

Description

The invention relates to an improved arrangement and method for illuminating a liquid crystal cell in a display to provide larger viewing angles.

A liquid crystal display includes a liquid crystal cell and means for illuminating the cell. The liquid crystal cell typically includes a pair of light transmissive substrates with an optically anisotropic liquid crystal material therebetween. The surfaces of each substrate which face the liquid crystal typically have thereon patterned light transmissive electrodes and are also treated, typically by rubbing or by slant evaporation of a dielectric material, to preferentially align the liquid crystal material adjacent to the surfaces.

The properties of the liquid crystal with its long range order are like those of a uniaxial crystal and are described by a director, a unit vector defined as the local average direction of the molecules. The orientation of the director adjacent to a treated surface is typically in the direction of the rubbing or towards the evaporation source. The director may also have a tilt bias, that is, an angle between the director and the substrate surface depending upon the technique used to provide the orientation.

In a twisted nematic cell the substrate and the nematic liquid crystal are typically assembled so that the directors adjacent to the two surfaces are at a non-zero angle, preferably at a right angle, to one another. The liquid crystal between the plates then adjusts so that the director rotates uniformly from the orientation at one surface to that at the other surface. Light polarized parallel or perpendicular to the director at one surface undergoes an optical rotation in passing through the liquid crystal with its plane of polarization being rotated by the twist angle. Plane polarizers oriented parallel to the projection of the director onto each substrate surface will then provide substantially complete transmission of the incident polarized light. Application of a voltage greater than the threshold voltage between the electrodes will cause the director to tilt toward the direction perpendicular to the substrate surfaces, the homeotropic alignment, thereby reducing the optical rotation and causing the light transmission, in the ideal case, to decrease towards zero. The converse of this polarizer arrangement, namely parallel polarizers provides an increase in the transmitted light with applied voltage.

For a small area, essentially personal display the required viewing angle is small. However, in a larger area display, such as a television display, wider viewing angles are desirable in both the vertical and, particularly, in the horizontal plane, relative to the display normal. However, with known techniques the useful range of viewing angles is limited because light rays passing through the cell

at different angles experience differing optical birefringence. In particular, the electro-optic curve, which describes the change in the transmitted light as a function of applied voltage, varies with viewing angle. Light transmission through a picture element (pixel) and thus its grey scale then varies with viewing angle. In the extreme case a contrast reversal is observed with varying viewing angle.

One approach to providing this wider viewing angle is to illuminate the cell with highly collimated light in both the vertical and horizontal planes. A two-dimensional diffuser is then positioned between the cell and the viewer to diffuse the transmitted collimated light, as disclosed in U.S. Patent No. 4,171,874. This approach is undesirable in many applications since the light source must be substantially a point source with its resulting low illuminance or high energy consumption. Alternatively, a line source, such as a fluorescent tube, which provides a point source in one plane and an uncollimated, substantially Lambertian source in the perpendicular plane has been used. This source provides a higher luminance and can be collimated in one plane. The cell typically is illuminated with the light polarized parallel to the director at the light entry surface, collimated in the vertical plane and uncollimated in the horizontal plane. An image displayed on this cell, however, can be viewed only over a limited range of angles in the plane of uncollimated illumination because of the birefringence effects described above.

Thus it would be desirable to have a liquid crystal display having a wide viewing angle, particularly in the horizontal plane which is greater than that presently available.

The invention is an improved arrangement for illuminating a liquid crystal cell which provides a significant increase in the range of viewing angles in a plane orthogonal to the principal viewing plane, the principal viewing plane being defined as the plane containing the director at the midpoint of the liquid crystal and the normal to the light entry surface. The improvement comprises means for illuminating the cell having a substantially collimated beam in the principal viewing plane and a substantially uncollimated beam in the orthogonal plane. Preferably, the thickness of the liquid crystal in the cell corresponds to the first Gooch-Tarry minimum.

The invention is also a method for providing a wide viewing angle for a liquid crystal display comprising the step of illuminating a liquid crystal cell with a beam of light which is substantially collimated in the principal viewing plane and which is substantially uncollimated in an orthogonal plane.

In the accompanying drawings:

FIG. 1 is a block diagram of a liquid crystal display.

FIG. 2 is a cross-sectional view of a liquid crystal cell.

FIG. 3 is a perspective view of the liquid crystal cell illustrating the orientation of the director in the cell.

FIG. 4 is a cross-sectional view of a means for illuminating the cell.

