an observer on the front or incident surface and that of the light reaching a
 viewer behind the rear surface (wearer for sunglasses) can be varied over an extremely broad
 65 range. In the practical embodiment of the invention, this allows the user to reduce the light 65

reaching the inside viewer to a desirable level, e.g. 30% of neutral or near neutral shading for a sunglass wearer, while obtaining the desired color and intensity level for an external viewer. It has been demonstrated in practicing the invention that neutral shading can be obtained by having a substrate having neutral absorption at the proper level. This can be used to overcome or wash out coloring effects due to light coming from the front surface (non-reflected) which is the complement of that reflected and is therefore colored, although of much less effective density than the reflected component because of the much higher background ($\sim 74\%$ of light being transmitted in 20% reflecting and non-absorbing substrate case). The light reaching the inside receiver can also, of course, be colored if desired.

A, R and t, for example, may be adjusted to yield other values of external coloring and intensity for other purposes, e.g. for office windows. For this use, in one test of the invention the absorbing substrates were of glasses manufactured by PPG Industries, Inc. under the names solarbronze, solargray and solarex. The metal layer reflectivity was adjusted to reduce the light level penetrating to the inside to a comfortable level while maintaining the neutral characteristics (particularly for solarbronze or solargray) and changing the color as viewed from the outside to that desired but for this purpose deliberately of less intensity than in the normal sunglass case. However, it should be noted that all ranges of values for external color intensity and transmitted light intensity may be used for any and all applications. Of course, in a limited number of embodiments of the invention (such as wall panels) the transmitted light intensity may be of no consequence.

A very important factor that is observed in the practical embodiment of the invention is that the colors so formed have an extremely metallic appearance; i.e. a metallic nature similar to that obtained with a highly polished metal reflector such as Al, but with deep color shading resulting in a striking "colored metallic" appearance. This occurs because the differential effect primarily results from reflection at a very thin layer in the same way that reflection results at the surface of a neutral metal reflector. The resulting radiation is therefore space as well as time coherent and the eye perceives that the light emanates from a restricted layer or layers. (This is in contrast, for example, to absorbing glasses which have a color due to absorption and reemission of radiation at many spatially separated atomic layers in the glass and which therefore do not have a metallic appearance). This factor when optimized by proper use of the present invention gives a recognizable and distinctive appearance when A, R and t, for example, are chosen for vivid coloring.

The practice of the invention can best be understood and mastered by a full appreciation of the effect of using a partially - reflecting metal layer as discussed previously in conjunction with Table I which gives the colors observed by previous investigators (Pliskin and Conrad - IBM Journal, Jan. 1964) for thermally grown films of SiO_2 on polished (i.e. opaque maximum reflecting) slices of silicon. The latter is the case normally observed previously, where the coloration is not enhanced nor has a strong metallic appearance as in the present invention. Similar, but not exactly the same, colors were observed in the practical demonstrations of the present invention. Exact coloring depends on the metal used as the reflecting layer and varies in each case.

Table I has been prepared specifically for this invention to explain the colors obtained to show detailed operation. It gives the calculated wavelengths for constructive interference ($t =$) and destructive interference ($t =$) in association with the colors observed by Pliskin and Conrad. Note that the value of t given is the real value, not the optical thickness t_n and the λ_c 's and λ_D 's having effects in the visible are outlined.

At a thickness t of 500 Å, there is no visible wavelength λ_c or λ_D at which interference effects should occur if the glass (SiO_2) has an index of refraction of ~ 1.46 (used for calculating Table 1). The tan color observed by Pliskin and Conrad can be explained by the following considerations. If the SiO_2 is oxygen deficient and has an appreciable proportion of SiO having an index of refraction of 1.95 (or other oxygen-deficient SiO_x compounds) as can occur at the interface for thin thermally grown SiO_2 layers on Si, the λ_D for destructive interference ($m = 0$) is 3,900 Å which is above the edge for optical interference ($\sim 3,800$ Å) in the visible. Some of the violet component will be removed from the reflected light under these conditions, so that the remaining reflected light has a tan appearance or color as observed by Pliskin and Conrad. However, for $n = 1.46$ which is obtained if the silicon is deposited by ion beam sputtering or ion beam implantation sputtering techniques, no tan color is apparent when layers of 500 Å thickness are deposited on highly reflective metal layers such as opaque ion beam sputtered Al on smooth glass or plastic substrates. Such layers, if hermetic as in the ion beam sputtering case, can be used to protect the reflecting metal against corrosion without altering its optical characteristics at wavelengths longer than $\sim 3,000$ Å. This has been clearly demonstrated for the present invention.

