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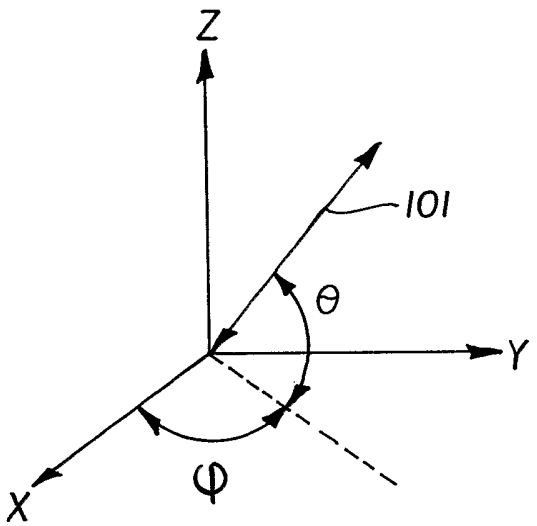
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(54) Title: MULTILAYER OPTICAL COMPENSATION FILM



(57) Abstract: A multilayer optical compensation film includes at least one optically anisotropic first layer and at least one optically anisotropic second layer. The indices of refraction of the first layer satisfies the relation $nx_1 \geq ny_1 \geq nz_1$. The second layer includes amorphous polymer with a glass transition temperature above 160C°, and the indices of refraction of the second layer satisfy the relations $|nx_2 - ny_2| < 0.001$ and $nz_2 - (nx_2 + ny_2)/2 > 0.005$.

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MULTILAYER OPTICAL COMPENSATION FILM

FIELD OF THE INVENTION

The present invention generally relates to optical compensation films and to liquid crystal displays containing optical compensation films. More particularly, the present invention relates to an optical compensations film containing two or more optically anisotropic layers, to a liquid crystal display containing an optical compensation film, and to a process of forming an optical compensation film.

BACKGROUND OF THE INVENTION

In liquid crystal display (LCD) systems, a liquid crystal cell is typically situated between a polarizer and an analyzer. An incident light polarized by the polarizer passes through a liquid crystal cell and is affected by the molecular orientation of the liquid crystal material, which can be altered by the application of a voltage across the cell. The altered light then enters the analyzer. By employing this principle, the transmission of light from an external source, including ambient light, can be controlled. The energy required to achieve this control is generally much less than required for the luminescent materials used in other display types such as cathode ray tubes (CRT). Accordingly, liquid crystal technology is used for a number of electronic imaging devices, including but not limited to digital watches, calculators, portable computers, and electronic games for which light-weight, low-power consumption and long-operating life are important features. Also, replacement of the CRT television (CRT-TV) with LCD-TV is rapidly progressing. LCD modes such as In-Plane Switching (IPS) are known to offer high contrast, high speed response and good color reproduction, making LCD systems suitable for TV applications.

Contrast, color reproduction, and stable gray scale intensities are important quality attributes for electronic displays. The primary factor limiting the contrast of an LCD system is the propensity for light to "leak" through liquid crystal elements or cells which are in the dark or "black" pixel state. Furthermore, the leakage and hence contrast of a liquid crystal display are also dependent on the

direction from which the display screen is viewed. Typically the optimum contrast is observed only within a narrow viewing angle range centered about the normal incidence to the display and falls off rapidly as the viewing direction deviates from the display normal. In color displays, the leakage problem not only degrades contrast but also causes color or hue shifts with an associated degradation of color reproduction. This is a common problem with most display modes. However, in the IPS mode LCD, the liquid crystal optic axis changes its direction while remaining in the plane of the liquid crystal cell. This results in better viewing angle characteristics than those associated with other more conventional modes such as the Twisted Nematic (TN) mode.

One of the factors that permits light leakage in the dark state of the LCD is the viewing angle dependence of the crossed polarizes. Here "cross polarizers" shall be understood as a pair of two polarizers with their transmission axes (or equivalently, absorption axes) forming an angle of 90 ± 5^{O}. The polarizers are absorptive dichroic type commonly used for LCD display applications. Very little light can go through crossed polarizers provided the light is impinged in the direction normal to the plane of the crossed polarizers. However, when the light propagation direction deviates from the normal, there occurs a significant amount of light leakage with the maximum leakage occurring at a large polar viewing angle and 45 degrees of azimuthal viewing angle relative to the transmission axis of the polarizer. This is because the effective angle between the transmission axes of the polarizers deviates from 90^{o}.

One way to reduce the light leakage through two crossed polarizers is to insert a compensator between them. The compensators used for polarizers are nominally a combination of an A-plate and a C-plate, as suggested by Chen et al. ("Optimum film compensation modes for TN and VA LCDs", SID 98 Digest, pp.315-318 (1998)).

U.S. Patent No. 6,606,193 discloses a compensator using two biaxial films having $0.15 \leq Nz \leq 0.35$ and $0.65 \leq Nz \leq 0.85$, respectively, where Nz is defined as $(nx - nz)/(nx - ny)$ with a relation $nx > ny$. Here, x and y lie in the plane of the layers, and z lies in the plane normal to the layers. Thus, indices of refraction satisfy $nx > nz > ny$. The two biaxial films are placed between the pair

of crossed polarizers of the LCD. The fast axes (the y direction having index of refraction ny) of both biaxial films are placed parallel to the absorption axis of one of the polarizers. A similar technique is disclosed in Japanese patent publication JP2001-350022, where two biaxial films are used to suppress spectrum dependence of light leakage.

In the afore-mentioned references using compensation films, the aim is to reduce the viewing angle dependence of the effective angle formed by the transmission (or absorption) axis of the crossed polarizers. These techniques can be used to increase the contrast ratio of, for example, the IPS mode liquid crystal display.

Saitoh et al. (SID digest 1998 page 706-709) proposed viewing angle improvement in the IPS mode liquid crystal display (IPS-LCD). A single biaxial compensation film was used in combination with the IPS mode liquid crystal cell and a pair of polarizers. The direction of slow axis of the biaxial compensation film is parallel to the direction of transmission axis of the polarizer and the azimuthal direction of the liquid crystal optic axis of the IPS mode liquid crystal cell in the OFF state. The transmission axis of the other polarizer is perpendicular to the transmission axis of the other polarizer. The configuration reduces the light leakage through the crossed polarizers and thereby increases the contrast ratio of the IPS-LCD.

While compensation film techniques have been suggested for reducing light leakage through the crossed polarizers or combination of crossed polarizer and liquid crystal cells (e.g., IPS mode liquid crystal cells), conventional techniques fail to provide a low-cost and/or simple method of providing such compensation films. For Chen's method to work, the sign of retardation of the A and C plate must have the same sign. U.S. published patent application US2004002750, filed by the current inventors and incorporated herein by reference, discloses a manufacturing process for a negative C plate. However, there is no straightforward manner to obtain a negative A plate with sufficient phase retardation. Thus, the combination of negative A and C plates for compensation is not plausible. While a positive A plate is widely available, a positive C plate is not. A positive C plate can be made from uniformly and

perpendicularly aligned liquid crystal polymer. Polymerizable liquid crystal, such as the one disclosed in U.S. Patent No. 6,261,649 gives perpendicular alignment. However, liquid crystal polymers are high cost compounds and creating a uniform alignment of liquid crystals poses significant obstacle in large-scale manufacturing. Often non-uniform alignment occurs even in a small size which results in a hazy appearance. Such haze decreases the optical transmission of the compensation film. Polymerizable liquid crystal also requires a photo-polymerization process in order to freeze the perpendicular alignment of the liquid crystal polymer, adding extra processes and cost.

