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(54) An improved liquid crystal display device

(57) The present invention relates to an improved Liquid Crystal Display Device comprising, a pair of transparent substrates, each substrate having on one of its surfaces a coating of a transparent electrically conducting material which serves as an electrode. A nematic discotic material is sandwiched between the coated surfaces of the said substrates thereby forming a cell. The cell may be placed between a pair of cross polarizers.

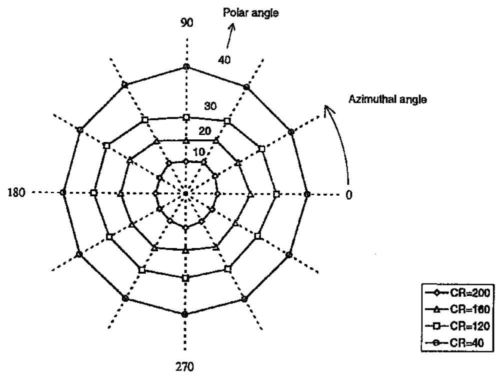

Figure 12

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Description

FIELD OF THE INVENTION

[0001] This invention relates to an improved Liquid Crystal Display (LCD) device which is used many electronic systems such as photoconducting system, ferroelectries, light emitting diodes, photovoltaic solar cell, optical data storage devices and hybrid computer chips for molecular electronics.

BACKGROUND OF THE INVENTION

[0002] The Liquid Crystal Device industry is currently a multi-billion dollar industry. In this industry,the products range from simple watch displays to flat panel colour TV screens. The device described in the present invention has advantages over the conventional LCD devices in that it has a wide and symmetrical viewing angle, no reversal of the contrast ratio in any direction, and also results in a simplification of the fabrication process. Accordingly, the device of the present invention will be very useful for various applications in liquid crystal industry.
[0003] When molecular crystals are heated to their melting point, they usually change into the liquid phase. The periodic structure of the lattice as well as the orientational ordering of the molecules are destroyed simultaneously. However, if the constituent molecules have a pronounced anisotropy of shape, such as a rod or a disc, the melting of the lattice may precede the disappearance of the orientational ordering. One, then, has an intermediate phase composed of molecules which are more or less parallel to each other, but at the same time exhibiting a certain degree of fluidity. The molecules can slide over on one another while still preserving their parallelism. The fluid is, therefore, anisotropic, turbid and, like a crystal, shows optical birefringence and dielectric anisotropy. At a higher temperature there is orientational melting and the anisotropic fluid transforms into the ordinary isotropic clear liquid. Such intermediate phases, which occur as a result of heating or cooling, are referred to as thermotropic liquid crystals
[0004] Thermotropic liquid crystals can be classified broadly into two types, (i) those composed of rod-shaped molecules (called "calamitic" liquid crystals) which are known from the end of 19th century and form the majority of the currently known liquid crystals and (ii) those composed of disc-shaped molecules (called "discotic" liquid crystals) which have been developed recently.