FIG. 5 illustrates the orientation of a light ray transmitted by the cell relative to the coordinate system of FIG. 3.

FIG. 6 is a graph of the electro-optic curve in the plane orthogonal to the principal viewing plane at different viewing angles for a cell thickness corresponding to the first Gooch-Tarry minimum.

FIG. 7 is a graph of the electro-optic curve in the principal viewing plane at different viewing angles for a cell thickness corresponding to the first Gooch-Tarry minimum.

FIG. 8 is a graph of the electro-optic curve in the plane orthogonal to the principal viewing plane at different viewing angles for a cell thickness corresponding to the second Gooch-Tarry minimum.

In the FIGURES corresponding elements have the same numerical identification.

In FIG. 1 a liquid crystal display 10 includes a liquid crystal cell 12 with means 14 positioned adjacent the cell for illuminating the cell in transmission for a viewer 16 through means 17 for diffusing the transmitted light. Means 18 for applying a pattern of electrical signals to modulate the transmitted light corresponding to an image to be displayed thereon are attached to the cell 12.

In FIG. 2 the cell 12 includes a first substrate 20 having first and second major surfaces 22 and 24, respectively, and a second substrate 26 having first and second major surfaces 28 and 30, respectively. A first electrode structure 32 overlies the first major surface 22 of the first substrate 20 and a first alignment layer 34 overlies the structure 32. A second electrode structure 36 overlies the first major surface 28 of the second substrate 26 and a second alignment layer 38 overlies the structure 36. A liquid crystal 40 fills the space between the alignment layers 34 and 38 and a sealant 42 contains the liquid crystal between the substrates 20 and 26. Means 44 for polarizing light incident on the second major surface 24 of the first substrate 20 and means 46 for analyzing the polarized light transmitted through the second substrate 26 are attached to the second major surfaces 24 and 30, respectively. The means 44 and 46 are typically sheet polarizers. Spacers typically used to maintain a uniform spacing between the substrates are not shown.

In FIG. 3 the orientation of the director between the substrates 20 and 26 varies along an optical

axis 50 which is collinear with a normal 52 to the second major surface 30. Typically the directors 54 and 56 adjacent the first and second substrates 20 and 26, respectively, are oriented at 90° to one another with the midpoint director 58 being oriented halfway between the orientation of the directors 54 and 56 adjacent the surfaces. The principal viewing plane is defined as the plane containing the midpoint director 58 and the normal 52. The plane of constant electro-optic response is orthogonal to the principal viewing plane and is defined as the plane containing the normal 52 and a line perpendicular to both the midpoint director 58 and the normal 52. The illumination means 14 is positioned so that the light incident on the second major surface 24 is substantially uncollimated in the plane of constant electro-optic response. Light incident on the second major surface 24 is preferably polarized either parallel or perpendicular to the director 54 adjacent the first substrate 20 and the analyzing means 46 are preferably oriented to transmit light polarized at 0° or 90° to the polarization of the incident light.

The substrates 20 and 26 are typically composed of a material such as glass which is substantially transparent in the visible wavelength spectrum. The electrode structures 32 and 38 are well-known in the art and are typically composed of tin oxide or indium tin oxide about 100 nanometers (nm) thick which are transparent in the visible wavelength spectrum and which may be deposited by evaporation, sputtering or chemical vapor deposition. These layers are patterned to form the electrodes of individual pixels. The structures 32 and 38 include any associated conductive lines necessary to address the individual pixels and may also include active elements such as diodes, transistors and capacitors used in active addressing of a pixel as disclosed, for example, by Mao in U.S. Patent No. 3,653,745 and by Marlowe et al. in U.S. Patent No. 3,654,606, both of which are incorporated herein by reference. Preferably these active elements are small so as to maintain a high optical transmission through the display. The first and second electrode structures 32 and 38 comprise means for modulating the transmission of the liquid crystal 40 in response to a pattern of electrical signals applied thereto. The alignment layers 34 and 38 are preferably composed of a polyimide material about 100 nm thick deposited by spin coating followed by thermal curing. This material is typically treated by rubbing with a cloth in the desired alignment direction.

The liquid crystal is typically a nematic material having a positive dielectric anisotropy and containing a small amount of a cholesteric liquid crystal to insure uniform twist. Preferably a material such as Type No. ZLI-1800-000 or ZLI-2293

nematic material, manufactured by E. Merck, Inc., Darmstadt, Republic of Germany, is used. The liquid crystal is loaded into the cell and the director adjacent the substrate surfaces aligned using techniques well known in the art.

