



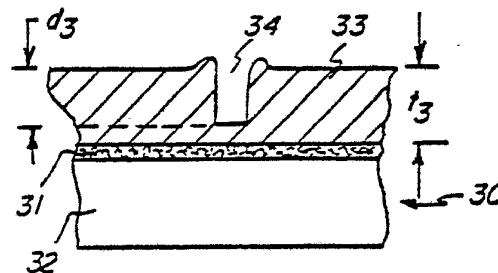
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(54) Title: OPTICAL DISC AND METHOD OF USING SAME

(57) Abstract

An optical disc adapted for real-time writing and reading with light of a single predetermined wavelength comprises a heat-deformable recording layer (33) overlying a reflective support (30). In contrast with prior art real-time optical discs in which the optical properties and nominal thickness of the recording layer are selected to maximize the difference in amplitude of light reflected respectively from recorded and non-recorded regions on the disc surface, the optical disc of the invention comprises a recording layer in which the optical properties and nominal thickness are selected so that the phase difference in light reflected respectively from recorded and non-recorded regions is substantially maximized, and so that a substantial portion of incident light is reflected from both recorded and non-recorded regions, whereby the detection of such phase difference is facilitated. Whereas the prior art discs require, for optimum signal-to-noise ratio, that the pits be of a depth substantially equal to the recording layer thickness and that the readout beam be focused to a spot size smaller than the pit size, no such requirements are attendant the optical disc of the invention. Moreover, gradual bleaching of the dye-binder material does not adversely affect the signal-to-noise ratio of the readout signal.



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OPTICAL DISC AND METHOD OF USING SAME

The present invention relates to real-time optical writing and reading of high density information on a heat-deformable medium. More particularly, the invention relates to improvements in real-time optical discs and the like and to methods for using such discs to record and readout high density information.

For several years now, optical discs have been used as high density storage media for storing information in digital form. Such discs typically comprise a heat-deformable recording layer which overlies a reflective support. The information stored in the recording layer is in the form of small (e.g. a micron or less) pits or craters which are arranged along a single spiral track or along concentric circular tracks. The stored information is recovered (i.e. read) by scanning the tracks with a tightly focused spot of light, e.g. from a laser. The recovered information is in the form of a fluctuating electrical signal obtained from a photodetector that senses the readout light reflected from the disc, as modulated in intensity by the pits. As will be apparent to those skilled in the art, the term "light" is used herein in its general sense, i.e. to include electromagnetic radiation within the visible range as well as radiation outside that range (e.g. ultraviolet and infrared radiation).

Generally speaking, there are two types of optical discs: (1) real-time discs and (2) processed discs. Real-time discs are those which can be read immediately after having information recorded (i.e. written) thereon; such discs are described in more detail below and are the type to which this invention relates. Processed discs, on the other hand, are those which require further processing after



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recording before they can be read. Such processing, for example, may take the form of chemical development of a photoresist to form a relief pattern, and subsequent metallization of the relief pattern.

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Real-time optical discs typically comprise a relatively thin (e.g. 200 to 1000 Angstrom) recording layer made from a heat-deformable material. To record information thereon, the disc is rapidly rotated while an intensity-modulated laser beam is focused on the recording layer. The intensity of the laser beam is controlled by an information source, and when the beam is "on", the recording layer is ablated at the focal point, thereby forming a pit in the recording layer. To detect such a pit during readout of the stored information, the intensity of the laser beam is reduced and scanned along the information track. Where no pit is formed, the readout light is absorbed by the recording layer before and after it strikes the underlying reflective surface, and a relatively small amount of light is reflected from the disc surface. On the other hand, where a pit is formed, a lesser amount of recording layer serves to absorb the incident readout light, and the intensity of the reflected light from the disc surface is relatively high. As indicated above, a photodetector is positioned to be illuminated by the reflected readout light and its output signal is proportional to the reflected light it receives.

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Heretofore, it has been common to design the recording layer of real-time optical discs to maximize, for a given wavelength of light (i.e. the wavelength of the write/read laser), the difference in intensity of the light reflected from pitted and non-pitted regions on the disc surface. Towards this end, one significant aim has been to efficiently



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couple energy from the writing laser beam into the recording layer. A discussion of how writing energy can be efficiently coupled into the recording layer by proper selection of layer thickness is presented by A. E. Bell and F. W. Spong in the July 1978 issue of IEEE Journal of Quantum Electronics at page 487. In general, this article explains that efficient coupling can be achieved when there is strong destructive interference, i.e. a substantial antireflection condition, between the writing light reflected back through the recording layer from the underlying reflective surface and the light initially incident on, and reflected from, the upper surface of the recording layer. This condition can be obtained by designing the recording layer so that its nominal optical thickness is about one-fourth the wavelength of the writing light in that layer, and by selecting the absorption parameter of the layer so that the amplitude of the internally reflected light that twice traverses the recording layer approximately equals that of the light reflected from the outer surface of the recording layer. The above-mentioned article further explains that such a nominal thickness also provides good signal-to-noise ratios for readout with light of the write/read wavelength if the pit depth formed during writing substantially disrupts the antireflection condition. The preferred pit depth condition removes substantially all of the recording layer above the underlying reflective surface.

In attempting to practice the above-described teaching, one finds that it is difficult to completely ablate the entire recording layer in the pit portions. This problem occurs because the reflective layer acts as a heat sink for the lower portions of the recording layer. Also, a minimum in



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the distribution of light (vertically through the recording layer) caused by optical interference effects usually occurs deep within the recording layer near the reflector layer interface. This reduces the amount of light absorbed in the lower regions of the recording layer (in the vicinity of the recording layer/reflective surface interface) and limits the depth of recorded pits. Such difficulties can be lessened by providing a transparent heat barrier layer between the recording layer and underlying the reflective surface, but this complicates disc fabrication. The extent to which the recording layer remains in the recorded pits (because pits do not form readily through the entire recording layer depth) adversely affects the readout signal contrast.

The difficulty in completely ablating the pit portions is compounded because the surface of prior art discs does not afford a good reference for focus control of the writing light spot. That is, since the recording laser beam is substantially absorbed by the non-pitted regions of the recording layer, little light will be available (reflected) to operate focus control servo mechanisms, which require light returned from the disc to generate their error signal.

Another further difficulty which has existed with such a prior art approach when using a dye or analagous light-absorbing material in the recording layer is that continual re-readings, or even exposure to ambient light conditions, can cause fading or bleaching of the entire recording layer. As this occurs, the difference between the amplitude of a read light beam reflected from pitted and non-pitted portions becomes less, and the signal-to-noise ratio of the disc decreases.



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Still another problem associated with the above teaching is that, in order to achieve maximum depth of modulation in the readout signal, the read spot size for such amplitude readout systems should be no larger than the pit size. This necessitates accurate tracking and focus control.