PRIOR ART REFERENCES

[0005] Discotic liquid crystals which were discovered by us as recently as 1977 represent a new class of theremotropic liquid crystal. In this context, reference may be made to the publication of S.Chandrasekhar, B.K.Sadashiva and K.A.Suresh; Pramana, 9, 471-480 (1977). In this case, the discs are stacked one on top of the other to form columns, the different columns constituting a two-dimensional lattice. The basic columnar structure is shown in figure 1 of the drawings accompanying this specification. A number of modifications of the above said basic structure have been identified. Some discotic compounds exhibit a nematic (N_D) phase as well. It is a fluid phase consisting of an orientationally ordered arrangement of discs, but with no long range translational order, somewhat like a pile of coins as shown in figure 2 of the drawings accompanying this specification. However, unlike the usual nematic calamitic, the nematic discotic is optically negative. The preferred orientation of the axis of the disc is termed as the director as shown in figure 2 of the drawings.
[0006] The advent of discotic liquid crystals triggered off a spate of activity in this field and well over a thousand discotic compounds have been reported to date. A few discotic compounds are exemplified below: Hexaalkonoyloxy benzenes, hexaalkoxy triphenylenes, bis-(4-n-decylbenzoyl)methanato copper (II), hexa-n-alkanoates of truxene and octasubstituted phthalocyanines.
[0007] The potential uses of such materials are as quasi-one-dimensional conductors, photoconducting systems, ferroelectrics, light emitting diodes, photovoltaic solar cells, optical data storage devices and hybrid computer chips for molecular electronics.
[0008] Display devices based on calamitic liquid crystals are well known. A widely used device is the twisted nematic (TN) display device. In a twisted nematic display device, two transparent glass plates are coated on their inner surfaces with a thin layer of transparent electrically conducting material, such as indium tin oxide, and further with a thin layer of a polyimide. The method of unidirectionally rubbing the said substrates with cotton or rayon or nylon fabric is widely used to achieve a macroscopic orientation of the liquid crystal director. The two glass plates are held apart at a distance of approximately 6-10μm by means of spacers to form a cell, with the rubbing directions of the polyimide layers orthogonal to each other. The gap between the substrates of the cell is filled with a calamitic nematic liquid crystal. Owing to the boundary conditions, the nematic liquid crystal will become oriented parallel to the rubbing direction of each glass plate and consequently the director will undergo a twist of 90° over the nematic layer distance. Polarizer sheets are attached to the outer surfaces of the glass plates with the axis of vibration (polarizing axis) of each sheet parallel to the

rubbing direction of the plate to which it is attached. Unpolarized light is transformed into linearly polarized light by the polarizer fixed on the entrance side of the cell and emerges on the exit side with the polarization axis rotated through 90°. The emergent light will be transmitted by the second polarizer. Thus, in this configuration, the so called normally white mode, the display appears bright in the unactivated state. A white mode with enhanced viewing angle can be achieved by setting the polarizers with their polarizing axes perpendicular to the rubbing directions. The application of an electric field normal to the layer orients the liquid crystal molecules (of positive dielectric anisotropy, $\Delta\varepsilon>0$) with their long axes along the layer normal. In this activated state, the polarization axis of light is not rotated by the liquid crystalline medium and the display appears black. Orientation of one polarizer parallel and the second polarizer perpendicular to the rubbing direction results in a black appearance in the unactivated state and a bright appearance in the activated state. This so called black mode is useful for automobile dash board applications.

[0009] The major disadvantage of the above type of device is that when it is viewed obliquely, the viewing angle characteristic is poor, resulting in a loss of contrast, and even contrast inversion at certain azimuthal angles. See figure 3 of the drawings, which is taken from the publication of Y.Toko, T.Sugiyama, K.Katoh, Y.Imura and S.Kobayashi, *J. Appl. Phys.*, 74, 2071-75 (1993) showing a typical polar plot of the contrast ratio (CR) for a conventional TN device.

[0010] Another widely used device is the supertwisted nematic (STN) device. The construction of such a device is similar to that of a TN device as explained above except that the twist angle of the director is between 180° and 270°, instead of 90°. The higher twist angle is achieved by incorporating a suitable quantity of a chiral compound as a dopant in the nematic material before it is filled into the cell. However, this device does not lead to any of improving the viewing angle characteristic.

[0011] Both the TN and STN devices suffer from the additional disadvantage that for multiplexed displays there is a large difference in the pixel capacitance between the ON and OFF states, which gives rise to the problem of cross talk between pixels.

[0012] The viewing angle profiles, the symmetry and the angle dependence of the intensity contrast ratio between the ON and OFF states of any display device are important criteria for determining the quality of performance of the device. Several attempts have been made to enhance the performance of such devices. These attempts are directed mainly to improve the viewing angle characteristics using different techniques such as dividing each pixel into sub-pixels, adding retardation films, applying an electric field parallel to the substrate plane. The noteworthy point in all these attempts is the fact that the liquid crystalline material used is of the nematic calamitic type. No attempts have been made to date employing nematic discotic material for fabricating a display device.