The transmission T , through a cell with a 90° twist angle and parallel polarizers, as disclosed, for example, by Gooch et al. in *Electronics Letters*, 10, 2 (1974) is:

$$T = \frac{\sin^2 \frac{\pi}{2} (1 + x^2)^{\frac{1}{2}}}{(1 + x^2)}$$

where $x = 2d\Delta n/\lambda$, d is the material thickness, Δn is the difference in the principal refractive indices and λ is the wavelength. The transmission of the cell is an oscillatory function of the liquid crystal thickness. This thickness is typically chosen to correspond to a minimum in the transmission of light through the cell. In particular, a thickness corresponding to the first Gooch-Tarry minimum in the transmission is preferred. This preferred thickness d is $0.87 \lambda/\Delta n$. Typically the thickness is chosen to correspond to the first minimum for a wavelength between 400 and 700 nm. For illumination with a band of wavelengths the wavelength at about the center of the band is preferably used to determine the thickness. Alternatively, the different elements of a pixel corresponding to the different primary colors may have different thicknesses corresponding to the first Gooch-Tarry minimum at the wavelength of the particular primary color.

The means for illuminating the cell 12 provides a beam of light which is substantially collimated, typically having a divergence half-angle of about 30° or less and preferably less than 15° in one plane, and substantially uncollimated, typically having a divergence half-angle greater than about 45° and preferably approximating a Lambertian distribution, in the orthogonal plane. The divergence half-angle is defined as the angle from the center of symmetry of the light beam to its half intensity point. In FIG. 4 a suitable means 14 for illuminating the cell 12 includes a light source 62 mounted in a parabolic reflector 64. The light source 62 is typically a line source such as a fluorescent tube. The parabolic reflector 64 is shaped such that the emitted light is substantially collimated in the plane of FIG. 4 and substantially uncollimated in the orthogonal plane.

The means 17 for diverging the substantially collimated light in the principal viewing plane is typically a cylindrical lenticular screen typically having a pitch of about 50 micrometers (μm) and a

full half-circle depth. The closer the screen is placed to the cell 12, the less it will degrade the resolution of the display 10.

It has been found that, when the incident light is substantially collimated in the principal viewing plane and substantially uncollimated in the orthogonal plane, as described with reference to FIG. 3, the electro-optic curve is substantially constant over a wide range of viewing angles in this orthogonal plane. In FIG. 5 the viewing angles θ and ϕ for a light ray 70 are defined relative to a normal 52 and the orientation of a midpoint director 58. Preferably the collimated light beam in the principal viewing plane is substantially perpendicular to the light entry surface but may be at an angle to this surface. The effect of a non-normal incidence is to shift the electro-optic curve in voltage.

The electro-optic curves were measured on a cell with a Merck ZLI-1800-000 nematic liquid crystal having a refractive index anisotropy $\Delta n = 0.08$ with a 90° twist angle and a thickness of 6 or $13.5 \mu\text{m}$ corresponding approximately to the first and second Gooch-Tarry minima, respectively, at a wavelength of 550 nm. The transmission through crossed polarizers of an incandescent light source was measured at different viewing angles using a detector having an angular resolution less than $\pm 2^\circ$.

In FIG. 6 the electro-optic curve in the orthogonal plane (ϕ equal to 90° and 270° as defined in FIG. 5) is substantially the same up to a polar angle θ of about 45° for a cell having a thickness of $6 \mu\text{m}$. At polar angles θ of 60° and 70° the curves are displaced to slightly lower voltages. For all viewing angles the electro-optic curve is symmetrical about the principal viewing plane. In FIG. 7 the electro-optic curve for the same cell in the principal viewing plane (ϕ equal to 0° and 180° as defined in FIG. 5) changes markedly with the polar angle θ , exhibiting a greater variation for a 15° change in polar angle θ than a 70° change produced in the orthogonal plane and is also asymmetrical about the orthogonal plane.

In FIG. 8 the electro-optic curve for a cell having a thickness of $13.5 \mu\text{m}$ shows a variation with polar angle θ which is significantly greater than that for a first minimum cell in the orthogonal direction but which is still much less than that observed in the principal viewing plane for a first Gooch-Tarry minimum cell.

While the principles of the invention have been described in terms of particular embodiments, it is to be understood that the invention is not limited to the details contained therein. In particular the principles of the invention are applicable to twist angles other than 90° and to polarizer orientations other than parallel or perpendicular to the director adjacent the light entry surface. For example, a cell

having a 0° twist with the polarizers oriented at 45° to the director is useful.