If the thickness is increased to 700 Å, λ_D becomes 4,088 Å, moving the removed (i.e. destructively interfered) component farther towards the blue, producing a brown appearance. At 1,000 Å, λ_D is 5,840 Å which is in the yellow part or middle of the spectrum. Both

ends of the spectrum therefore show up in the reflected light which is dark violet to red-violet. At $t = 1,200\text{\AA}$ the red end of the spectrum is removed and the reflected light centers around the blue region. These results are confirmed by Pliskin and Conrad's observations, and one can assume that for these thicker layers the problem of oxygen deficiency at the interface is relatively less severe.

At approximately $1,300\text{\AA}$ thick, a new effect occurs; i.e. "constructive" interference at $3,800\text{\AA}$ with the first corresponding value in the table being a λ_c of $4,380\text{\AA}$ for $t = 1,500\text{\AA}$. For this value of t , the coloring is primarily due to constructive interference rather than destructive effects so the reflected light has a color (light blue) dominated by λ_c . In fact the royal blue observed at $1,200\text{\AA}$ probably has a constructive component in the deep violet due to the spread around λ_c (see Figure 3(b)) and the extension of enhancement effects to higher and lower values of λ than the precise value λ_c .

In addition, because of the spatial as well as time coherent nature of the reflected light, it assumes a metallic appearance which is also observed at $t = 1,700\text{\AA}$ and $2,000\text{\AA}$. However, these effects for opaque maximum reflecting substrates as in the Pliskin and Conrad case are very small and disappear at larger values of t , but are very prominent and continue throughout the large values of t if the present invention is practised to produce large differential effects as discussed previously.

Also beginning at $t = 2,000\text{\AA}$ is a definite simultaneous occurrence of λ_c and λ_D . At $t = 2,200$, $\lambda_c = 6,424\text{\AA}$ while $\lambda_D = 4,283\text{\AA}$ so the reflected light is enhanced around λ_c and has a decreased value around λ_D , the resulting color being a combination of the two effects, or gold with slight yellow orange for this example. Using the present invention, the enhancement of the color through the differential effect plus the spatially coherent nature of the reflected light results in a "strong" metallic appearance for all colors corresponding to thicknesses greater than $1,300\text{\AA}$. This metallic appearance and strong coloration continue until the thickness is such that there are so many interference effects occurring simultaneously at different λ_c 's and λ_D 's (i.e. for different values of m - see Table 1) that the resulting reflected light again tends to white (e.g. in Table 1, for $t = 15,400\text{\AA}$, there are 6 λ_c 's corresponding to $m = 6, 7, 8, 9, 10$ & 11 and 6 λ_D 's corresponding to $m = 6, 7, 8, 9, 10$ and 11). Above $> 15,000\text{\AA}$ the interference colors become hard to observe on opaque maximum reflecting substrates although still easily observed on the partially-reflecting substrates of the present invention because of the color enhancement.

From Table 1, one can also see that for the values of t which would be used in practising the invention, there are values of λ_c and λ_D corresponding to effects in the IR (infrared) and UV (ultraviolet) regions of the spectrum. Such effects are discussed below in connection with an important variation on the invention.

Table 1 allows the user to choose the correct values of t to practise and optimize the effects of the present invention when used in conjunction with appropriate reflectivity calculations. No precise format can be given for the latter since it depends on factors (e.g. light levels, color density, and means of depositing materials) which must be chosen for a given application. The most enhanced colorations are obtained for one or two orders of λ_c combined with one or two orders of λ_D which in general applies for t between $1,500\text{\AA}$ and $6,000\text{\AA}$. This is not rigid, since the coloration depends on other factors such as reflectivity, absorption in the substrate, and type of reflecting metal but serves as a guideline for easiest practice of the invention. SiO_2 layers of this thickness are also found to supply adequate chemical and mechanical protection for the underlying metal and/or plastic in many applications (e.g. sunglasses or windows).

Another variation which can be used to extend the range of colors obtained by the present invention is to use an absorbing dielectric medium between the front surface and the semi-reflecting layer. The color thus obtained is a combination of the interference effect and the absorption and reemission effects in the dielectric medium. It should also be noted that light penetrating from the rear through an absorbing substrate will affect the coloring to an extent depending on the intensity of the rear light and the color of the absorbing substrate. The latter may be used to modify the color or to "mute" the metallic effect in applications such as office building windows.

Another variation is to choose the partially-reflecting metal from those that do not have near constant reflectivity across the visible spectrum but which have varying R . An example is copper which has a reflectivity of $\sim 58\%$ at $4,500\text{\AA}$ and $\sim 97\%$ at $7,000\text{\AA}$. This difference in reflectivity can be used further to enhance certain colors, e.g. red tones, because of their obvious enhancement of the differential effect due to the difference in reflectivity. Gold, nickel, and brass are other examples of such metals or alloys. Others will be obvious to those skilled in the art.