[0013] For example, regarding the modification based on applying an electric field parallel to the plane of the substrates reference may be made to the publications of G. Baur, R. Kiefer, H. Klausmann and F. Windscheid, *Liquid Crystal Today*, 5, 13-14 (1995); M.Oh-e, M. Yoneya and K. Kondo, *J. Appl. Phys.*, 82,528-535 (1997); S.H. Lee, H.Y. Kim, I.C. Park, B.G. Rho, J.S. Park, H.S. Park and C. H. Lee, Appl. Phys. Lett., 71, 2851-2853, (1997). In this method, the authors have improved the viewing angle characteristic of liquid crystal devices by employing in-plane electrodes on only one of the substrates and by avoiding the assymmetry of the director profile.

[0014] In the publications of H. Mori, *Jpn. J. Appl. Phys.*, 36, 1068-1072 (1997); H. Mori, Yoji Itoh, Yosuke Nishiura, Taku Nakamura, Yukio Shinagawa, *Jpn. J. Appl.* Phys., 36, 143-147 (1997) an optical compensator with negative birefringence was introduced to reduce the amount of light leakage in the dark state.

[0015] In the publications of K. H. Yang, *Jpn. J. Appl. Phys.*, 31, L1603-1605 (1992) and J. Chen, P. J. Bos, D.R. Bryant, D. L. Johnson, S.H.Jamal, J.R. Kelly, SID 95 Digest, 865-868 (1995) the authors have employed multiple domains of the liquid crystals in which the orientation of the director was different in each of the domains (pixels).

[0016] The devices fabricated as mentioned above do not improve the viewing angle characteristics of the device satisfactorily. Further they also involve additional steps in the fabrication process.

[0017] In the publications of Y. Toko, T. Sugiyama, K. Katoh, Y. Limura and S. Kobayashi, SID 93 Digest, 622-625 (1993); *J. Appl. Phys.*, 74, 2071-75 (1993) a simpler process for producing LCD having improved viewing angle characteristic has been disclosed. In this process,polymer films are coated on the transparent conducting substrates, but no rubbing is done. The non-rubbed polymer film is optically and structurally isotropic and the director is parallel to the surfaces of the substrates but randomly oriented in the plane of the substrate in the OFF state. In the ON state, the director is normal to the surfaces of the substrates. This so called amorphous TN device gives an improved viewing angle characteristic, free from contrast inversion. See figure 4 of the drawings, which is taken from the publication of Toko et.al. referred to above. It is to be noted that the liquid crystal material used in this device is again of the nematic calamitic type and not of the nematic discotic type.

[0018] Recognising the importance of improving the viewing angle characteristics of liquid crystal devices we undertook intensive research work in this direction. Our sustained research work resulted in our finding that if nematic discotic materials are employed in liquid crystal devices the viewing angle characteristics of such devices can be further enhanced.

OBJECTS OF THE INVENTION

[0019] Therefore, the main object of the present invention is to provide a liquid crystal device having improved viewing angle characteristics employing nematic discotic material.
[0020] Another preferred aim of this invention is to provide a liquid crystal device having no reversal of the contrast ratio in any direction.
[0021] Yet another preferred aim of the present invention is to provide a liquid crystal device with reduced difference in the pixel capacitance between the ON and the OFF states resulting in lowering of the cross talks substantially in the case of a multiplexed display device.
[0022] Still another preferred aim of the present invention is to provide a liquid crystal device employing a simple fabrication process.

SUMMARY OF THE INVENTION

[0023] To meet the above aims, the invention, for the first time, provides a Liquid Crystal Device comprising nematic discotic material.