According to the present invention, there is provided an optical disc in which the above-identified problems are substantially overcome. The disc of the invention comprises a recording layer that is optimized in thickness and optical constants to achieve, for a single wavelength of light, a maximum phase change (cf. amplitude changes in the prior art) in the light reflected from pitted and non-pitted portions of the recording layer. To detect such phase changes, the recording layer thickness and optical properties are chosen so that a substantial portion of incident light from the write-read laser is reflected from both pitted and non-pitted regions on the recording layer. Preferably, such portions are equal. Moreover, the nominal thickness of the recording layer is selected so as to be proximate a transition between zones of relatively gradual and relatively rapid change in the phase-shift to thickness relation of the recording layer material at the chosen wavelength. Such a thickness assures a relatively large change in readout signal level as the read laser scans across pitted and non-pitted regions and, moreover, assures that artifacts (e.g. as crater rims) and dirt which represent increases in the nominal thickness of the recording layer do not produce significant phase changes in the reflected read light. Pits can thus be recorded in the recording layer to a depth which provide (1) a desired phase difference between light reflected from pitted and non-pitted disc portions,



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and (2) an approximate amplitude equality between light reflected from such pitted and non-pitted portions. Immediately after recording, such a disc will constitute, with respect to the write-read wavelength, a phase-shift type system.

It is an advantageous characteristic of the disc of the present invention, that as the recording layer subsequently decreases in its absorption to the write-read wavelength, e.g., upon repeated reading with the chosen wavelength, the phase difference between the light from pitted and non-pitted portions remains effectively the same. Thus as dye fading occurs, the read signal strength is not reduced. Prior to fading of the absorptance of the recording layer, the disc must be read at reduced power levels so that no re-melting or ablating of the recording layer occurs; but reading power can be increased after the absorption has been substantially decreased.

In accord with another advantageous feature, this system provides substantial light returned (reflected) from the disc prior to recording, an important feature for optical focus and tracking servo operation; but this substantial reflectance from unrecorded areas does not diminish the contrast or depth of modulation of the read-out signal since the recorded information is carried in a phase-shift type system.

Although the discs of the present invention are substantially reflective prior to recording, they can still possess high recording sensitivity. This is accomplished by designing the system to have high absorption (at the write-read wavelength) in the vicinity of the upper surface portion of the recording (dye/binder) layer even though light absorbed in the total thickness of the recording layer is decreased somewhat. Thus, high absorption



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is maintained in that depth of the recording layer that is equal to the depth of the marks (pits) that are to be made.

Further advantages of the present invention will become apparent from the following more detailed description with reference to the attached drawings in which:

Figure 1 is a cross-sectional view of a portion of a prior art optical disc structure;

Figure 2 is a graph illustrating the variation, with respect to recording layer thickness, of the reflectance (R) of write-read light from a disc such as shown in Fig. 1;

Figure 3 is a cross-sectional view of a portion of an optical disc according to one embodiment of the present invention;

Figure 4 is a graph illustrating the variation, with respect to recording layer thickness, of the absorption (A) in the recording layer and of the reflectance (R) and relative phase ϕ of write-read light reflected from a disc such as shown in Fig. 3;

Figure 5 is a graph showing the phase-shift curve of Fig. 4 in superposition with a similar phase shift curve of the recording layer when faded to a condition of substantially zero absorption with respect to the write-read wavelength;

Figure 6 is a graph indicating pit depth per constant $\pi/2$ phase shift, $D\pi/2$, and layer absorptance within that pit depth, $A\pi/2$. Superimposed on this graph is a dotted line representation of the quotient curve $D\pi/2 \div A\pi/2$ which constitutes a recording sensitivity parameter; and



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Figures 7a-h are reflectance and phase shift versus thickness variation curves for various stages of dye bleaching of a recording layer material.

5 The prior art disc shown in Fig. 1 is exemplary of the amplitude variation read-out type and typically has a thin light absorptive layer 2 overlying a reflective layer 3 on a support 4. The layer 2 can be formed by vapor depositing a dye that is absorptive to the write-read wavelength, e.g., to
10 a thickness in the order of 200 to 1000 Angstroms. Focused light of the write-read wavelength and having high irradiance is used to ablate the layer to form the pit 5, thereby locally reducing the thickness of layer 2 and increasing the reflectance of the
15 recorded pit area. Upon read-out, with light of the write-read wavelength but at reduced intensity, the light is highly reflected from the pit areas but absorbed in non-pit areas. This variation in the amplitude of the light reflected from the recorded
20 disc is sensed by a far-field detector. In such prior art amplitude variation systems, any phase differences in the light that returns to the detector from pitted and non-pitted (i.e., recorded and non-recorded) portions is neglected.

25 As indicated above, the previous approach has been to select the nominal recording layer thickness to coincide with the first reflective minimum of the write-read light wavelength reflection versus thickness curve. (See Fig. 2) Such a
30 thickness causes maximum energy to be coupled into the recording layer, aiming to ablate away as much as possible of the recording layer locally at the pit positions. When read back using a light beam of the same wavelength a good contrast in amplitude is
35 provided between pitted and non-pitted portions. Referring to Fig. 2, this prior art approach suggests

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that the recording layer 2 have a nominal thickness as indicated by the arrow at t_1 . That is, the nominal thickness should be at a minimum of the reflectance curve R, slightly less than 50 nm in the example shown. The pit depth d_1 should be such as to substantially expose the reflective layer 3, so that the residual layer thickness optimally would have a value such as indicated by the arrow at $(t_1 - d_1)$ in Fig. 2. The sensed amplitude difference between the light reflected from portions of thickness t_1 and those of thickness $(t_1 - d_1)$ would then be substantial. But, as described above, there are several potential problems with such a prior art approach. The difference in amplitudes in read light beams reflected respectively from pitted and non-pitted portions becomes less, and the signal-to-noise ratio of the disc decreases.

Referring to Figs. 3 and 4, the general approach of the present invention for obviating the above-described difficulties with prior single wavelength write-read systems will now be described. Fig. 3 illustrates in cross-section one portion of a disc 30, constructed according to one embodiment of the present invention, and which comprises a recording layer 33, overlying a reflective layer 31 on a support 32. Figure 4 indicates, for an exemplary write-read wavelength, plots of: (1) the variation of absorption in recording layer 33 to variation in thickness of the recording layer (curve A), (2) the variation of the reflectance of disc 30 to variation in thickness of the recording layer 33 (curve R) and (3) the variation in light phase-shift imparted by the disc 30 with respect to the variation in thickness of its recording layer 33 (curve ϕ).