Claims

1. A liquid crystal display including a liquid crystal cell and means for illuminating said cell, said cell comprising:
 - first and second light transmissive substrates, each having first and second major surfaces, said substrates being disposed such that said first major surfaces face one another and said second surface of said first substrate is the light entry surface for illumination of the cell;
 - electrode structures on said first major surfaces;
 - a liquid crystal between said substrates, said liquid crystal being a twisted nematic material having a director oriented in one direction adjacent the first substrate and in an orthogonal direction adjacent the second substrate, said cell having a principal viewing plane which contains the midpoint director and a normal to one of said second major surfaces, and having a thickness between said substrates corresponding to the first Gooch-Tarry minimum for said cell at a wavelength between about 400 and 700 nanometers;
 - characterized in that
 - said means for illuminating said cell provides an output beam which is substantially collimated in said principal viewing plane and which is substantially uncollimated in an orthogonal plane which is substantially perpendicular to said principal viewing plane and contains said normal.
2. A display as in Claim 1, characterized in that the angular distribution of the uncollimated light in said orthogonal plane is substantially Lambertian.
3. A display as in Claim 2, characterized in that said means for illuminating said cell comprises:
 - a light source positioned to illuminate said liquid crystal through said first substrate;
 - means for polarizing light incident on said first substrate; and
 - means for analyzing the polarized light transmitted through said cell.
4. A display as in Claim 3, further characterized by means for diffusing said substantially collimated light beam in the principal viewing plane for passage through said cell.

5. A display as in any preceding Claim, further characterized by means for applying to said electrode structures a pattern of electrical signals corresponding to an image to be displayed.

6. A method for illuminating a liquid crystal cell comprising a liquid crystal between electrode structures on the surfaces of first and second substrates; said liquid crystal being a twisted nematic material having a director oriented in one direction adjacent the first substrate and in an orthogonal direction adjacent the second substrate, and said cell having a principal viewing plane which contains the midpoint director of the liquid crystal and a normal to a major surface of one of said substrates and having a thickness corresponding to the first Gooch-Tarry minimum for said cell at a wavelength between about 400 and 700 nanometers;

said method characterized by the step of illuminating said cell with a beam of light which is substantially collimated in said principal viewing plane and which is substantially uncollimated in an orthogonal plane which is substantially perpendicular to said principal viewing plane and contains said normal.

Revendications

1. Un affichage à cristaux liquides comprenant une cellule de cristal liquide et un moyen pour éclairer ladite cellule,
 - ladite cellule comprenant :
 - des premier et second substrats transmetteurs de lumière, ayant chacun des première et seconde surfaces principales, lesdits substrats étant disposés de telle sorte que les premières surfaces principales soient l'une en face de l'autre et la seconde surface du premier substrat soit la surface d'entrée de lumière pour l'éclairage de la cellule;
 - des structures à électrodes sur les premières surfaces principales;
 - un cristal liquide entre lesdits substrats, le cristal liquide étant un matériau nématique tordu ayant un directeur orienté dans une direction adjacent au premier substrat et dans une direction orthogonale adjacent au second substrat, ladite cellule ayant un plan d'observation principal qui contient le directeur de point milieu et une normale à l'une des secondes surfaces principales, et ayant une épaisseur entre lesdits substrats correspondant au premier minimum de Gooch-Tarry pour ladite cellule à une longueur d'onde entre environ 400 et 700 nanomètres;
 - caractérisé en ce que

having a 0° twist with the polarizers oriented at 45° to the director is useful.

Claims

1. A liquid crystal display including a liquid crystal cell and means for illuminating said cell, said cell comprising:

first and second light transmissive substrates, each having first and second major surfaces, said substrates being disposed such that said first major surfaces face one another and said second surface of said first substrate is the light entry surface for illumination of the cell;

electrode structures on said first major surfaces;

a liquid crystal between said substrates, said liquid crystal being a twisted nematic material having a director oriented in one direction adjacent the first substrate and in an orthogonal direction adjacent the second substrate, said cell having a principal viewing plane which contains the midpoint director and a normal to one of said second major surfaces, and having a thickness between said substrates corresponding to the first Gooch-Tarry minimum for said cell at a wavelength between about 400 and 700 nanometers;

characterized in that

said means for illuminating said cell provides an output beam which is substantially collimated in said principal viewing plane and which is substantially uncollimated in an orthogonal plane which is substantially perpendicular to said principal viewing plane and contains said normal.