Use of biaxial films also poses problems. Biaxial plates used in both U.S. Patent No. 6,606,193 and JP2001-350022 have the property $nx > nz > ny$. Films with such optical property cannot be made without difficulty. Standard manufacturing processes (e.g., stretching of the polymer film) gives films with $nx > ny \geq nz$. Several methods have been suggested to obtain increased nz so that the film can have $nx > nz > ny$. U.S. Patent No. 6,606,193 teaches a process in which heat-shrinkable base film is bonded to the secondary film. By heating such an article, the base film shrinks with heat resulting in a higher nz in the secondary film. Another method is the alignment of the polymer segment by an applied electric field. The applied field aligns the polymer segments in the film normal direction, and thus the procedure achieves a higher nz value. Often, however, subsequent stretch is necessary to control all three indices of refraction, nx, ny and nz to their desired values, and careful stretching process is necessary to maintain the relation $nx > nz > ny$ in the final films. Without such fine-tuned stretching, only films having $nx > ny \geq nz$ are obtained. Such a fine-tuned process is not suitable for mass manufacturing and may jeopardize the manufacturing repeatability of optical properties of the film.

Thus, problems arise in attempts to provide a multilayer optical compensation film that can be used to prevent light leakage through an LCD in the dark or "black" state.

SUMMARY OF THE INVENTION

According to one aspect of the present invention, a multilayer optical compensation film is provided which includes at least one optically anisotropic first layer and at least one optically anisotropic second layer. The indices of refraction of the first layer satisfy the relation $nx1 \geq ny_1 \geq nz_1$. The second layer includes amorphous polymer with a glass transition temperature above 160C°, and the indices of refraction of the second layer satisfy the relations $|nx_2-ny_2|< 0.001$ and $nz_2-(nx_2+ny_2)/2 > 0.005$.

According to another aspect of the present invention, the above-described multilayer optical compensation film is located between one or both of a pair of crossed polarizers and a liquid crystal cell.

According to yet another aspect of the present invention, a process of forming the above-described multilayer optical compensation film is provided.

BRIEF DESCRIPTION OF THE DRAWINGS

While the specification concludes with claims particularly pointing out and distinctly claiming the subject matter of the present invention, it is believed that the invention will be better understood from the following description when taken in conjunction with the accompanying drawings, wherein:

FIG.1 shows the definitions of azimuthal angle φ and tilt angle θ of the optic axis;

FIG.2A and FIG. 2B show the optic axis direction with respect to the planes of A and C plates, respectively;

FIG. 3 is a view of a layer with thickness d and x-y-z coordinate system attached to the layer;

FIG. 4A and FIG. 4B are schematic views of perpendicular alignment of liquid crystals, and random in-plane orientation of an amorphous polymer chain, respectively;

FIG. 5A, FIG. 5B and FIG. 5C are cross sectional schematics of exemplary compensation films according to embodiments of the present invention;

FIG. 6 is a schematic of a liquid crystal display according to an embodiment of the present invention; and

FIG. 7A is a schematic showing definitions of polar and azimuthal viewing angles, FIG. 7B is a polar plot format, FIG. 7C and FIG. 7D are iso-leakage plots for an LCD without and with the inclusion of a compensation film, respectively.

DETAILED DESCRIPTION OF THE INVENTION

The compensation film described herein can be used to improve the image quality and contrast ratio of a liquid crystal display (LCD) system. The compensation film can be manufactured with a simple process that does not require use of liquid crystal polymer or any alignment procedure of liquid crystal polymer. Also, manufacture of the compensation film does not require shrinking of the film, application of an electric field to align polymer segments, or a subsequent fine-tuned stretching process.

With reference to FIGS. 1 through 3, the following definitions apply to the description herein:

"x", "y" and "z" define directions relative to a given layer, where x and y lie perpendicularly to each other in the plane of the layer, and z is normal the plane of the layer.

"Optic axis" is denoted by reference number 101 of FIG. 1 and refers to the direction in which propagating light does not see birefringence. Its direction is described by the azimuthal angle φ and the tilt angle θ. As can be seen in FIG. 1, the tilt angle θ measures the angle between the x-y plane and the optic axis 101, and the azimuthal angle φ is an angle measured in the x-y plane with respect to the reference direction x.

"ON and OFF state" refers to respective states with and without an applied voltage to the liquid crystal cell.

"A-plate" and "C-plate" refer to the plates schematically illustrated in FIGS. 2A and 2B, respectively. The A-plate 203 is defined by the condition $\theta = 0^{o}$, i.e., the optic axis 201 is in the plane of the plate 203. In contrast, the C-

plate 204 is defined by the condition $\theta = 90^{o}$, i.e., the optic axis 201 is perpendicular to the plane of the plate 204. Each plate can be a positive or negative plate depending on the sign of the birefringence of the constituent material.

"nx", "ny" and "nz" are indices of refraction of a layer in the x, y and z directions, respectively. Following the convention well known in the art, the relation $nx \geq ny$ is taken for the indices of refraction in the plane of the layer. Hereinafter, notation is used such that nx_1, ny_1 and nz_1 are indices of refraction for the first layer, and nx_2, ny_2 and nz_2 are those for the second layer.

"Optically uniaxial" means that at least two of nx, ny and nz are substantially equal, i.e., an absolute value of the difference between at least two of nx, ny and nz is less than 0.005. "Optically biaxial" means that none of nx, ny and nz are substantially equal to the other.

"Intrinsic Birefringence Δn_{int}" of a polymer refers to the quantity defined by (ne-no), where ne and no are the extraordinary and ordinary index of the polymer, respectively. Intrinsic birefringence is determined by factors such as the polarizabilities of functional groups and their bond angles with respect to the polymer chain. Indices of refraction nx, ny and nz of a layer are dependent upon manufacturing process conditions of the layer and Δn_{int} of the polymer of the layer.

"Out-of-plane phase retardation, R_{th}" of a layer is a quantity defined by [nz-(nx+ny)/2]d, where d is the thickness of the layer 301 shown in FIG. 3. The quantity [nz-(nx+ny)/2] is referred to as "out-of-plane birefringence, Δn_{th}". If nz > (nx+ny)/2, then Δn_{th} and Rth are positive. If nz <(nx+ny)/2, then Δn_{th} and Rth are negative. Without limiting the invention, the values of Δn_{th} and Rth hereafter are given at the wavelength λ=550nm.

"In-plane retardation Rin" of a layer 301 is defined by $|nx-ny|d$. Without limiting the invention, the value of Rin hereafter is given at λ=550nm.

"Amorphous" means a lack of long-range order. Thus an amorphous polymer does not show long-range order as measured by techniques such as X-ray diffraction.