In accordance with the present invention the recording layer of disc 30 has a nominal thickness,

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t_3 , yielding a significant reflectance of write-read light, rather than a minimal reflectance as in prior techniques. In the embodiment illustrated by Figs. 3 and 4, the layer nominal thickness t_3 is selected (see Fig. 4) generally proximate the second reflection maximum of curve R, e.g., about 80 nm. This clearly does not provide for maximum coupling of energy into the entire recording layer during writing; however, we have found that a major proportion of the energy is absorbed in the vicinity of the surface of the recording layer and is sufficient for forming pits of a depth d_3 which are of a type highly useful in accordance with the approach of the present invention. That is, in the example shown, the recording layer of nominal thickness t_3 still couples about 60% of the incident recording energy versus 84% for layer thickness t_1 (corresponding to the first reflection minimum and first absorption maximum). However, in the case where the thickness $(t_3 - d_3) = 30$ nm the thickness t_3 layer couples about 48% of the incident light into a depth $t_3 - 30$ nm from its top surface while the thickness t_1 layer only couples about 54% into a depth $t_1 - 30$ nm from its top surface. It will be recognized that the resultant recording would not provide a high contrast signal using amplitude read-out techniques because the magnitude of light reflected from pitted and non-pitted portions is roughly equal (see curve R). However, when detection is accomplished using phase interference between pitted and non-pitted portions, a high contrast signal is provided. The large change in phase of the net light reflected from pitted and non-pitted portions can be noted by reference to curve ϕ of Fig. 4.

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Several unique advantages are obtained by the disc construction and mode of operation of the present invention as described above. First, the nominal thickness t_3 affords significant disc reflectance to the write-read light, and this allows focus control signals to be derived from the write-read light directed at the recording surface. Second, the pit depth d_3 need not extend to the reflective layer 31. Thirdly, debris and crater rims formed around the pits (and which constitute recording layer thickness somewhat greater than the nominal thickness t_3) are substantially invisible to the phase interference detector; note the generally flat portion of the phase shift and reflection curves to the right of the nominal thickness, t_3 .

An additional, highly significant attribute of this mode of operation is that dye fading in the recording layer subsequent to recording does not cause a decrease in read signal contrast. This can be appreciated more readily by reference to Fig. 5 which shows in dotted line the phase shift to thickness curve ϕ_2 for the recording layer 33 when completely faded (i.e., substantially transparent to the write-read light) superimposed with the phase shift to thickness curve ϕ_1 (solid line) for the recording layer in its unfaded initial condition. It will be noted that the signal contrast for phase interference read-out actually may improve in some respects with fading of the recording layer. That is, the shoulder portion of the curve becomes much flatter while the sharp phase shift change between pitted and non-pitted thickness regions remains.

From the foregoing explanations, it will be understood that the present invention contemplates



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record elements having a nominal thickness and optical constants that are optimized with respect to a selected write-read wavelength. Specifically, the optical constants and nominal thickness of the recording layer are so designed that a major proportion (e.g. about 70%) of the incident write-read light is absorbed by the recording layer (in the vicinity of its upper surface) but a significant minor proportion (e.g. 30%) of incident write-read light will be reflected from the element. It will be understood that in this context, the term "significant minor proportion" means a proportion adequate to achieve focus error information prior to recording and good-contrast, phase interference read-out subsequent to recording. The element's optical constants also are optimized with respect to the chosen write-read wavelength so that decreases from said predetermined nominal thickness cause relatively high magnitude phase shifts of reflected write-read light and so that increases from said predetermined nominal thickness cause relatively low magnitude phase shifts of reflected write-read light. Another criterion in selection of the optical constants and nominal thickness of the recording layer is that the depth of modulation imparted to write-read light by recorded (pitted) and unrecorded portions does not change substantially when the absorption to such read light decreases. Approaches for designing such elements will be explained in more detail subsequently; however, a description of some useful and preferred record element materials is appropriate first.

There are a wide variety of materials suitable for the supports and recording stratum of recording elements of the present invention. Important support characteristics are that it have a



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melting point high enough to avoid deformation and a smooth reflective surface. Materials such as reflective metals or glass or resin films (such as polyethylene terephthalate) coated with thin metal layers, e.g., 500 Å of aluminum, are exemplary but there are many others.

Although there are other recording layer materials that can be used in implementing element design according to the present invention, we have found dye-binder material to be particularly suitable.

A number of useful binders and dyes are disclosed in U.S. Patent Application Serial No. 023,434, filed March 23, 1979. That disclosure is incorporated herein for its teachings of such binders and dyes as well as for teachings of other examples of other element structures such as supports. In general it is preferred according to the present invention that the recording layer be an amorphous material. Thus the mixture of binder and absorptive material (e.g., the dye which absorbs at the writing wavelength) desirably are compatible to mix in such a way that no crystalline structure is formed.

Useful binders include for example cellulose acetate butyrate, polystyrene, polysulfonamide, Lexan (polycarbonate), cellulose nitrate, hydroabietyl alcohol (sold by Hercules Chemical Company as Abitol AUK 257), poly(ethyl methacrylate), poly(vinyl butyral), and combinations thereof. In some instances it may be useful to include a plasticizer in the mixture to achieve desired deformation capabilities. It is highly desirable that the selected recording layer be soluble in a solvent (e.g., such as cyclohexanone, acetone, benzene, xylene or the like) to facilitate coating.

There are a wide variety of useful dyes that can be considered for their absorptivity at the



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writing wavelength and compatibility with the binder of choice. A number of such dyes that are useful for consideration when writing and reading with an argon-ion laser (wavelength = 488 nm) are described in the above-cited application, such disclosure being incorporated by reference. Additional useful light absorber-binder materials are disclosed in U.S. Patent Application Serial No. 001,519, filed January, 8, 1979, Research Disclosure Publication No. 16167 by Industrial Opportunities Ltd., U.K., and U.S. Application No. 124,382, entitled " α , α' -Bis-(Dialkylaminobenzylidene) Ketone Dyes And Their Use in Optical Recording Elements", and filed February 25, 1980 in the names of Specht and Thomas, which are also incorporated herein by reference for that purpose.

The following procedure is one useful way to design a recording layer of optical constants and nominal thickness in accordance with the present invention:

First, based upon knowledge of the particular write-read wavelength with which the record element is to be used, a dye-binder combination is selected from materials such as described above. As previously explained, it is desirable that the dye-binder layer have a reflectance versus thickness relation exhibiting a high modulation with respect to the write-read wavelength at the first reflectance minimum. In this context, the term "high modulation" is intended to describe the condition where the second reflectance maximum has a substantially larger magnitude than the first reflectance minimum, e.g., as shown in Figs. 2 and 4. In order to achieve this characteristic, the dye-binder combination desirably has a moderately high extinction coefficient with respect to the



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selected write-read light. An imaginary refractive index in the range from about 0.3 to about 0.8 is preferred for most useful dye-binder combinations. Additionally, it is preferred that the real

5 refractive index of the dye-binder combination be greater than about 1.4 with respect to the selected write-read wavelength in order to provide a relative phase shift versus thickness variation curve exhibiting zones of relatively steep slope, i.e.,

10 relatively rapid phase change per thickness variation.