2. A display as in Claim 1, characterized in that the angular distribution of the uncollimated light in said orthogonal plane is substantially Lambertian.

3. A display as in Claim 2, characterized in that said means for illuminating said cell comprises:

a light source positioned to illuminate said liquid crystal through said first substrate;

means for polarizing light incident on said first substrate; and

means for analyzing the polarized light transmitted through said cell.

4. A display as in Claim 3, further characterized by means for diffusing said substantially collimated light beam in the principal viewing plane for passage through said cell.

5. A display as in any preceding Claim, further characterized by means for applying to said electrode structures a pattern of electrical signals corresponding to an image to be displayed.

6. A method for illuminating a liquid crystal cell comprising a liquid crystal between electrode structures on the surfaces of first and second substrates, said liquid crystal being a twisted nematic material having a director oriented in one direction adjacent the first substrate and in an orthogonal direction adjacent the second substrate, and said cell having a principal viewing plane which contains the midpoint director of the liquid crystal and a normal to a major surface of one of said substrates and having a thickness corresponding to the first Gooch-Tarry minimum for said cell at a wavelength between about 400 and 700 nanometers;

said method characterized by the step of illuminating said cell with a beam of light which is substantially collimated in said principal viewing plane and which is substantially uncollimated in an orthogonal plane which is substantially perpendicular to said principal viewing plane and contains said normal.

Revendications

1. Un affichage à cristaux liquides comprenant une cellule de cristal liquide et un moyen pour éclairer ladite cellule,

ladite cellule comprenant :

des premier et second substrats transmetteurs de lumière, ayant chacun des première et seconde surfaces principales, lesdits substrats étant disposés de telle sorte que les premières surfaces principales soient l'une en face de l'autre et la seconde surface du premier substrat soit la surface d'entrée de lumière pour l'éclairage de la cellule;

des structures à électrodes sur les premières surfaces principales;

un cristal liquide entre lesdits substrats, le cristal liquide étant un matériau nématique tordu ayant un directeur orienté dans une direction adjacent au premier substrat et dans une direction orthogonale adjacent au second substrat, ladite cellule ayant un plan d'observation principal qui contient le directeur de point milieu et une normale à l'une des secondes surfaces principales, et ayant une épaisseur entre lesdits substrats correspondant au premier minimum de Gooch-Tarry pour ladite cellule à une longueur d'onde entre environ 400 et 700 nanomètres;

caractérisé en ce que



ledit moyen pour éclairer ladite cellule produit un faisceau de sortie qui est sensiblement collimaté dans le plan d'observation principal et qui est sensiblement non collimaté dans un plan orthogonal qui est sensiblement perpendiculaire au plan d'observation principal et qui contient ladite normale.

2. Un affichage selon la revendication 1, caractérisé en ce que la distribution angulaire de la lumière non collimatée dans le plan orthogonal précité est sensiblement de Lambertian.
3. Un affichage selon la revendication 2, caractérisé en ce que le moyen précité pour éclairer la cellule précitée comprend :
 - une source de lumière positionnée pour éclairer le cristal liquide précité à travers le premier substrat précité;
 - un moyen pour polariser la lumière incidente au premier substrat; et
 - un moyen pour analyser la lumière polarisée transmise à travers la cellule.
4. Un affichage selon la revendication 3, caractérisé de plus par un moyen pour diffuser le faisceau de lumière sensiblement collimaté précité dans le plan d'observation principal pour passage à travers la cellule précitée.
5. Un affichage selon l'une des revendications précédentes, caractérisé de plus par un moyen pour appliquer aux structures à électrodes précitées un motif de signaux électriques correspondant à une image à visualiser.
6. Un procédé pour éclairer une cellule de cristal liquide comprenant un cristal liquide entre des structures à électrodes sur les surfaces de premier et second substrats, le cristal liquide étant un matériau nématique tordu ayant un directeur orienté dans une direction adjacent au premier substrat et dans une direction orthogonale adjacent au second substrat, et la cellule ayant un plan principal d'observation qui contient le directeur de point milieu du cristal liquide et une normale à une surface principale de l'un desdits substrats et ayant une épaisseur correspondant au premier minimum de Gooch-Tarry pour ladite cellule à une longueur d'onde entre environ 400 et 700 nanomètres;

ledit procédé caractérisé par l'étape d'éclairer ladite cellule par un faisceau de lumière qui est sensiblement collimaté dans le plan d'observation principal et qui est sensiblement non collimaté dans un plan orthogonal qui est sensiblement perpendiculaire au plan

d'observation principal et qui contient ladite normale.