"Chromophore" is defined as an atom or group of atoms that serve as a unit in light adsorption. (Modern Molecular Photochemistry, Nicholas J. Turro Editor, Benjamin/Cummings Publishing Co., Menlo Park, CA (1978) Pg 77). Typical chromophore groups include vinyl, carbonyl, amide, imide, ester, carbonate, aromatic (i.e. heteroaromatic or carbocylic aromatic such as phenyl, naphthyl, biphenyl, thiophene, bisphenol), sulfone, and azo or combinations of these chromophores. A non-visible chromophore is one that has an absorption maximum outside the range of λ=400-700nm.

"Contiguous" means that articles are in contact to each other. In contiguous two layers, one layer is in direct contact to the other. Thus, if a polymer layer is formed on the substrate by coating, the substrate and the polymer layers are contiguous.

Reference will now be made to the drawings in which the various elements of the present invention will be given numerical designations and in which the invention will be discussed so as to enable one skilled in the art to make and use the invention.

The multilayer optical compensation film of embodiments of the present invention includes first and second optically anisotropic layers. The first satisfies the relation (1):

$$nx_1 \geq ny_1 \geq nz_1 \qquad (1)$$

and the second layer satisfies the relations (2) and (3):

$$|nx_2 - ny_2| < 0.001 \qquad (2)$$

$$\Delta n_{th} = nz_2 - (nx_2 + ny_2)/2 > 0.005 \qquad (3)$$

In addition, the second layer includes amorphous polymer with a glass transition temperature above 160C°. Preferably, the first and second layers are contiguous.

It is noted that the first "layer" and the second "layer" can each be constituted by a single continuous layer, or by a plurality of layers satisfying the aforementioned relations.

Characteristics of the first and second layers are described in turn below.

The first layer has indices of refraction satisfying the relation (1). In the case where $nx_1 \geq ny_1 = nz_1$, the first layer is optically uniaxial. The optic

axis is in the plane of the substrate and it is therefore an A-plate (FIG. 2A). In most cases, however, the indices of refraction satisfy $nx_1 > ny_1 > nz_1$ and the first layer is optically biaxial. In both cases, the first layer physically takes the form of a film and is made from polymer or glass.

Examples of materials for the first layers include triacetylcellulose (TAC), cellulose acetate butylate (CAB), cyclic polyolefin, polycarbonate, polysulfonate, poly norbornene, other polymers known in the art, glass, and combinations thereof. These materials can be made into a film form by solvent casting, heat extrusion, or other methods such as those disclosed in US 2003/0215608A1 and US 2003/0215582A1, incorporated herein by reference, wherein the first layer would be solvent coated onto a moving carrier substrate. If necessary, the film is stretched to achieve the relation $nx_1 > ny_1 \geq nz_1$. If the first layers are made from polymer film with positive Δn_{int}, indices of refraction in the plane of the layer satisfy $nx_1 > ny_1$, where "x" denotes the primary direction of stretching and "y" is the direction perpendicular to x. On the other hand, polymer film with negative Δn_{int} gives $nx_1 > ny_1$, but y is now the primary stretching direction and x is perpendicular to y. By stretching polymeric materials, individual polymer chain segments are oriented predominantly to the direction of primary stretch, thus increasing the birefringence of the polymer layer. As it is necessary to orient the polymer segment, the stretching is carried out above the glass transition temperature Tg of the polymeric materials. Thus, the polymeric film is heated above Tg and stretched. Otherwise the birefringence diminishes as the applied tension for stretching is removed.

Another method is to stretch the film while solvents are incorporated within the film. Residual solvent after the casting of the film effectively lowers the Tg of the polymer, and thus stretching at room temperature becomes possible. With this method, the film can be stretched immediately after the polymer is solvent-casted into a film form. The film can be stretched uniaxially or biaxially. In uniaxial stretching, the film is stretched only in one direction. In biaxial stretching, two stretching directions are typically perpendicular to each other. The direction with the larger amount of stretching becomes the primary stretching direction.

The present invention is not limited to particular stretching mechanisms or techniques so long the stretched film has sufficient uniformity in indices of refraction.

The in-plane retardation Rin of the first layer is preferably 0nm < Rin < 300nm, or more preferably 10nm < Rin < 275nm.

The thickness of the first layer is not critical. However, overly thick layers can result in a bulky LCD module, and conversely, if the first layer is too thin, handling of the compensation film becomes cumbersome. Thus, the thickness of the first layers is preferably between 10μm to 200μm, or more preferably between 20μm to 100μm.

Turning now to the second layer, the relation (2) implies that the optic axis is essentially in the z direction and thus normal to the plane of the layers. Further, the birefringence of the second layers is positive as dictated by the relation (3). Thus, the second layer is essentially a positive C-plate (FIG. 2B) having a small in-plane birefringence, $0<|nx_2-ny_2|<0.001$ (by relation (2)) and positive out-of-plane birefringence Δn_{th} larger than 0.005 (relation (3)).

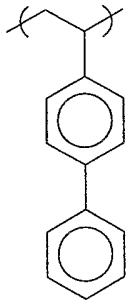
To generate the second layer having positive out-of-plane birefringence Δn_{th}, solvent coat of amorphous polymer with negative intrinsic birefringence Δn_{int} is used. As is well known to those who are skilled in the art, the out-of-plane birefringence of polymer layer, Δn_{th}, is given by $\Delta n_{th} = S\Delta n_{int}$, where S is an order parameter of the polymer segment. Thus, to generate positive Δn_{th}, two combinations are possible: 1) positive S and positive Δn_{int}, or 2) negative S and negative Δn_{int}. Referring to FIG. 4A, conventional techniques having a perpendicular alignment (in the z direction) of liquid crystals 401 falls into the first combination 1): positive S ($0 \leq S \leq 1$) and positive Δn_{int}. However, the layers thus generated using liquid crystal tend to have misaligned areas causing haze. The haze decreases optical transmission and is undesirable. In contrast with conventional techniques, the positive Δn_{th} of the second layers according to embodiments of the present invention results from combination 2): negative S and negative Δn_{int}. Referring to FIG. 4B, the polymer chain 403 of the amorphous polymer is randomly oriented in the plane of the polymer layer. For such an

orientation, the order parameter S of the polymer chain is in the range of $-0.5 < S < 0$. Thus, in order to obtain positive Δn_{th} for amorphous polymeric layer on the substrate, polymers with negative Δn_{int} are used. The negative value of S has to be sufficiently large or relation (3) cannot be satisfied.

Examples of such polymers would include materials that have non-visible chromophores off of the polymer backbone. Such non-visible chromophores would include: vinyl, carbonyl, amide, imide, ester, carbonate, sulfone, azo, and aromatic heterocyclic and carbocyclic groups (e.g.. phenyl, naphthyl, biphenyl, terphenyl, phenol, bisphenol A, and thiophene). In addition, combinations of these non-visible chromophores could be desirable (i.e. copolymers). Examples of such polymers and their structures are shown below.