Having selected a dye-binder combination, the optical constants can be measured. The dependence on thickness of the reflectance and relative phase shift (such as ϕ and R in Fig. 4)

15 for a non-faded recorded layer condition and the relative phase shift (such as ϕ_2 in Fig. 5) for a completely faded recording layer condition can be calculated and plotted by procedures known to those skilled in the art. The curves shown in Fig. 4 are

20 for the recording layer material and recording light wavelength described hereinafter in the specific detailed Example of a preferred recording element.

Based upon analysis of such curves, ranges of nominal recording stratum thicknesses and pit

25 depths which are operable in accordance with the present invention can be identified. More specifically, the nominal thickness should be selected to be sufficiently greater than the thickness corresponding to the first reflection

30 minimum to afford (when the dye-binder layer is in a non-faded condition) adequate reflected light intensity for good contrast, phase-interference read-out with the selected read power and detection system. Because (1) the usable reading light power

35 is constrained (in an unfaded condition) by the possibility of melting the dye-binder layer or fading

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the dye and (2) high bandwidth detection systems which produce low-noise signals from low-power light input are difficult to design, it is highly preferred to select the nominal thickness generally proximate the second reflectance maximum. In some systems it may be useful to select the nominal thickness slightly beyond the second reflectance maximum; however, it will be understood that this involves the formation of deeper pits. It is therefore highly preferred that the nominal thickness be selected along the positively sloping portion of the reflectance curve sufficiently beyond the first reflectance minimum to provide reflectance of a significant minor portion of the write-read wavelength when the dye-binder layer is in its unfaded (i.e., maximally absorptive) condition.

Having identified a range for selection of nominal thickness as indicated above, it is preferred to consider two other aspects in selection of a final nominal thickness. First, as will be understood by those skilled in the art, the power required for forming a pit of given depth will be related to some extent to the interlayer interference characteristics of a particular recording stratum, these being governed by the thickness and optical constants of the various layers in the recording structure. The selection of a final nominal layer thickness can be further optimized by taking such interlayer interference characteristics into account. Reference to Fig. 6 will clarify how this can be done, bearing in mind that the general desired condition is to have a large fraction of the recording light absorbed near the upper portion of the recording layer.

In Fig. 6, the parameters $D_{\pi/2}$, $A_{\pi/2}$ and $D_{\pi/2} \div A_{\pi/2}$ for an exemplary recording element (described in the subsequent Example) are

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plotted as a function of recording layer overall thickness. The $D\pi/2$ curve is illustrative of the physical pit depth required to yield a $\pi/2$ phase shift at varying recording layer thickness, and the $A\pi/2$ curve is illustrative of the percentage of light absorbed in the depth $D\pi/2$ at varying overall recording layer thicknesses. Those curves can be calculated based on the recording stratum's optical constants (the optical constants for the $A\pi/2$ parameter being of the recording layer in its unfaded condition and the $D\pi/2$ parameter being of that layer in its wholly faded condition). It is to be noted that the same analysis can be undertaken regarding other desired phase shifts, e.g., $\pi/4$, that might be used in particular detection systems. The $D\pi/2 \div A\pi/2$ curve thus is a plot indicating the power requirement for obtaining the desired phase shift (i.e., a $\pi/2$ shift) during recording and will be of assistance in final selection of nominal thickness. More specifically, it will be understood that recording sensitivity of a recording layer will be improved by selecting the nominal thickness of its recording layer within the operable nominal thickness range, identified as described above, and at or near a minimum of the power curve $D\pi/2 \div A\pi/2$. Thus, considering the $D\pi/2 \div A\pi/2$ power curve of Fig. 6 in connection with the reflectance and phase shift curves of Fig. 4, it will be seen that a nominal thickness in the order of 80 to 90 nm will be desirable from the recording power viewpoint as well as from the criterion used to identify the operable nominal thickness range and described previously with respect to Fig. 4.

The other aspect which can be considered in selection of the final nominal thickness is the



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nature of the recording layer's reflection and phase shift characteristics during transition between a wholly unfaded and a wholly faded condition. That is, it is desirable to confirm (e.g. see Figs. 7a-h) that the phase shift characteristic curve ϕ and reflectance curve R do not exhibit any change during the transition between the ϕ_1 and ϕ_2 shown in Fig. 5 that would prevent good phase read-out. The curves shown in Fig. 7a-7h illustrate the manner in which the curve ϕ and curve R for a specific recording structure (described in the subsequent Example) change during various stages of the dye fading or bleaching cycle from the condition where the dye in the recording layer is 100% unbleached (Fig. 7a) to the condition where the dye is 0% unbleached (Fig. 7h). Curves such as Figs. 7a-h can be plotted for a particular recording structure composition and write-read wavelength by measuring the optical constants of recording layer material at various thickness and stages of bleaching. However, more simply, the recording layer material characteristics at a nominal thickness selected in accordance with the previous guidelines can be checked at various stages of fading.

Having selected the dye-binder layer combination and the nominal recording layer thickness, the recording structure can be formed, e.g., by solvent coating techniques in accordance with these selections.

At this stage it is also useful to consider the procedure of recording, i.e., pit formation. From the foregoing discussion with respect to Fig. 4, it will be appreciated that it is desirable according to the present invention to provide recorded pit depths such that the magnitude of light reflected from pitted areas is sufficiently equal to that



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reflected from the non-pitted areas to provide a good phase interference read-out condition. This can be implemented by referring to the reflectance versus thickness variation curve of the record element. For example, once the nominal thickness is selected, the reflectance magnitude corresponding to that thickness can be noted and a point of approximately equal reflectance magnitude noted on the portion of the reflectance curve to the left (in the direction of decreased thickness) of the nominal thickness. The thickness which corresponds to this point will provide a useful "beneath-pit-thickness" in accordance with the present invention. As will be apparent, the difference between the nominal thickness and the beneath-pit-thickness will be the desired pit depth; and the recording parameters, e.g., power and disc rotation speed can be adjusted (e.g., empirically) to attain this pit depth.

It will be noted that a substantial phase difference will result between light reflected from pitted and non-pitted regions of the disc. In some instances it may be useful and preferred to adjust this phase difference for the particular detection scheme utilized in read-out, e.g., by slightly adjusting the selected nominal thickness and the selected pit depth while preserving the general requisite that the reflectance from pitted and non-pitted regions should be approximately equal. Likewise, it will be understood that the phase shift curves in both non-faded and faded conditions (and in intermediate bleaching stages, see Figs. 7a-h) should be considered also in selection of pit depth to assure maintenance of an adequate $\Delta\phi$. In general, it is desirable also to allow a sufficient beneath-the-pit thickness to insulate the upper pit-

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forming region of the layer from substantial heat loss to the reflective layer during pit formation.