A most important variation of the invention is obtained by extending its application to other wavelengths outside of the visible, in particular into the infrared (IR) region. This is of special importance for windows designed to reduce or control the amount of radiant heat (from sun, atmosphere, or other hot sources such as others buildings) entering the building in

order to conserve energy by reducing the air conditioning load. In order to optimize this saving, it is desirable that any optical layers used to reflect or reject the incident IR radiation be on the outside surface of the window. If applied to the inside, much of the incident IR radiation will be absorbed in the glass itself, either on the first pass through or on the second pass after reflection, thereby heating up the glass. Much of this heat in the glass is then transferred into the interior of the building by convection currents of the internal air or by reradiation at longer λ 's. Applied to the outside, such reflecting layers are therefore more effective in summer but are still effective in preventing heat losses in winter since the IR energy radiated by internal objects will either be absorbed in the glass, and partially returned to the room by convection, or for the portion that passes through the glass to the metal layer, will be reflected back and absorbed in the glass or returned to the room.

With the present invention, this control of the IR radiation entering or leaving the inside of the building can be effected while still controlling the visible light entering the building and also the external and internal coloring effects. This capability results from the longer wavelengths of the IR radiation. By reducing the thickness of the partially reflecting metal layer, one can control the amount of visible light entering the building for lighting needs (e.g. $\approx 50\%$ of incident light for $R \approx 20\%$ and 40% absorbing substrate), while achieving the condition for optimizing color effects as discussed previously, and maintaining a high IR reflectivity. In demonstrating this invention, it has been demonstrated that this combination can be achieved if the partially-reflecting metal is one of inherently high IR reflectivity which is put down by a technique or process (such as ion beam sputtering) which provides uniform dispersion of the metal without appreciable agglomeration. At thicknesses where the layer looks relatively open to visible λ 's, the same partially-reflecting layer looks relatively opaque to the IR λ 's since their size is such that they intercept more of the metal atoms on the average, leading to increased reflection.

In practice, visible reflectivities have been reduced to the 20-50% range in the visible, while maintaining the IR reflectivity at $> 70\%$ and as high as 95% in the near (e.g. 2.5μ) and far IR (e.g. $> 10\mu$). An important region for control of heat load on buildings is below 2.5μ for air conditioning requirements (most of heat incident from outside) since the terrestrial solar spectrum is such that approximately half of the sun's radiation is in the visible and half in the near IR (below 2.5μ). However, the buildings also receive longer wavelength (4-100 microns with maximum intensity near 10 microns) radiation from the atmosphere which also exerts a heat load. For winter conditions, where one wants to prevent radiation of heat from internal bodies with temperatures of $\sim 25-30^\circ\text{C}$, the far IR characteristic is important since the peak of the black body radiation spectrum for a body at 28°C is approximately at 10μ . It is therefore desirable that the reflectivity be high across the IR spectrum. This has been demonstrated with the present invention using Cu or brass as the reflecting metal, both of which have higher reflectivity at the longer visible λ 's than at the shorter end of the spectrum. The value of reflectivity can thus be adjusted to give relatively high IR reflectivity, including the region from $8,000\text{\AA}$ up to 2.5μ ($25,000\text{\AA}$) while keeping the average visible light reflectivity low. Other materials such as Au and Ag may be used to achieve the desired function but are relatively expensive and for many application methods difficult to deal with.

As evident from Table 1 and discussed previously, interference effects also occur in the IR as well as in the visible for interference layers of interest for coloring effects. These interference effects in the IR are, however, of much less importance since the IR reflectivity is high (for properly chosen metal layer) with or without interference effects, and differential effects are relatively unimportant.

In demonstrating the present invention, ion beam sputtering and ion beam implantation sputtering have been used. However, any process that is capable of putting down the necessary materials in the necessary form may be used without affecting the operation of the invention. The deposition technique used in demonstrating the invention can also put down materials such as Au or Ag on both glass and/or plastic as well as other materials without intermediate or bonding layers, as required with many other techniques (e.g. evaporation). This is important in achieving the correct degree of reflectivity for proper operation of the invention. More importantly, it is of utmost necessity that the glass interference layer over the metal layer protect the metal layer from chemical (environmental) and mechanical (cleaning) attack as well as providing the necessary interference function. This is only possible if the glass is impervious to chemical vapors or liquids in very thin layers, is mechanically hard and is of optical quality. Ion beam sputtered fused SiO_2 has been used to demonstrate the invention since it meets all of these requirements because of its unique characteristics. However, any other method of applying the interference glass with the necessary characteristics will result in successful operation of the invention.

It is important that the glass layer be applied immediately over the metal layer and in such a manner that the metal does not oxidize or otherwise alter its reflecting state. If, for example, the metal is a freshly deposited layer of Cu, and it is exposed to air or O_2 for an appreciable

time before the hermetic interference layer (or equivalent) is applied, the Cu will oxidize and the reflectivity will decrease, affecting the visible coloration, reflected and transmitted light intensities and IR rejection capability. If the glass is not hermetic, the characteristics of the structure will degrade with time. Au is not subject to severe degradation but is relatively expensive and for some application techniques difficult to apply.