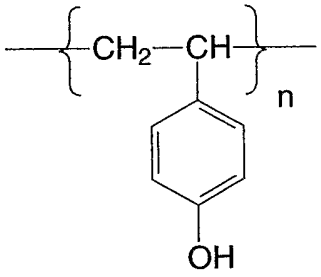
Example I:

poly (4 vinylbiphenyl)



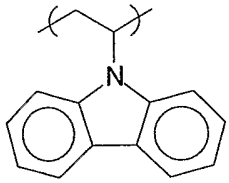
Example II:

poly (4 vinylphenol)



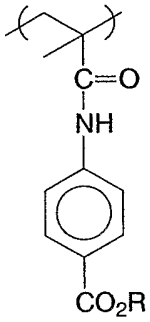
Example III:

poly (N-vinylcarbazole)



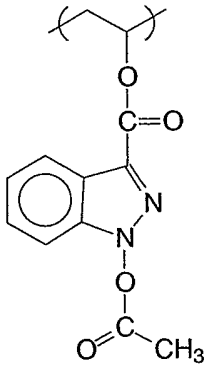
Example IV:

poly(methylcarboxyphenylmethacrylamide)



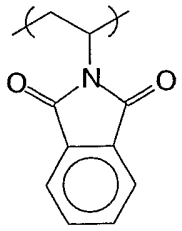
Example V:

poly[(1-acetylindazol-3-ylcarbonyloxy)ethylene]



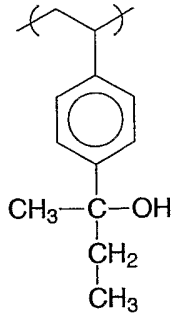
Example VI:

poly(phthalimidoethylene)



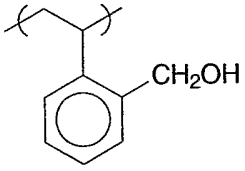
Example VII:

poly(4-(1-hydroxy-1-methylpropyl)styrene)



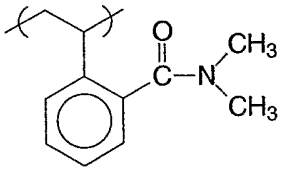
Example VIII:

poly(2-hydroxymethylstyrene)



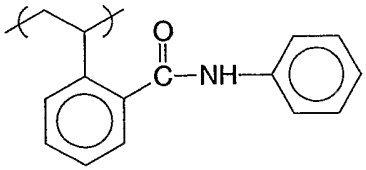
Example IX:

poly(2-dimethylaminocarbonylstyrene)



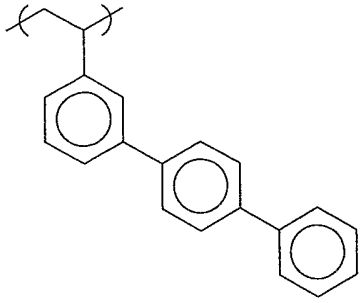
Example X:

poly(2-phenylaminocarbonylstyrene)



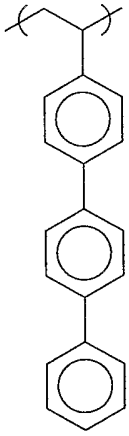
Example XI:

poly(3-(4-biphenylyl)styrene)



Example XII:

poly(4-(4-biphenylyl)styrene)



Another important factor is to obtain finite negative value of S. One way to achieve such negative S values is to solvent coat polymers whose glass transition temperature Tg is greater than 160°C. Such polymers will not have sufficient time to relax upon solvent evaporation and will retain a negative S value.

As alignment of the polymer segment is not thermodynamically controlled, the negative S value is achieved during the coating and drying process. After examinations of various polymers with negative Δn_{int}, the current inventors discovered that only amorphous polymers having a Tg higher than 160C° retain a sufficiently large negative value of S. Thus, the second layers satisfying both relations (2) and (3) can only be obtained from such polymers. These amorphous polymers do not have sufficient time to relax upon solvent evaporation and will

retain a sufficiently large negative S value. The thickness of the coating is preferably less than 30μm, more preferably less than 20μm, and most preferably less than 10μm.

In the compensation film of embodiments of the present invention, other additional first layers can be included. For example, adhesion promotion layer can be disposed between the first and the second layers. Good adhesion between the layers is critical for application, especially in the assembling process of the LCD unit and the use of the LCD in high temperature-humidity environments. Another example of an additional first layer is a barrier layer which prohibits diffusion of the chemical species that have adverse effects on the optical properties of the first and the second layers. For example, the barrier layer may potentially be desired or necessary if the first layer is TAC film. Typically TAC contains low-molecular weight plasticizer to improve mechanical properties. It is often the case that the plasticizer migrates to the second layer, degrades the polymer alignment state and lowers the Δn_{th} (thus Rth). Barrier and/or adhesion layers can be placed between the first layer and the second layer, or between two first layers or two second layers in the case where either is made up of more than one layer. In many cases, a single layer can function as both barrier and adhesion layers. In order to optimize both functionalities, the layer can contain two or more polymers. For example, the layer may contain a water-soluble polymer such as gelatin and a water dispersible polymer such as a polyesteriomonomer. Alternatively, the barrier layer may contain two different water dispersible polymers such as polyesterionomer and polyurethane. The second layer would be directly applied on to the moving carrier by solvent coating.

The Rth of the multilayer compensator is preferably larger than 20nm, or more preferably between 30nm and 300nm, or most preferably between 40nm and 200nm. The thickness of multilayer compensator is preferably less than 250μm, or more preferably less than 200μm, and most preferably between 20μm and 100μm.

FIGS. 5A, 5B and 5C show the schematic cross sections of exemplary compensation films according to the invention. It is noted that relative

dimensions illustrated in the figures may not scale to the actual dimensions of the compensation films.

In the structure shown in FIG. 5A, a single second layer 501 is disposed directly on a single first layer 503. In the compensation film shown in FIG.5B, an additional first layer 505 (such as a barrier layer and/or adhesive layer) is inserted between the second layer 501 and the first layer 503. FIG. 5C is a structure where the second layer is constituted by two layers 501 and 507 disposed on single first layer 503. Those who are skilled in the art can readily conceive other possible structures that are appropriate for individual applications.

FIG. 6 schematically illustrates an LCD 601 using the compensation film according to an embodiment of the present invention. The relative dimensions illustrated in the FIG. 6 may not scale to the actual dimensions of the LCD. The LCD 601 includes pair of crossed polarizers 603 and 611 having transmission axes (or equivalently absorption axes) 605 and 613 forming an angle $90\pm5^{\circ}$, liquid crystal cell 609, and a compensation film 607. The compensation film 607 is placed adjacent to the liquid crystal cell 607 on the side of the polarizer 603. Although not shown, the LCD 601 may optionally include a second compensation film on the side of the polarizer 611.

Compared to prior art compensation films, the compensation film according to the invention can be manufactured with a simple process that does not require use of liquid crystal polymer or any alignment procedure of liquid crystal polymer. Thus, it is free from haze. It does not involve shrinking of the film, application of an electric field to align the polymer segment, or subsequent fine-tuned stretching processes. The invention also enables the use of standard films having $nx > ny \geq nz$ instead of the ones with $nx > nz > ny$ that are difficult to obtain. The compensation films of the invention can be made with much simpler processes, and are suitable for mass manufacturing.