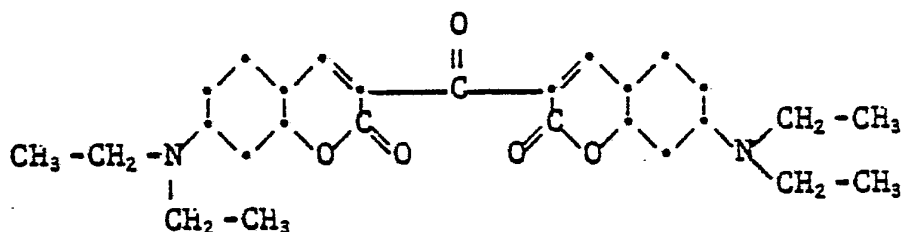
Such "beneath-the-pit" thickness should, in general, be greater than the thermal diffusion length "l"

of the recording layer material. "l" is given by $l = \sqrt{K\tau}$, where K is the thermal diffusivity of the material and τ is the maximum time for which a point on the disc will be irradiated by the recording laser.

The following more specific example of one preferred embodiment of the present invention will aid in further understanding thereof.

Example I

A recording layer coating solution was formed containing one part cellulose nitrate binder, one part of the dye SK-1 and 60 parts solvent (cyclohexanone). The dye SK-1 has the structural formula:



and the mode of preparation and utility of coumarin compounds such as SK-1 are described in Research Disclosure Publication No. 16167 by Industrial Opportunities Ltd., U.K. In this Example, the recording layer coating is to be formed on a smoothed circular glass substrate with a radius of about 150 nm and a thickness of about 1/4-inch, having a reflective aluminum layer of about 500Å. The following parameters characterized the significant optical constants of such a recording element with respect to the selected write-read light (488Å):

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 $\lambda_w (488)$ Recording Layer: $n_c = 2.25 + i0.45$ Reflective Layer: $n_c = 0.70 + i4.80$ Substrate: $n = 1.53$

5 The curves in Figs. 4-6 were plotted based on these optical constants of the recording element and a nominal thickness of about 850Å selected based on the criteria discussed above. The coating solution described above was filtered and whirl
10 coated onto the reflectively coated glass substrate and then dried so as to form a recording layer of the selected nominal thickness (about 850Å).

 The curves of Figs. 7a-h were calculated based on measurements of such a coating and a
15 mathematical model indicating how the real and imaginary refractive indices of such a coating composition vary with progressive dye bleaching. This confirmed that no changes in phase shift or reflection would prevent good phase read-out
20 performance between the non-faded and faded conditions. Thus a pit depth of about 550Å was selected as the nominal pit depth.

 After complete bleaching of the recording layer (i.e. in the condition indicated in Fig. 7h)
25 the optical constants of the element are:

 $\lambda_w (488)$ Recording Layer: $n_c = 1.50 + i0.00$ Reflective Layer: $n_c = 0.70 + i4.80$ Substrate: $n = 1.53$

30 We have found a particularly effective mode for read-out of discs formed in accordance with the present invention to be point detection such as disclosed in U.S. Patent Application Serial No. 161,486 entitled "Apparatus and Method for Reading
35 Optical Discs" and filed June 20, 1980 in the name of D. G. Howe. When using this technique the relative



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phase shift due to pits may change from π to $\pi/2$ as the disc bleaches, but the depth of modulation will remain essentially constant.

5 The invention has been described in detail with particular reference to certain preferred embodiments thereof, but it will be understood that variations and modifications can be effected within the spirit and scope of the invention.



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What is claimed is:

1. A real-time optical disc for storing high density information, said disc comprising a heat-deformable, dye-binder recording layer overlying
5 a substantially smooth reflective surface, said layer being adapted to have a plurality of pits formed therein by a focused light beam of predetermined wavelength and to have such pits detected by scanning
10 a light beam of the same wavelength over such pits to produce a modulation in the reflected light, said disc being characterized in that said layer has optical properties and a nominal thickness such that a substantial portion of incident light of said wavelength is reflected from both pitted and
15 non-pitted regions of said layer, and that a substantial change in phase is produced between light reflected respectively from non-pitted and pitted regions.

2. The real-time optical disc as defined in
20 claim 1 characterized in the nominal thickness of said recording layer is proximate a transition, from a zone of gradual slope to a zone of rapid slope, in the relative phase shift versus thickness variation
25 curve of said recording layer with respect to light of said predetermined wavelength, whereby decreases in thickness of the recording layer during recording will yield a substantial change in phase with respect to light reflected from non-pitted regions, and increases in thickness of the recording layer will
30 produce a relatively small phase change in light reflected from regions of increased thickness.

3. The real-time optical disc as defined in claim 2 characterized in that the optical properties of said recording layer are such that said transition
35 is substantially unaffected by decreases in



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absorption of the recording layer to said predetermined wavelength.

4. The real-time optical disc as defined in claim 1 characterized in that the real component of the refractive index of said recording layer at said
5 predetermined wavelength is greater than about 1.4.

5. The real-time optical disc as defined in claim 1 characterized in that the imaginary component refractive index of said recording layer is in the
10 range of from about 0.3 to about 0.8.

6. The real-time optical disc as defined in claim 1 characterized in that the real component of the refractive index of said recording layer at said wavelength is greater than about 1.4 and in that the
15 imaginary component of the refractive index of the recording layer is in the range of from about 0.3 to about 0.8.

7. The real-time optical disc as defined in claim 1 characterized in that the amounts of incident
20 light reflected respectively from pitted and non-pitted regions on said disc are approximately equal.

8. A method for using an optical disc of the type defined by claim 1 to record and read-out
25 high density information, such method including the steps of scanning an intensity-modulated light beam of said predetermined wavelength across said recording layer to record information in the form of pitted and non-pitted regions arranged along a track,
30 scanning said tracks with a continuous-wave light beam of said predetermined wavelength to produce a reflected beam which is modulated by said pitted and non-pitted regions, and sensing said reflected beam with a photodetector, characterized in that during
35 the recording step the pits are recorded to a depth such that, upon being scanned to produce said



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reflected beam, the proportions of such beam reflected from pitted and non-pitted regions are approximately equal, and such that the modulation in said reflected beam is caused by differences in phase
5 between light reflected respectively from said pitted and non-pitted regions.