Application of the hermetic seal immediately over the reflecting layer can be used to provide very thin (500Å or less) non-colored protective layers if the applied glass is impervious to chemical attack in thin layers. As discussed previously, the coloration observed by Pliskin and Conrad at 500Å may be due to inadequate characteristics of the glass layer. The use of such thin layers avoids the expense of applying thick layers ($>2\mu$) to eliminate interference color effects. This innovation has been demonstrated and is of importance for protecting front surface mirrors while maintaining optical characteristics, for applications such as optical instrument mirrors and concentrators for energy conservation and generation systems, and for hermetically sealing solar cells for the terrestrial applications.

Another variation of the present invention is its use on plastic substrates, both absorbing and non-absorbing at visible λ 's, to provide IR rejection. Whereas glass substrates, in many practical areas of interest such as sunglasses, absorb some of the incident IR, plastics in general do not. Thus wearers of plastic sunglasses are subjected to IR heating of the eye, leading to drying out of the membranes and irritation, even if the glasses are adequate for visible radiation purposes. The present invention avoids this effect through rejection of undesirable IR radiation while controlling visible light and coloring effects at desirable levels. With the metal applied as a thicker highly reflecting opaque layer, "plastics" can also be used as excellent visible plus IR mirrors and concentrators for solar energy generation and conservation systems, with the metal layer protected by a thin ($\sim 500\text{\AA}$) hermetic and mechanical seal as discussed previously. These effects have been demonstrated.

Still another variation of the invention is its use to produce coloring effects in wall panels, without regard to transmission properties.

TABLE 1

	Color	t (Å)	
5	Tan	500	5
	Brown	700	
	Dark Violet to Red-Violet	1,000	
	Royal Blue	1,200	
	Light Blue to Metallic Blue	1,500	
10	Metallic to very light Yellow-Green	1,700	10
	Light Gold on Yellow - slightly metallic	2,000	
	Gold with slight yellow-orange	2,200	
	Orange to Melon	2,500	
	Red-Violet	2,700	
	Blue to Violet-Blue	3,000	
	Blue	3,100	
15	Blue to Blue-Green	3,200	15
	Light Green	3,400	
	Green to Yellow-Green	3,500	
	Yellow-Green	3,600	
	Green-Yellow	3,700	
	Yellow	3,900	
20	Light Orange	4,100	20
	Carnation Pink	4,200	
	Violet-Red	4,400	
	Red-Violet	4,600	
	Violet	4,700	
	Blue-Violet	4,800	
25	Blue	4,900	25
	Blue-Green	5,000	
	Green (broad)	5,200	
	Yellow-Green	5,400	
	Green-Yellow	5,600	
	Yellow to "Yellowish"	5,700	
30	Light Orange on Yellow to Pink borderline	5,800	30
	Carnation Pink	6,000	
	Violet-Red	6,300	
	Bluish (borderline violet to bluegreen - appears greyish)	6,800	
	Blue-Green to Green (quite broad)	7,200	
	"Yellowish"	7,700	
35	Orange (rather broad for Orange)	8,000	35
	Salmon	8,200	
	Dull, light red-violet	8,500	
	Violet	8,600	
	Blue-Violet	8,700	
	Blue	8,900	
40	Blue-Green	9,200	40
	Dull Yellow-Green	9,500	
	Yellow to "Yellowish"	9,700	
	Orange	9,900	
	Carnation Pink	10,000	
	Violet-Red	10,200	
	Red-Violet	10,500	
45	Violet	10,600	45
	Blue-Violet	10,700	
	Green	11,000	
	Yellow-Green	11,100	
	Green	11,200	
	Violet	11,800	
50	Red-Violet	11,900	50
	Violet-Red	12,100	
	Carnation Pink to Salmon	12,400	
	Orange	12,500	
	"Yellowish"	12,800	
	SkyBlue to Green-Blue	13,200	
55	Orange	14,000	55
	Violet	14,500	
	Blue-Violet	14,600	
	Blue	15,000	
	Dull Yellow-Green	15,400	
60			60
65			65

TABLE 1 (cont.)