The following specific examples are presented to particularly illustrate the invention and should not be construed to place limitation thereon.

The performance of the exemplary compensation films is measured in terms of an iso-leakage plot of an LCD in the dark state with polar and azimuthal viewing angles. Polar and azimuthal viewing angles are defined

according to FIG. 7A with respect to the LCD 701. The observer 703 views the LCD 701 from the direction specified by the polar viewing angle ϕ and azimuthal viewing angle ξ. The light leakage is measured in terms of % transmission of the LCD in the dark state. As it is in the dark state, the higher performance is yield for lower transmission. The results are plotted in polar plot form as shown in FIG. 7B. The concentric circles correspond to different ϕ (0°, 20°, 40°, 60° and 80°) and radial lines correspond to ξ (=0°, 45°, 90°, 135°, 180°, 225°, 270°, and 315°). Arrows 705 and 707 indicate the directions of increasing ϕ and ξ, respectively.

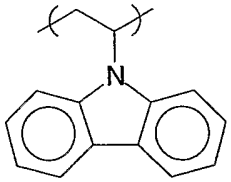
Example 1:

FIG. 7C shows the iso-leakage plot of the LCD including crossed polarizers and IPS mode liquid crystal cell. No compensation film was used. If ϕ is higher than 50°, the leakage exceeds 1% or higher at ξ=45°, 135°, 225° and 315°. Thus, contrast of the IPS-LCD is significantly reduced at these viewing angle ranges.

Example 2:

FIG. 7D shows the iso-leakage plot of crossed polarizers with IPS mode liquid crystal when compensation films were applied. The arrangement is the same as shown in FIG. 6. The compensation film includes one first layer and one second layer. The first layer of the compensation film is a stretched cyclic polyolephin having indices of refraction, nx_1 =1.5316, ny_1 =1.5307 and nz_1 =1.5306 (as measured with an ellipsometer, model M2000V, J.A. Woollam Co. at λ=550nm). Thus $nx_1 > ny_1 > nz_1$, satisfying the above-described relation (1). The thickness of the first layer is 100μm. The second layer is formed by coating the first layer with a solution (15% solids in toluene) of poly(N-vinylcarbazole), (from

Acros Organics). This poly(N-carbazole) is found to have a Tg of 172°C by differential scanning calorimetry (DSC).



The second layer does not show any sign of long-range order. Therefore the layer is determined to be comprised of an amorphous polymer. The indices of refraction of the second layer are measured (by ellipsometry at λ=550nm, model M2000V, J.A. Woollam Co.) to be $nx_2 = 1.690$, $ny_2 = 1.690$ and $nz_2 = 1.710$, which satisfy the above-described relations (2) and (3). The thickness is 8.1μm.

In comparison to FIG. 7C, the leakage is drastically decreased. It is surprising that in the entire viewing angle range ($0^\circ \le \phi \le 80^\circ$, $0^\circ \le \xi < 360^\circ$), the light leakage is less than 0.1%. Thus the contrast ratio of the IPS-LCD is considerably improved.

CLAIMS:

1. A multilayer optical compensation film comprising at least one optically anisotropic first layer and at least one optically anisotropic second layer,

wherein said first layer satisfies the relation:

$$nx_1 \geq ny_1 \geq nz_1$$

wherein said second layer comprises amorphous polymer with a glass transition temperature above 160C°, and satisfies the relations:

$$|nx_2 - ny_2| < 0.001$$

$$nz_2 - (nx_2 + ny_2)/2 > 0.005$$

wherein nx_1, ny_1 and nz_1 are indices of refractions of the first layer in x, y and z directions of the first layer, respectively, and wherein nx_2, ny_2 and nz_2 are indices of refractions of the second layer in x, y and z directions of the second layer, respectively.

2. The film of claim 1, wherein said first or second layer is contiguous to a carrier substrate.

3. The film of claim 1, wherein said first and second layers are contiguous.

4. The film of claim 1, further comprising an intermediate layer between the first and second layers.

5. The film of claim 2, wherein said first or second layers are contiguous to a carrier layer.

6. The film of claim 1, wherein the first layer is optically uniaxial where $|ny_1 - nz_1| < 0.001$.

7. The film of claim 1, wherein the first layer is optically biaxial where $ny_1 > nz_1$.

8. The film of claim 1, wherein the first layer is a material selected from the group consisting of triacetylcellulose (TAC), cellulose diacetate, cellulose acetate butylate (CAB), cyclic polyolefin, polycarbonate, polysulfonate,polynorbornene, glass , and combinations thereof.

9. The film of claim 1, wherein an in-plane retardation Rin of said at least one first layer is between 0nm and 300nm.

10. The film of claim 1, wherein an in-plane retardation Rin of said at least one first layer is between 10nm and 275nm.

11. The film of claim 1, wherein a thickness of said at least one first layer is between 5μm and 100μm.

12. The film of claim 1, wherein a thickness of said at least one first layer is between 20μm and 100μm.

13. The film of claim 1, wherein Δn_{int} and S of said amorphous polymer are both negative, where Δn_{int} is an intrinsic birefringence of the amorphous polymer and S is an order parameter of a polymer segment of the amorphous polymer.

14. The film of claim 13, wherein $-0.5 < S < 0$.

15. The film of claim 1, wherein a non-visible chromophore group is off of the backbone of said amorphous polymer.

16. The film of claim 15, wherein said amorphous polymer contains off the backbone a vinyl, carbonyl, amide, imide, ester, carbonate, aromatic, sulfone, or azo group.

17. The film of claim 15, wherein the non-visible chromophore group includes a carbonyl, amide, imide, ester, carbonate, phenyl, naphthyl, biphenyl, bisphenol, or thiophene group.

18. The film of claim 15, wherein the non-visible chromophore group includes a heterocyclic or carbocyclic aromatic group.

19. The film of claim 1, wherein said amorphous polymer is one selected from the group consisting of (A) poly (4 vinylphenol), (B) poly (4 vinylbiphenyl), (C) poly (N-vinylcarbazole), (D) poly(methylcarboxyphenylmethacrylamide), (E) poly[(1-acetylindazol-3-ylcarbonyloxy)ethylene], (F) poly(phthalimidoethylene), (G) poly(4-(1-hydroxy-1-methylpropyl)styrene), (H) poly(2-hydroxymethylstyrene), (I) poly(2-dimethylaminocarbonylstyrene), J) poly(2-phenylaminocarbonylstyrene), (K) poly(3-(4-biphenylyl)styrene), (L) poly(4-(4-biphenylyl)styrene), (M) poly(4-cyanophenyl methacrylate), (N) poly(2,6-dichlorostyrene), (O) poly(perfluorostyrene), (P) poly(2,4-diisopropylstyrene), (Q) poly(2,5-diisopropylstyrene), and (R) poly(2,4,6-trimethylstyrene)or (S) copolymers of any two or more of the foregoing.

20. The film of claim 19, wherein the first layer is a polymer selected from the group consisting of triacetylcellulose (TAC), cellulose diacetate, cellulose acetate butylate (CAB), cyclic polyolefin, polycarbonate, polysulfonate, or polynorbornene.