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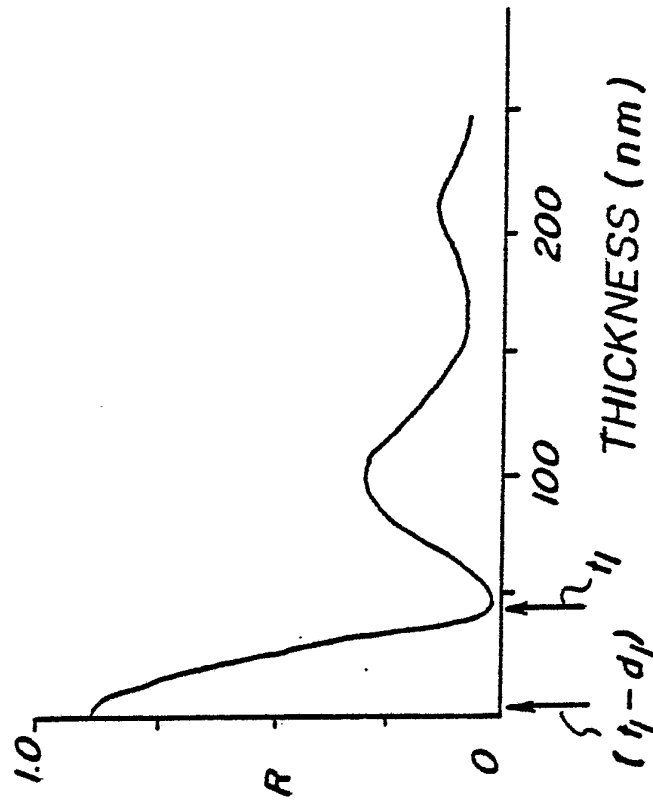