	t (Å)	m=1	2	3	4	5	λ_c 6	7	8	9	10	11	
5	500	1460	730	487	365								5
	700	2044	1022	681	511								
	1000	2920	1460	973	730								
	1200	3504	1752	1168	876								
10	1500	4380	2190	1460	1095								10
	1700	4964	2482	1655	1241								
	2000	5840	2920	1947	1460								
	2200	6424	3212	2141	1606								
	2500	7300	3650	2433	1825								
	2700	7884	3942	2628	1971								
15	3000	8760	4380	2920	2190								15
	3100	9052	4526	3017	2263								
	3200	9344	4672	3115	2336								
	3400	9928	4964	3309	2482								
	3500	10220	5110	3407	2555								
	3600	10512	5256	3504	2628								
20	3700	10804	5402	3601	2701								20
	3900	11388	5694	3796	2847								
	4100	11972	5986	3991	2993								
	4200	12264	6132	4088	3066								
	4400	12846	6424	4283	3212								
25	4600	13432	6716	4477	3358	2686							25
	4700	13724	6862	4575	3431	2745							
	4800	14016	7008	4672	3504	2803							
	4900	14308	7154	4769	3577	2862							
	5000	14600	7300	4867	3650	2920							
	5200	15184	7592	5061	3796	3037							
30	5400	15768	7884	5256	3942	3154							30
	5600	16352	8176	5451	4088	3270							
	5700	16644	8322	5548	4161	3463							
	5800	16936	8468	5645	4234	3387							
	6000	17520	8760	5840	4380	3504							
35	6300	18396	9198	6132	4599	3679							35
	6800	19856	9928	6619	4964	3971							
	7200	21026	10512	7008	5256	4205	3504	3003					
	7700	22484	11242	7495	5621	4497	3747	3212					
	8000	23360	11680	7787	5840	4672	3893	3337					
40	8200			7981	5986	4789	3991	3421					40
	8500			8273	6205	4964	4137	3546					
	8600			8371	6278	5022	4185	3587					
	8700			8468	6351	5081	4234	3629					
	8900			8663	6497	5198	4331	3713	3248				
	9200				6716	5373	4477	3838	3358				
45	9500				6935	5548	4623	3963	3468				45
	9700				7081	5665	4721	4046	3540				
	9900				7227	5782	4818	4130	3614				
	10000				7300	5840	4867	4171	3650	3244			
	10200				7446	5957	4964	4255	3723	3309			
	10500				7665	6132	5110	4380	3823	3407			
50	10600				7738	6190	5159	4422	3869	3439			50
	10700				7811	6249	5207	4463	3905	3472			
	11000				8030	6424	5353	4589	4015	3569			
	11100				8103	6482	5402	4630	4051	3601			
	11200				8176	6541	5451	4672	4088	3634			
	11800				8614	6891	5743	4922	4307	3828	3446		
55	11900					6950	5791	4964	4344	3861	3475		55
	12100					7066	5889	5047	4416	3926	3533		
	12400					7242	6035	5173	4526	4023	3621		
	12500					7300	6083	5214	4562	4055	3650		
	12800					7475	6229	5339	4672	4153	3738		
60	13200					7709	6424	5506	4818	4283	3854	3504	60
	14000					8176	6813	5840	5110	4542	4088	3716	
	14500					8468	7057	6049	5292	4704	4234	3849	
	14600						7105	6000	5329	4737	4263	3876	
	15000						7300	6257	5475	4867	4380	3982	
65	15400						7495	6424	5621	4996	4497	4088	65

TABLE 1 (cont.)

	t (Å)	m=0	1	2	3	4	5	6	7	8	9	10	11	
5	500	2920	973	584	417									5
	700	4088	1363	818	584									
	1000	5840	1947	1168	834									
	1200	7008	2336	1402	1001									
	1500	8760	2920	1752	1251									
10	1700	9928	3309	1986	1418									10
	2000	11680	3893	2336	1664									
	2200	12848	4283	2570	1835									
	2500	14600	4867	2920	2086									
	2700	15768	5256	3154	2253									
15	3000	17520	5840	3504	2503									15
	3100	18104	6035	3621	2586									
	3200	18688	6229	3738	2670									
	3400	19856	6619	3971	2837									
	3500	20440	6813	4088	2920									
20	3600	21024	7008	4205	3003									20
	3700	21608	7203	4322	3087									
	3900	22776	7592	4555	3254									
	4100	23944	7981	4789	3421									
	4200	24528	8176	4906	3504	2725								
25	4400	25696	8565	5139	3671	2855								25
	4600	26864	8955	5373	3838	2985								
	4700	27448	9149	5490	3921	3050								
	4800	28032	9344	5606	4005	3115								
	4900	28616	9539	5723	4088	3180								
30	5000	29200	9733	5840	4171	3244								30
	5200		10123	6074	4338	3374								
	5400		10512	6307	4505	3504								
	5600		10901	6541	4672	3634	2973							
	5700		11096	6658	4755	3699	3026							
35	5800		11291	6774	4839	3764	3079							35
	6000		11680	7008	5006	3893	3185							
	6300		12264	7358	5256	4088	3345							
	6800		13237	7942	5673	4412	3610							
	7200		14016	8410	6007	4672	3823	3234						
40	7700		14989	8994	6424	4996	4088	3459						40
	8000		15573	9344	6674	5191	4247	3594						
	8200				6841	5321	4354	3684						
	8500				7091	5516	4513	3818	3309					
	8600				7175	5580	4566	3863	3348					
45	8700				7258	5645	4619	3908	3387					45
	8900				7425	5775	4725	3998	3465					
	9200				7675	5970	4884	4133	3582					
	9500				7925	6164	5044	4268	3699					
	9700				8093	6294	5150	4358	3777					
50	9900				8259	6424	5256	4447	3854	3401				50
	10000					6489	5309	4492	3893	3435				
	10200					6619	5415	4582	3971	3504				
	10500					6813	5575	4717	4088	3607				
	10600					6878	5628	4762	4127	3641				
55	10700					6943	5681	4807	4166	3676				55
	11000					7138	5840	4942	4283	3779				
	11100					7203	5893	4986	4322	3813				
	11200					7268	5946	5031	4361	3848	3443			
	11800					7657	6265	5301	4594	4054	3627	3281		
60	11900					7722	6318	5346	4633	4088	3658	3309		60
	12100					7852	6424	5436	4711	4157	3719	3365		
	12400					8046	6583	5570	4828	4260	3811	3448		
	12500					8111	6636	5615	4867	4294	3842	3476		
	12800					8306	6796	5750	4983	4397	3934	3560		
65	13200						7008	5930	5139	4535	4057	3671		65
	14000						7433	6289	5451	4809	4303	3893	3554	
	14500						7698	6514	5645	4981	4457	4032	3682	
	14600						7751	6559	5684	5015	4488	4060	3707	
	15000						7964	6738	5840	5153	4610	4171	3809	
	15400						8176	6918	5996	5290	4733	4283	3910	