21. The film of claim 1, wherein a thickness of said at least one second layer is less than 30μm.

22. The film of claim 1, wherein a thickness of said at least one second layer is less than 20μm.

23. The film of claim 1, wherein a thickness of said at least one second layer is less than 10μm.

24. The film of claim 1, wherein an out-of-plane retardation Rth of the multilayer optical compensation film is greater than 20nm.

25. The film of claim 1, wherein an out-of-plane retardation Rth of the multilayer optical compensation film is between 30nm and 300nm.

26. The film of claim 1, wherein an out-of-plane retardation Rth of the multilayer optical compensation film is between 40nm and 200nm.

27. A liquid crystal (LC) display comprising a liquid crystal cell, first and second crossed polarizers located on opposite sides of the cell, and at least one multilayer optical compensation film located between the first polarizer and the cell, wherein the optical compensation film comprises at least one optically anisotropic first layer and at least one optically anisotropic second layer,

wherein said first layer satisfies the relation:

$$nx_1 \geq ny_1 \geq nz_1$$

wherein said second layer comprises amorphous polymer with a glass transition temperature above 160C°, and satisfies the relations:

$$|nx_2 - ny_2| < 0.001$$

$$nz_2 - (nx_2 + ny_2)/2 > 0.005$$

wherein nx_1, ny_1 and nz_1 are indices of refractions of the first layer in x, y and z directions of the first layer, respectively, and wherein nx_2, ny_2 and nz_2 are indices of refractions of the second layer in x, y and z directions of the second layer, respectively.

28. The display of claim 27, wherein said amorphous polymer is one selected from the group consisting of (A) poly (4 vinylphenol), (B) poly (4 vinylbiphenyl), (C) poly (N-vinylcarbazole), (D) poly(methylcarboxyphenylmethacrylamide), (E) poly[(1-acetylindazol-3-ylcarbonyloxy)ethylene], (F) poly(phthalimidoethylene), (G) poly(4-(1-hydroxy-1-methylpropyl)styrene), (H) poly(2-hydroxymethylstyrene), (I) poly(2-dimethylaminocarbonylstyrene), J) poly(2-phenylaminocarbonylstyrene), (K) poly(3-(4-biphenylyl)styrene), (L) poly(4-(4-biphenylyl)styrene), (M) poly(4-cyanophenyl methacrylate), (N) poly(2,6-dichlorostyrene), (O) poly(perfluorostyrene), (P) poly(2,4-diisopropylstyrene), (Q) poly(2,5-diisopropylstyrene), and (R) poly(2,4,6-trimethylstyrene)or (S) copolymers of any two or more of the foregoing.

29. The display of claim 28, wherein the first layer is a polymer selected from the group consisting of triacetylcellulose (TAC), cellulose diacetate, cellulose acetate butylate (CAB), cyclic polyolefin, polycarbonate, polysulfonate, or polynorbornene.

30. The display of claim 27, wherein the liquid crystal cell is arranged in In-Plane Switching mode.

31. The display of claim 27, further comprising another multilayer compensation film located between the second polarizer and the cell.

32. A process for forming a multilayer optical compensation film, comprising coating at least one second layer in a solvent onto at least one first layer,

wherein said first layer satisfies the relation:

$$nx1 \geq ny_1 \geq nz_1$$

wherein said second layer comprises amorphous polymer with a glass transition temperature above 160C°, and satisfies the relations:

$$|nx_2-ny_2|<0.001$$

$$nz_2-(nx_2+ny_2)/2 > 0.005$$

wherein nx_1, ny_1 and nz_1 are indices of refractions of the first layer in x, y and z directions of the first layer, respectively, and wherein nx_2, ny_2 and nz_2 are indices of refractions of the second layer in x, y and z directions of the second layer, respectively.

33. The process of claim 32, wherein the second layer is coated directly onto the first layer such that the first and second layers are contiguous.