DETAILED DESCRIPTION OF THE INVENTION

[0024] The present invention differs from any of the previously disclosed LCDs in that it employs a nematic discotic material and dos not use a calamitic material. To date a nematic discotic material has never been used for the fabrication of a liquid crystal display device. The material used is of negative dielectric anisotropy ($\Delta\varepsilon$<O).
[0025] Accordingly, the present invention provides a Liquid Crystal Display Device comprising a pair of transparent substrates, each substrate having on one of its surfaces a coating of a transparent electrically conducting material which serves as an electrode, characterised in that a nematic discotic material is sandwiched between the coated surfaces of the said substrates thereby forming a cell.
[0026] The cell may be placed between a pair of crossed polarizers.
[0027] The substrates employed in the device may be made of glass, plastic or other such transparent materials. The electrically conducting materials such as Indium Tin Oxide, Tin Oxide etc. may be employed for coating the substrates. The resulting substrates may be preferably coated with an additional layer of polymer so as to make the contact between the nematic discotic material and the substrate uniform. The polymer when employed may be selected from the class polymers such as polyimides, polyamides, polyvinyl alcohol or a similar class of polymers. The gap between the substrates in the cell is preferably defined by means of spacers which may be selected from polyethyleneterephthalate films, polyimide films, glass microspheres etc. The use of polarizers can be avoided by incorporating a suitable quantity of known discotic pleochroic dye as a dopant in the nematic discotic material before filling the cell. For this purpose, dyes such as derivatives of anthraquinone, phthalocyanine, porphyrin etc. may be employed.
[0028] The nematic discotic material is sandwiched between the substrates. Preferably, the disc-shaped molecules adhere flat against the coated surfaces of the substrates. As a result, the nematic discotic material is preferably uniformly oriented with the director perpendicular to the surface (ie along the z direction in figure 5 of the drawings). On application of an electric field along the z direction, the director in the material is realigned parallel to the surfaces of the substrates with random orientation of the director in the x-y plane (figure 6 of the drawings). Thus, between crossed polarizers there is a transition from a dark to a bright state when the field is switched ON.
[0029] The device can also be used in the reflecting mode. For such an application an optical reflector may be incorporated at the bottom surface of the display device.
[0030] The nematic discotic material employed in the device of the present invention may be selected from any substance having negative dielectric anisotropy such as hexakis ((4-nonylphenyl)ethynyl)benzene for example of the formula shown in Figure 7 of the drawings, undecenyl, pentakis[(4-pentylphenyl)ethynyl]phenyl ether for example of the formula shown in figure 8 of the drawings, and $\propto,\omega$-bis [penta(4-pentylphenylethynyl)phenoxy]phenoxy]alkane for example of the formula shown in figure 9 of the drawings, and derivatives of triphenylene for example of the formulae shown in figures 10(a) and (b) of the drawings.
[0031] The compound of the formula shown in figure 7 exhibits the following sequence of transitions [B.Kohne and K.Praefcke, Chimia, 41, 196-198 (1987); G.Heppke, A.Ranft and B.Sabaschus, Mol. Cryst. Liq. Cryst. Lett., 8, 17-25 (1991)]

$$\text{Isotropic} \xrightarrow{81.8^\circ C} N_D \xrightarrow{\sim 39^\circ C} \text{Crystal}$$

[0032] The compound of the formula shown in figure 8 has the following sequence of transitions [K.Praefcke, B.Kohne, B.Gündogan, D.Singer, D.Demus, S.Diele, G.Pelzl and U.Bakowsky, Mol. Cryst. Liq. Cryst., 198, 393-405 (1991)]

$$\text{Isotropic} \xrightarrow{101.4°C} N_D \xrightarrow{76.7°C} \text{Crystal}$$

[0033] The compound of the formula shown in figure 9 has the following sequence of transitions [K.Praefcke, B.Kohne, B.Gündogan, D.Singer, D.Demus, S.Diele, G.Pelzl and U.Bakowsky, Mol. Cryst. Liq. Cryst., 198, 393-405 (1991)]

$$\text{Isotropic} \xrightarrow{153.5°C} N_D \xrightarrow{129.1°C} \text{Crystal}$$

[0034] The compounds of the formulas shown in figure 10 have the following sequence of transitions [T. J. Phillips, J.C.Jones and D.C.McDonnell, Liquid Crystals, 15, 203-215. (1993)]

$$\text{(a) Isotropic} \xrightarrow{248°C} N_D \xrightarrow{129°C} \text{Crystal}$$

$$\text{(b) Isotropic} \xrightarrow{164°C} N_D \xrightarrow{75°C} \text{Crystal}$$