Patentansprüche

1. Flüssigkristallanzeige mit einer Flüssigkristallzelle und einer Vorrichtung zum Beleuchten der Zelle,
 - wobei die Zelle ein erstes und ein zweites lichtdurchlässiges Substrat, die jeweils eine erste und eine zweite Hauptfläche aufweisen und so angeordnet sind, daß die ersten Hauptflächen einander zugewandt sind und die zweite Fläche des ersten Substrats die Lichteintrittsfläche für die Beleuchtung der Zelle ist;
 - Elektrodenstrukturen auf den ersten Hauptflächen;
 - einen Flüssigkristall zwischen den Substraten, der ein verdrehtes nematisches Material mit einem Direktor, der beim ersten Substrat in einer bestimmten Richtung und beim zweiten Substrat in einer orthogonalen Richtung orientiert ist, wobei die Zelle eine Hauptbetrachtungsebene hat, die den Mittelpunkt-Direktor und eine Normale zu einer der zweiten Hauptflächen enthält, und zwischen den Substraten eine Dicke entsprechend dem ersten Gooch-Tarry-Minimum für die Zelle bei einer Wellenlänge zwischen etwa 400 und 700 Nanometern hat, aufweist,
 - dadurch gekennzeichnet, daß
 - die Vorrichtung zum Beleuchten der Zelle ein Ausgangsbündel liefert, welches in der Hauptbetrachtungsebene im wesentlichen kollimiert ist und welches in einer orthogonalen Ebene, die im wesentlichen senkrecht zu der Hauptbetrachtungsebene ist und die Normale enthält, im wesentlichen unkollimiert ist.
2. Anzeige nach Anspruch 1, dadurch gekennzeichnet, daß die Winkelverteilung des unkollimierten Lichtes in der orthogonalen Ebene im wesentlichen lambertisch ist.
3. Anzeige nach Anspruch 2, dadurch gekennzeichnet, daß die Vorrichtung zum Beleuchten der Zelle
 - eine Lichtquelle, die zur Beleuchtung des Flüssigkristalls durch das erste Substrat hindurch positioniert ist;
 - eine Einrichtung zum Polarisieren von auf das erste Substrat fallendem Licht, und
 - eine Einrichtung zum Analysieren des polarisierten Lichtes, das durch die Zelle hindurchgetreten ist,
 - enthält.
4. Anzeige nach Anspruch 3, weiterhin gekenn-



zeichnet durch eine Einrichtung zum Diffus-
machen des im wesentlichen kollimierten
Lichtbündels in der Hauptbetrachtungsebene
für das Hindurchtreten durch die Zelle.

5. Anzeige nach einem der vorhergehenden An-
sprüche, weiterhin **gekennzeichnet durch**
eine Einrichtung, um an die Elektrodenstruktu-
ren ein Muster von elektrischen Signalen zu
legen, das einem anzuzeigenden Bild ent-
spricht.

6. Verfahren zum Beleuchten einer Flüssigkristall-
zelle, die einen Flüssigkristall zwischen den
Elektrodenstrukturen auf den Oberflächen ei-
nes ersten und eines zweiten Substrats enthält,
wobei der Flüssigkristall ein verdrehtes nemati-
sches Material mit einem Direktor, der beim
ersten Substrat in einer vorgegebenen Rich-
tung und beim zweiten Substrat in einer ortho-
gonalen Richtung verläuft, hat und wobei die
Zelle eine Hauptbetrachtungsebene aufweist,
die den Mittelpunkt-Direktor des Flüssigkristal-
les und eine Normale zur Hauptfläche eines
der Substrate enthält, und eine Dicke entspre-
chend dem ersten Gooch-Tarry-Minimum für
die Zelle bei einer Wellenlänge zwischen etwa
400 und 700 Nanometern hat,

gekennzeichnet durch die Schritte, die
Zelle mit einem Lichtbündel zu beleuchten,
das in der Hauptbetrachtungsebene im wesent-
lichen kollimiert ist und das in einer orthogona-
len Ebene, die im wesentlichen senkrecht zu
der Hauptbetrachtungsebene ist und die Nor-
male enthält, im wesentlichen unkollimiert ist.

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