34. The process of claim 32, wherein the second layer is coated onto an intermediate layer formed on the first layer.

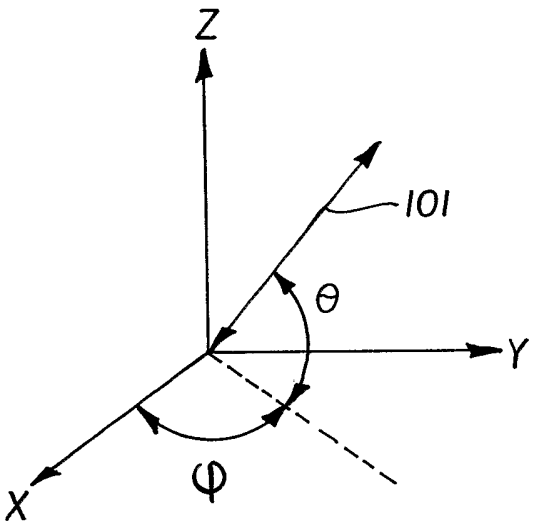


FIG. 1

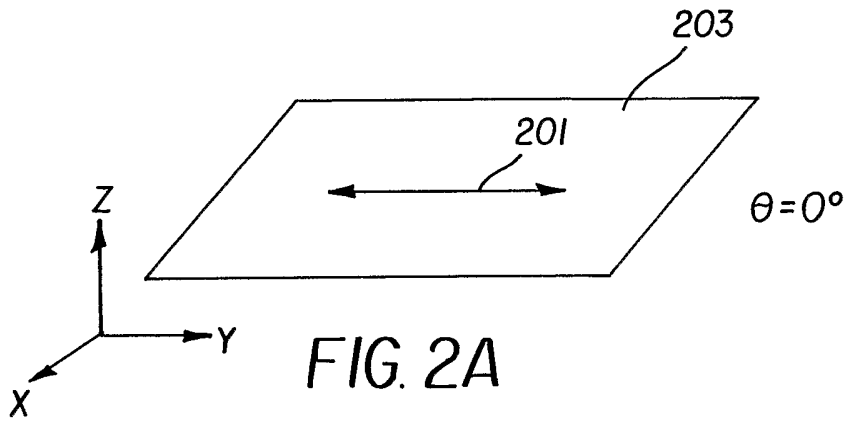


FIG. 2A

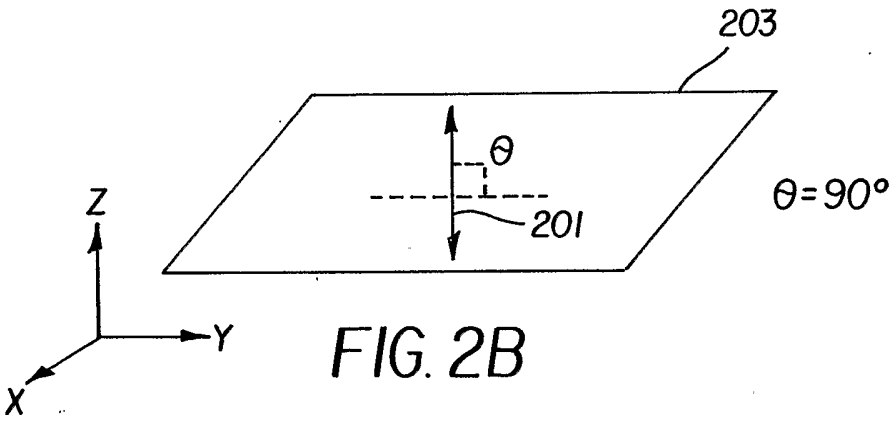


FIG. 2B

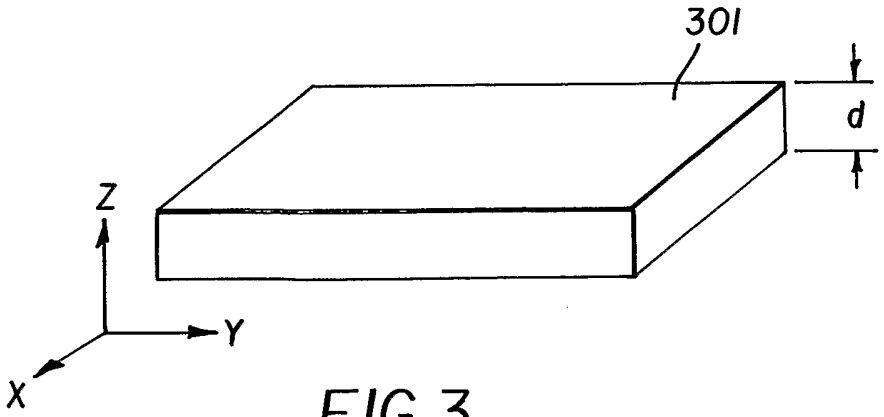


FIG. 3

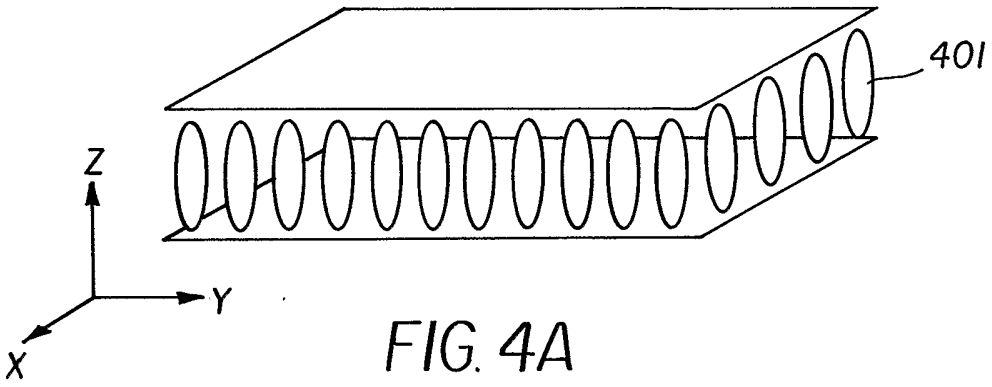


FIG. 4A

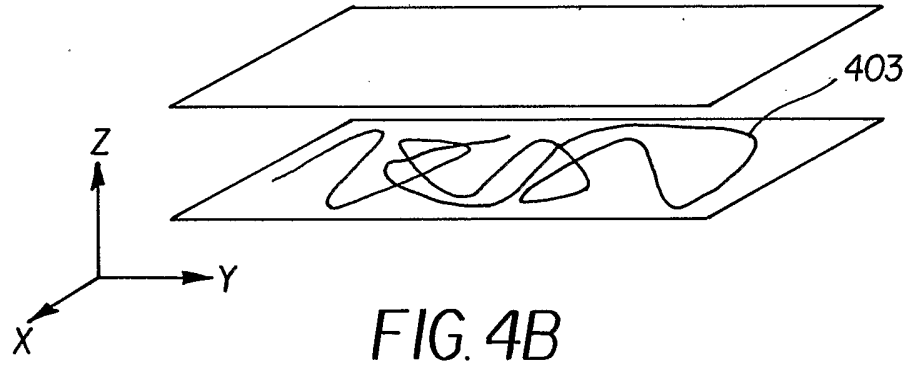


FIG. 4B

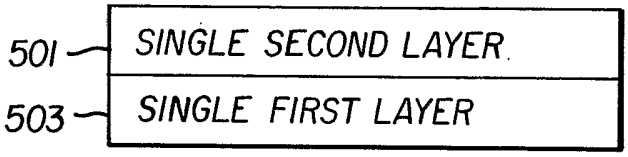


FIG. 5A

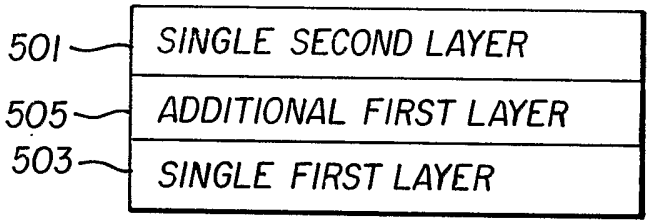


FIG. 5B

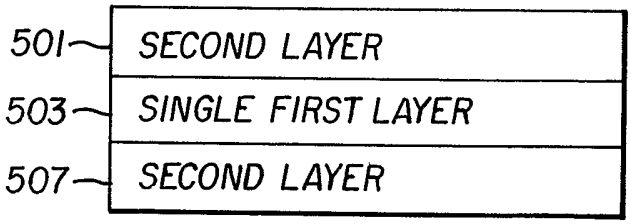


FIG. 5C

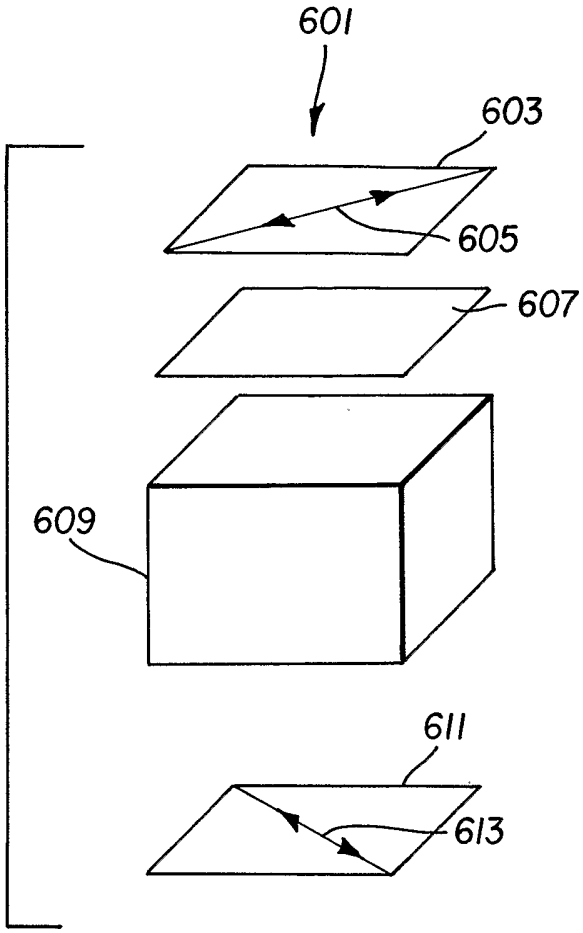


FIG. 6

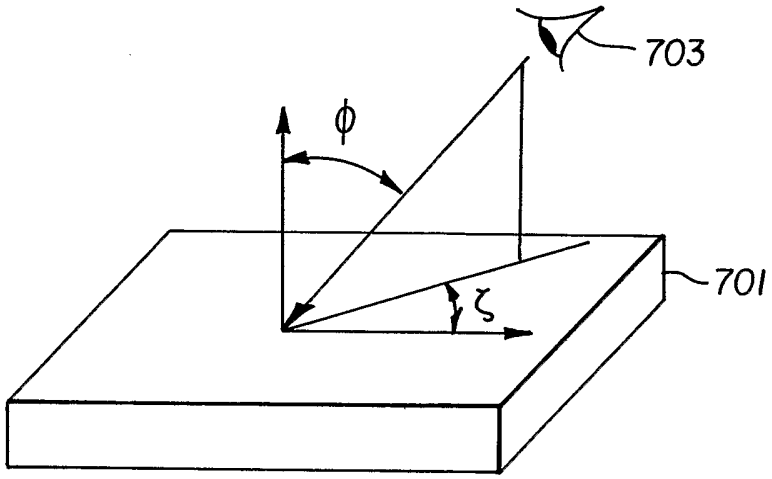


FIG. 7A

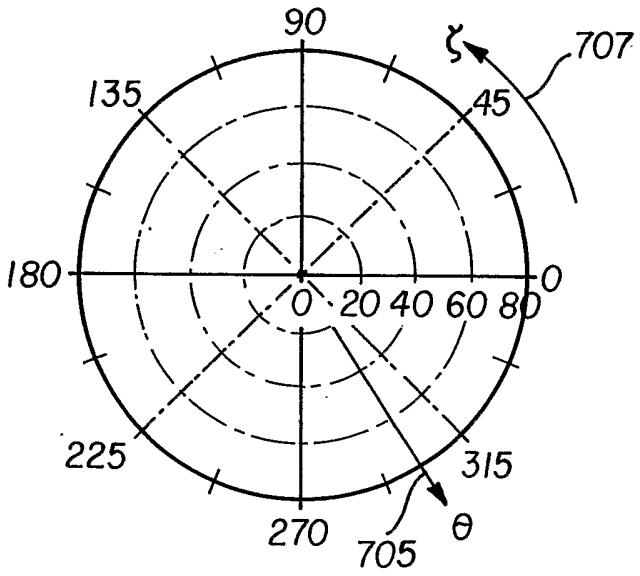


FIG. 7B

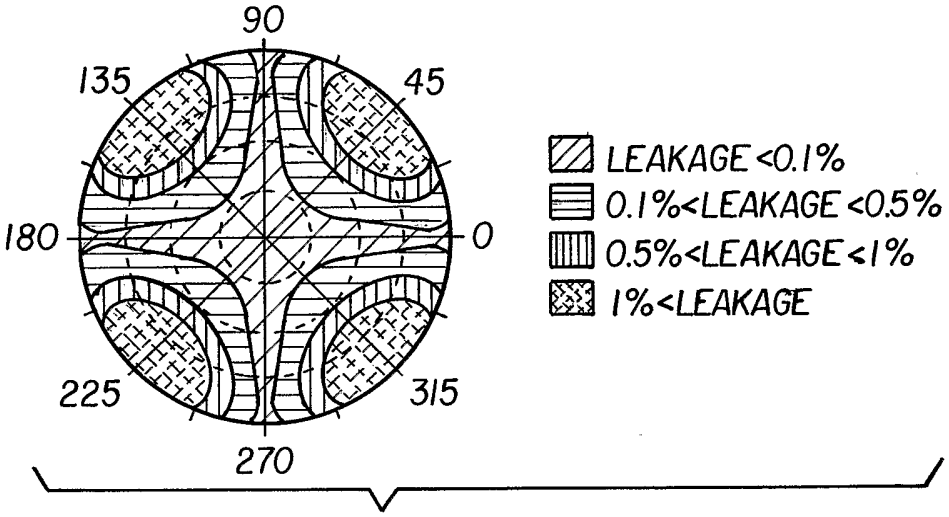

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FIG. 7C

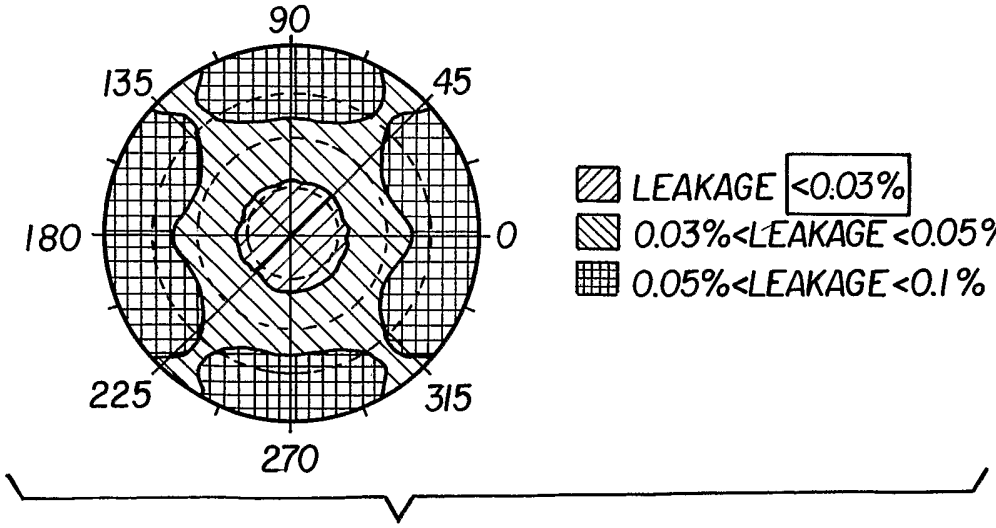

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FIG. 7D

INTERNATIONAL SEARCH REPORT

PCT/US2005/019136

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G02F1/13363 G02B5/30

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G02F G02B

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

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal, WPI Data, PAJ, INSPEC, COMPENDEX, IBM-TDB

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 2004/042461 A (MERCK PATENT GMBH; SKJONNEMAND, KARL) 21 May 2004 (2004-05-21) figures 1,7a-7d page 3, line 28 - line 32 page 12, line 1 - line 27 page 16, line 19 - page 17, line 9 page 17, line 28 - page 18, line 35 page 22, line 1 - line 13 table 1	1-34
P,Y	US 2004/223103 A1 (ELMAN JAMES F) 11 November 2004 (2004-11-11) abstract figures 1a-4b paragraph '0032! - paragraph '0050! paragraph '0053! - paragraph '0088!	1-34

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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

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

"T" later document published 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

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
26 September 2005	06/10/2005

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Kentischer, F

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INTERNATIONAL SEARCH REPORT

PCT/US2005/019136

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	US 5 699 136 A (ARAKAWA ET AL) 16 December 1997 (1997-12-16) column 5, line 21 - column 6, line 29 figures 4a,4b -----	13, 15-19,28

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