FIG. 2

PRIOR ART

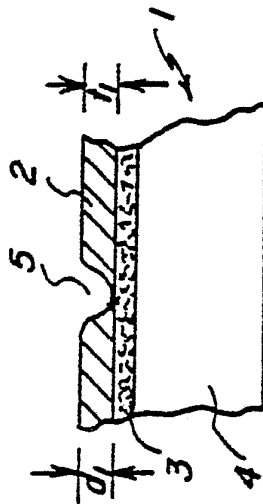
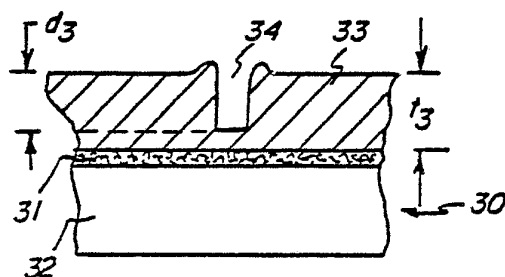
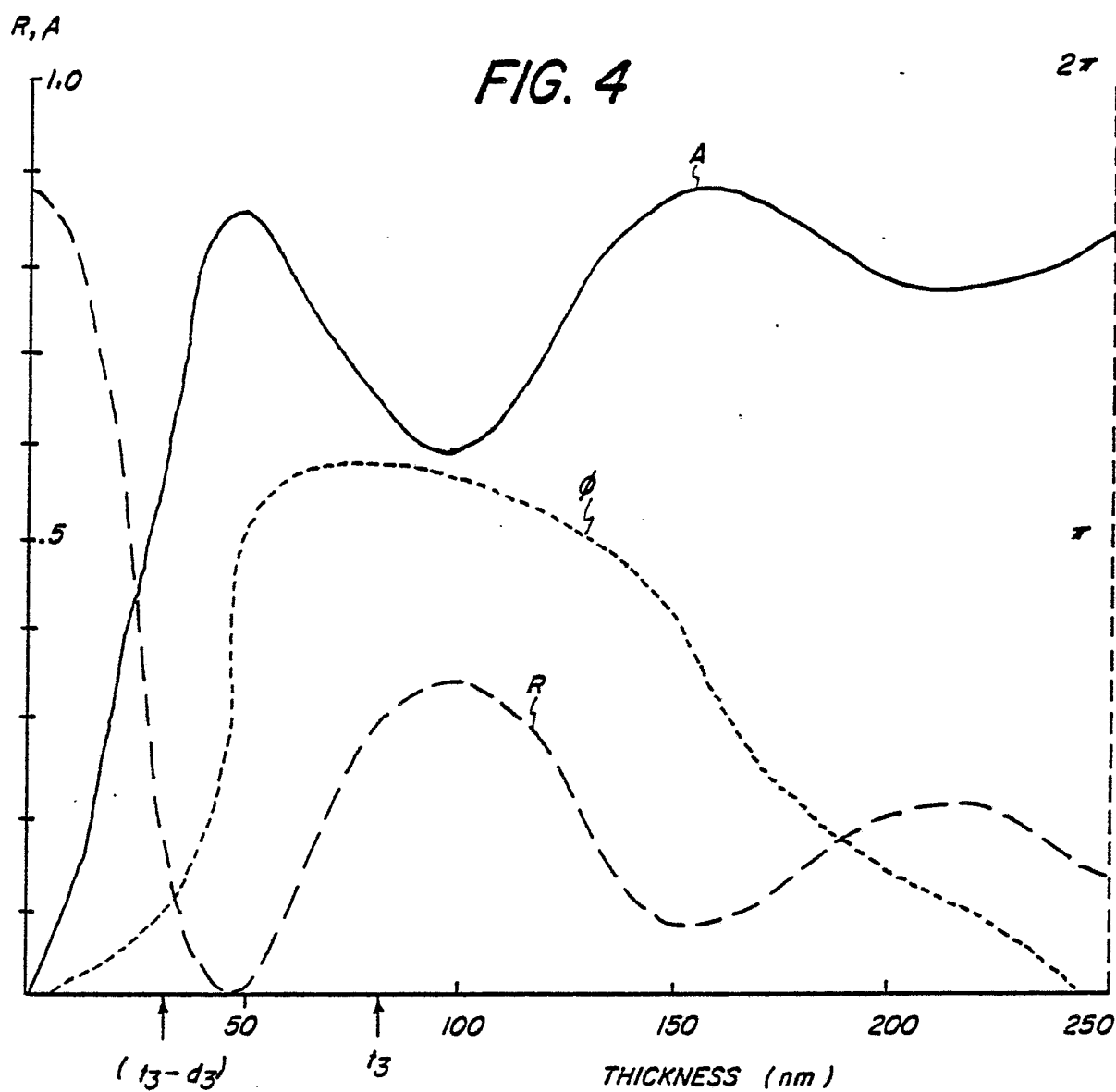
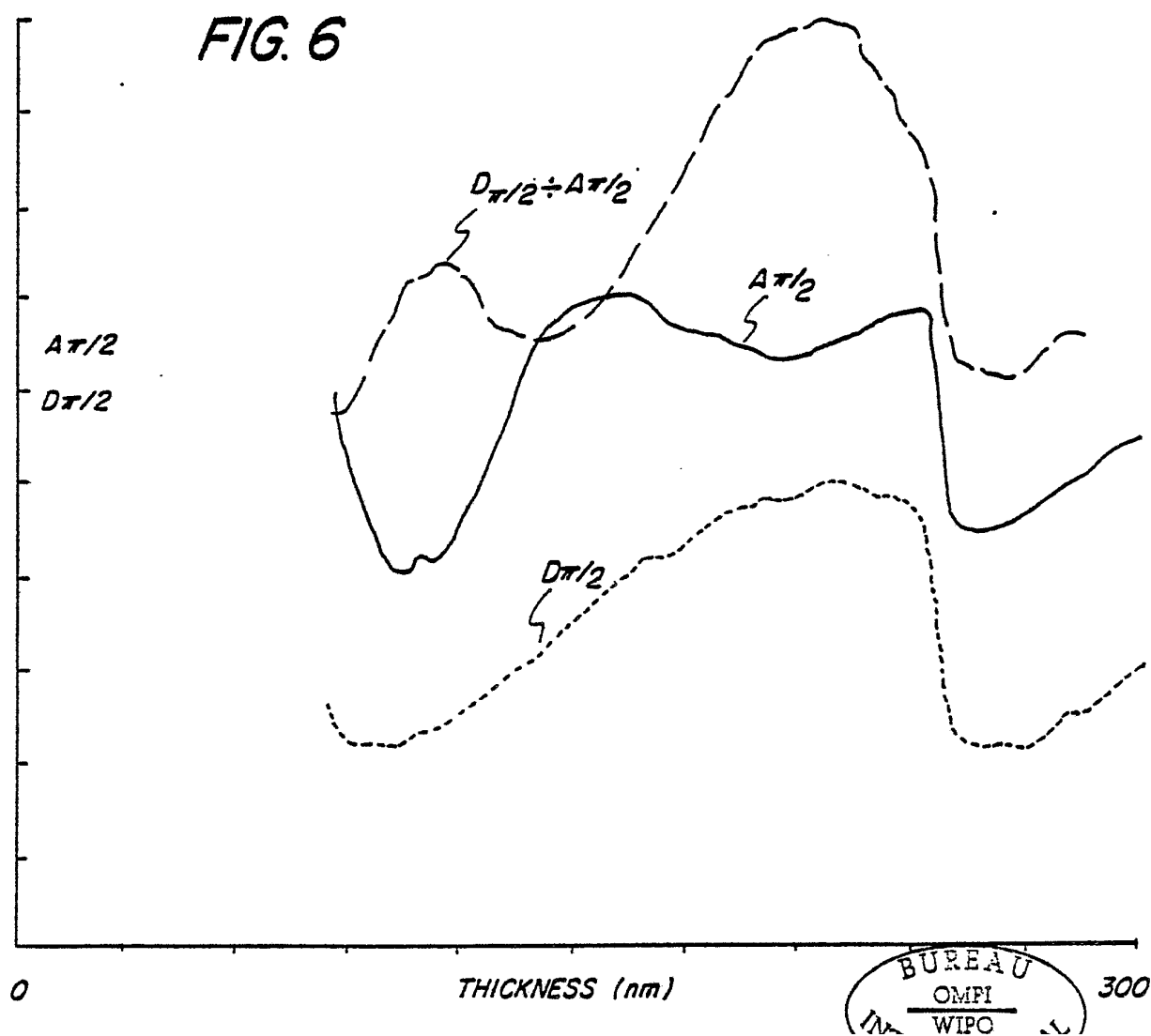
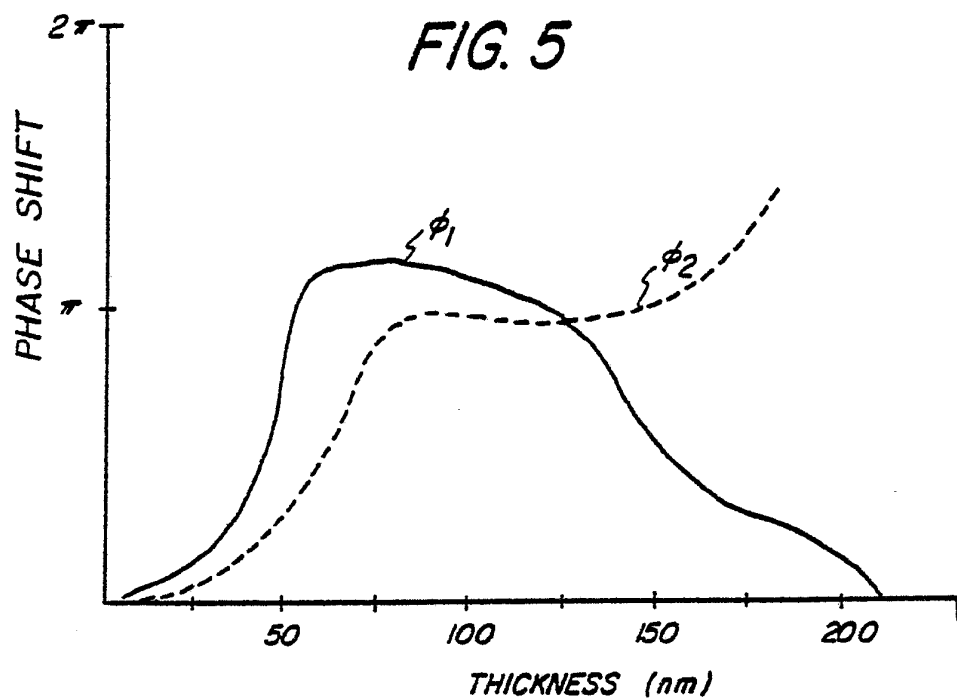