WHAT WE CLAIM IS:

1. A method of enhancing colour effects produced by ambient light while controlling light intensity produced thereby, comprising; reflecting with a phase change substantially equal to π radians between 1 and 25% of the ambient light at an interface while permitting substantially all of the remaining ambient light to continue as transmitted light, permitting said transmitted light to travel without reflection to an absorbing layer and then reflecting a portion of said transmitted light at said absorbing layer while permitting the remaining light to continue as retransmitted light, the distance between said first interface and said absorbing layer being such that a specific colour effect is produced due to interference at one, or a limited number of, specific wavelength(s) in the visible spectrum between the light reflected from said interface and the light transmitted back through said interface after reflection at said absorbing layer.
2. A method in accordance with Claim 1, wherein some of said transmitted light is absorbed prior to reaching said absorbing layer.
3. A method in accordance with Claim 1 or 2, wherein some of said retransmitted light is further absorbed after emerging from said absorbing layer.
4. A method in accordance with Claim 1, 2 or 3, wherein, much infrared light is reflected at said absorbing layer while much visible light is permitted to continue as retransmitted light.
5. Optical apparatus comprising a dielectric substrate, a semireflecting layer intimately bonded to one surface of said substrate, and a dielectric layer having an outer surface and an inner surface, said inner surface being hermetically sealed to said semireflecting layer, said dielectric layer having a uniform thickness such that, when ambient light is incident on the outer surface, a specific colour effect is produced due to interference at one, or a limited number of, specific wavelength(s) in the visible spectrum between light reflected from said outer surface and light transmitted back through said outer surface after reflection at said semireflecting layer.
6. Apparatus in accordance with Claim 5, wherein said dielectric substrate is absorbing.
7. Apparatus in accordance with Claim 5 or 6, wherein the reflectivity of said semireflecting layer is colour-dependent.
8. Apparatus in accordance with Claim 7 wherein said semireflecting layer comprises copper, gold or brass.
9. Apparatus according to Claim 5 or 6, wherein the reflectivity of said semireflecting layer is greater for infra-red wavelengths.
10. Apparatus in accordance with any of Claims 5 to 9, wherein said apparatus comprises a lens for sunglasses.
11. Apparatus in accordance with any of Claims 5 to 9, wherein said apparatus comprises glazing for a window.
12. Optical apparatus comprising a first interface for reflecting with a phase change substantially equal to π radians between 1 and 25% of the ambient light at the interface while permitting substantially all of the remaining ambient light to continue as transmitted light, an absorbing layer spaced from said interface for receiving said transmitted light, said absorbing layer being adapted to reflect a portion of said transmitted light while permitting the remainder to continue as retransmitted light, the distance between said first interface and said absorbing layer being such that a specific colour effect is produced due to interference at one, or a limited number of, specific wavelength(s) in the visible spectrum between light reflected from said interface and light transmitted back through said interface after reflection at said absorbing layer.
13. Apparatus in accordance with Claim 12 wherein some of said transmitted light is absorbed prior to reaching said absorbing layer.
14. Apparatus in accordance with Claim 12 or claim 13 wherein some of said retransmitted light is further absorbed after emerging from said absorbing layer.
15. Apparatus in accordance with any of claims 12 to 14, wherein, in use, the absorbing layer reflects at least some incident infrared radiation whilst transmitting a major portion of the visible light.
16. A method as claimed in Claim 1 substantially as hereinbefore described with reference to Figs. 1, 6 and 7 of the accompanying drawings.
17. Optical apparatus according to Claim 5 and substantially as hereinbefore described with reference to Figs. 1, 6 and 7 of the drawings.

BROOKES AND MARTIN
Chartered Patent Agents
High Holborn House
52/54 High Holborn
London WC1V 6SE
Agents for the Applicants

5

5

Printed for Her Majesty's Stationery Office, by Croydon Printing Company Limited, Croydon, Surrey, 1980.
Published by The Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from
which copies may be obtained.

1582338

COMPLETE SPECIFICATION

4 SHEETS

This drawing is a reproduction of
the Original on a reduced scale
Sheet 1

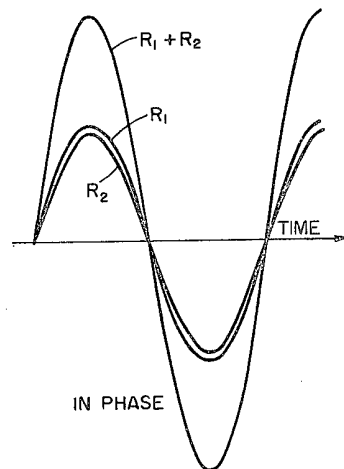
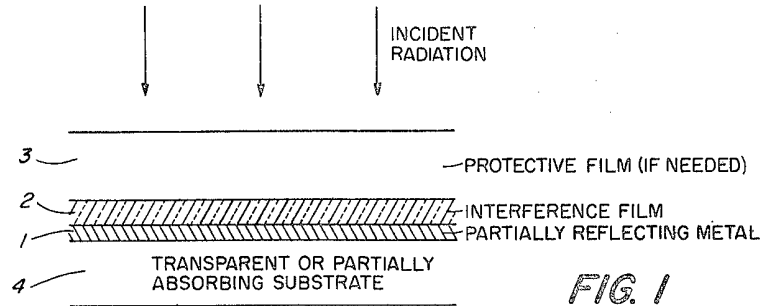


FIG. 3(a)

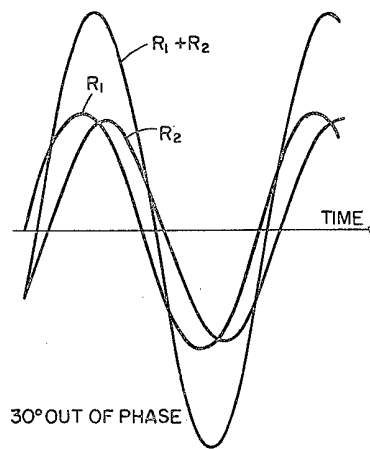
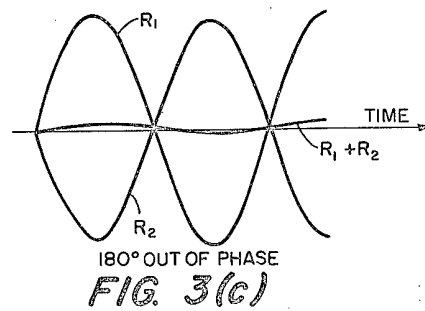


FIG. 3(b)



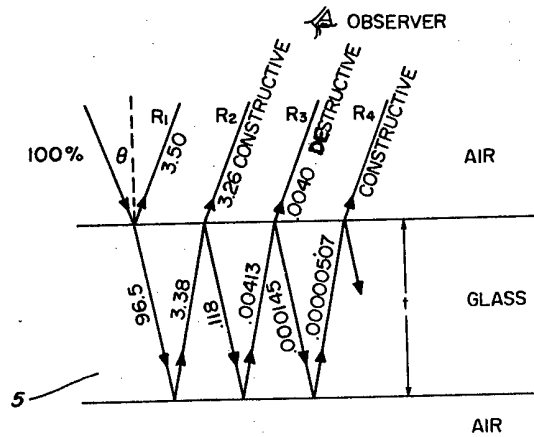


FIG. 2
(PRIOR ART)

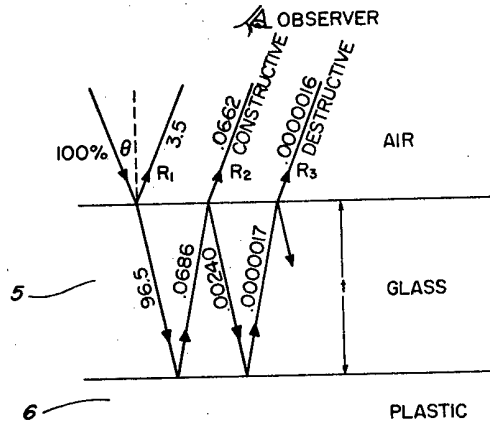


FIG. 4
(PRIOR ART)

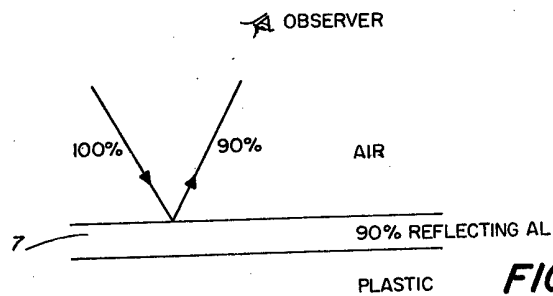


FIG. 5(a)
(PRIOR ART)