FIG. 1

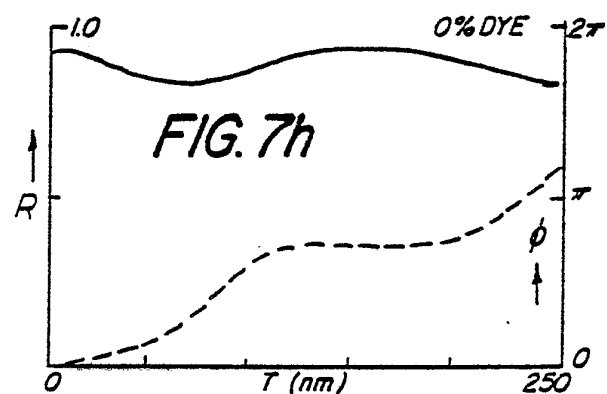
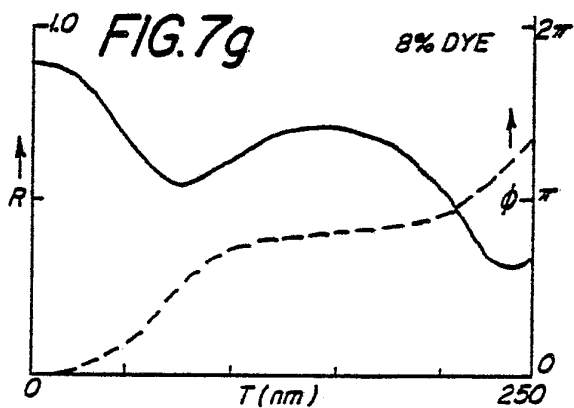
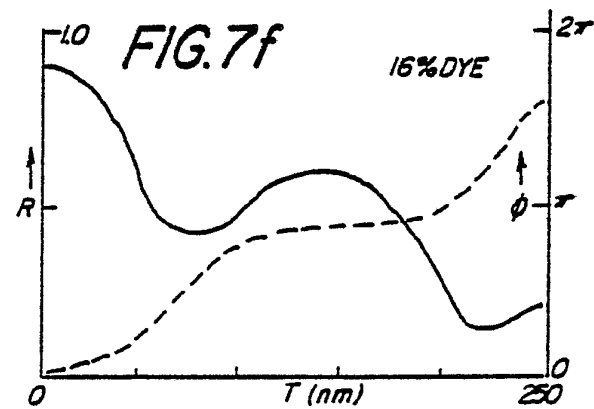
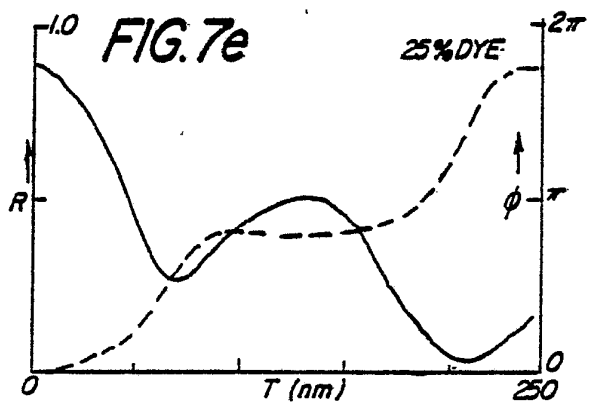
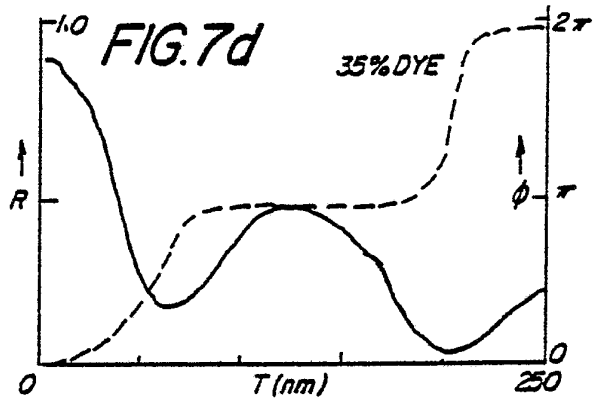
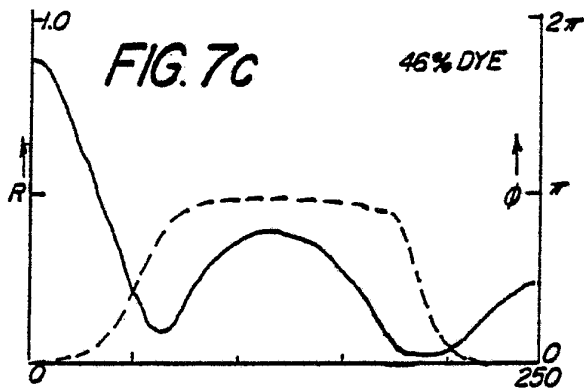
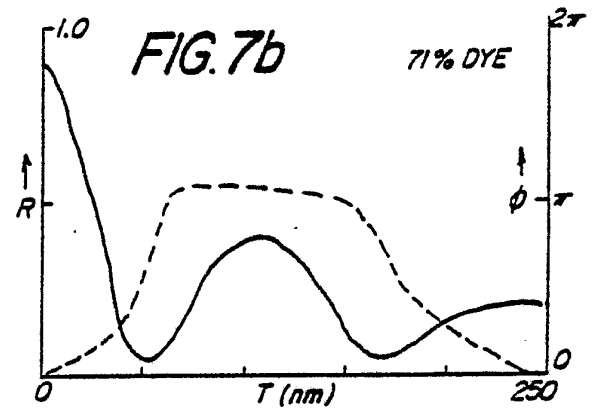
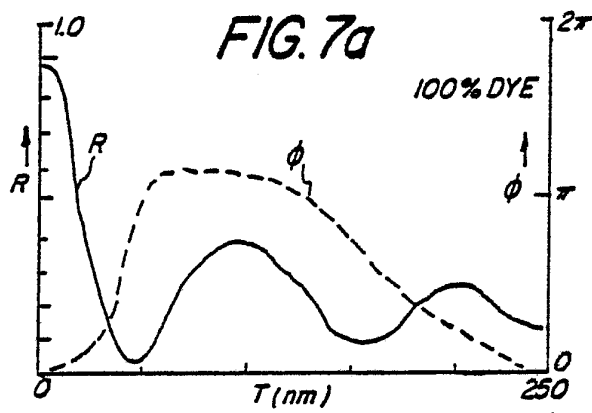
2 / 4

**FIG. 3**

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INTERNATIONAL SEARCH REPORT

International Application No PCT/US81/01536

I. CLASSIFICATION OF SUBJECT MATTER (If several classification symbols apply, indicate all) ³ According to International Patent Classification (IPC) or to both National Classification and IPC IPC³GOLD 15/34																							
II. FIELDS SEARCHED Minimum Documentation Searched ⁴ <table border="1" style="width: 100%; border-collapse: collapse; margin-top: 5px;"> <tr> <th style="width: 20%; font-size: 0.8em;">Classification System</th> <th style="font-size: 0.8em;">Classification Symbols</th> </tr> <tr> <td style="vertical-align: top; padding: 5px;">NATIONAL</td> <td style="padding: 5px;"> Cl. 346-76L Cl. 358-128.5 Cl. 346-135.1 Cl. 358-297 </td> </tr> </table> Documentation Searched other than Minimum Documentation to the extent that such Documents are included in the Fields Searched ⁵			Classification System	Classification Symbols	NATIONAL	Cl. 346-76L Cl. 358-128.5 Cl. 346-135.1 Cl. 358-297																	
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* Special categories of cited documents: ¹⁶ "A" document defining the general state of the art "E" earlier document but published on or after the international filing date "L" document cited for special reason other than those referred to in the other categories "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but on or after the priority date claimed "T" later document published on or after the international filing date or priority date and not in conflict with the application, but cited to understand the principle or theory underlying the invention "X" document of particular relevance																							
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