1582338

COMPLETE SPECIFICATION

4 SHEETS

This drawing is a reproduction of
the Original on a reduced scale
Sheet 3

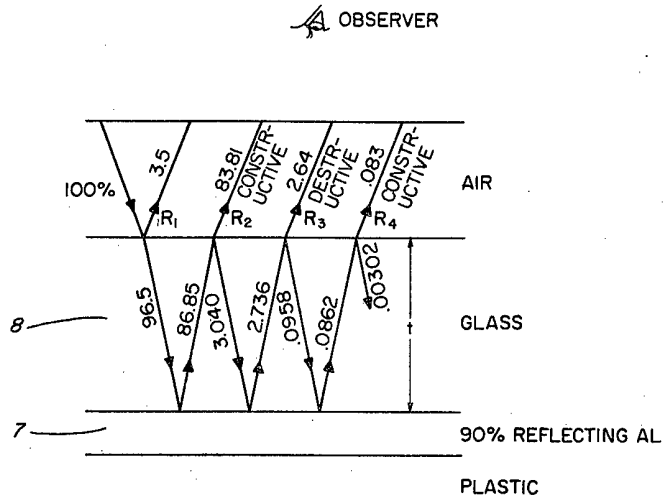


FIG 5(b)
(PRIOR ART)

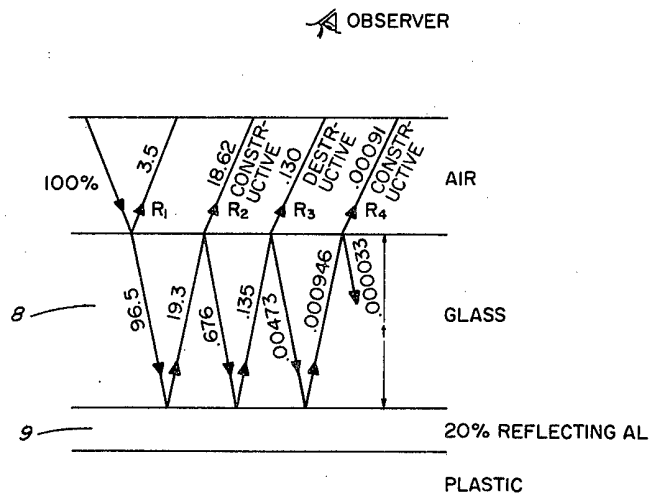


FIG 6(a)

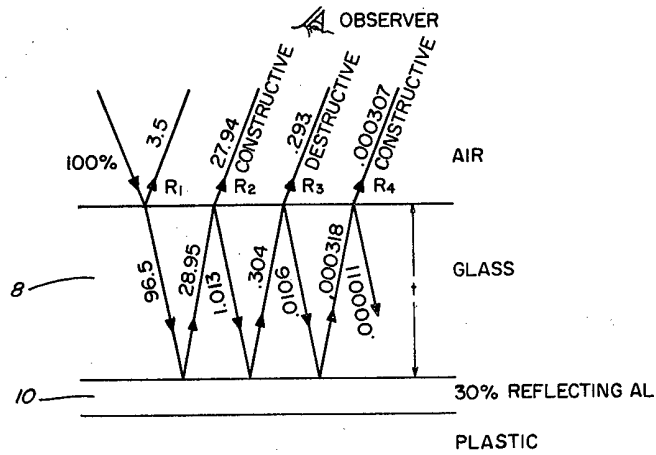


FIG. 6(b)

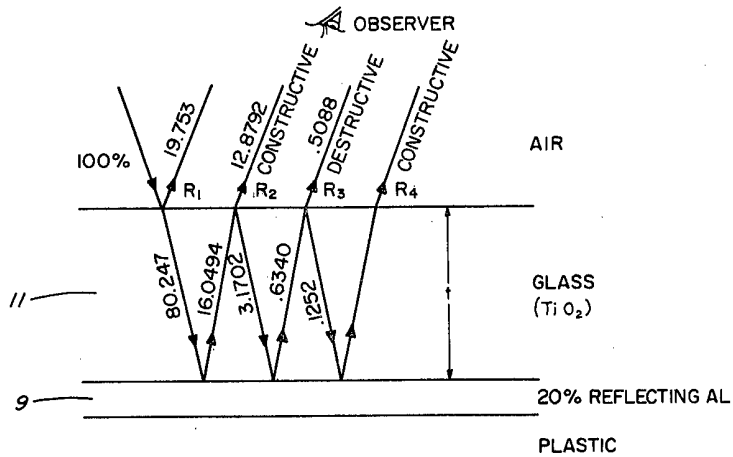


FIG. 7