[0035] The device of the present invention can be fabricated as per the details given below. Suitable substrates transparent in the visible region of spectrum are selected. On these substrates, a coating of transparent electrically conducting material is applied. If necessary, an additional coating of a polymer may be applied to enhance the uniform adhesion of the nematic discotic material to the substrates. A spacer material to fix the spacing between the substrates is used on the non-electrically active areas of the substrates. The gap between the two substrates is filled with the required amount of nematic discotic material to form a cell. This is effected by heating the cell, during the process of filling, to a temperature above the nematic-isotropic point, and then cooling it till the material transforms to the nematic phase. The nematic discotic is then spontaneously aligned with the disc-like molecules adhering flat against the surfaces, or, equivalently, with the director normal to the surfaces (figure 5). Since the ND material is of negative dielectric anisotropy, the application of a sufficiently strong electric field, greater than a threshold value, results in the directors to be aligned parallel to the surfaces of the substrates but randomly oriented in the x-y plane (figure 6). Thus, between crossed polarizers there is a transition from the dark to the bright state when the electric field is switched ON. Because of the anchoring of the molecules at the boundary layers, the material returns to the original configuration in the OFF state.

[0036] In one embodiment, an optical reflector is provided at the bottom surface of the device for its use in a reflective mode.

[0037] A liquid crystal display device was fabricated as explained above using hexakis ((4-nonylphenyl)ethynyl)benzene (of negative dielectric anisotropy $\Delta\varepsilon$= -0.18). The cell gap measured interferometrically was 2.6μm. A voltage of 10 V_{rms} 1kHz sinewave pulse of 5 seconds duration with a repetition rate of 0.1 s^{-1} was applied.

[0038] When the device is switched ON by applying the electric field, the time taken for the transmitted intensity to rise from 10% to 90% of the maximum intensity is ~100 ms and that from 10% to 80% of the maximum intensity is ~50 ms. A typical electro-optic response curve obtained employing the above said device is shown in figure 11 of the drawings.

[0039] The polar plot of the contrast ratio between the intensities in the ON to OFF states is given in figure 12 of the drawings. This figure reflects that the device of the present invention shows very good contrast ratios, the contours of equal contrast ratios being nearly concentric circles and free from contrast inversion.

ADVANTAGES OF THE PRESENT INVENTION

[0040]

1. The invention, for the first time, employs nematic discotic material for the fabrication of a liquid crystal display device.
2. The device of the present invention overcomes the disadvantages of conventional TN and STN devices which employ nematic calamitic materials.
3. The viewing angle characteristic of the device of the present invention is wide and symmetric thereby improving the performance of the device.
4. The difference in the pixel capacitance between the ON and OFF states for the nematic discotic is less than that obtained for the conventional TN and STN devices which use calamitic liquid crystals, thus reducing cross talk problems in multiplexed displays.
5. The fabrication of the device of the present invention is simplified as the step involving rubbing of the polymer is avoided.
6. The requirement of coating of the substrates by a polymer can also be avoided by employing substrates having

optically flat surfaces, thereby further simplifying the process of fabricating the device.

7. The use of polarizers can also be avoided by incorporating discotic pleochroic dyes in the nematic discotic material thereby making the device economical to fabricate.

Claims

1. A Liquid Crystal Display Device comprising a pair of transparent substrates, each substrate having on one of its surfaces a coating of a transparent electrically conducting material which serves as an electrode characterised in that a nematic discotic material is sandwiched between the coated surfaces of the said substrates thereby forming a cell.

2. A device as claimed in claim 1, wherein the cell is placed between a pair of crossed polarizers.

3. A device as claimed in any preceding claim, wherein a material such as glass, plastic or other such transparent material is employed as substrate.

4. A devices as claimed in any preceding claim, wherein a material such as Indium Tin Oxide or Tin Oxide is employed as the electrically conducting material for coating the substrates.

5. A device as claimed in any preceding claim, wherein the resulting substrates are coated with an additional layer of polymer so as to make the contact of the material with the substrates uniform.

6. A device as claimed in claim 5, wherein the polymer is selected from a group such as polyimides, polyamides, polyvinyl alcohol or a similar class of polymer.

7. A device as claimed in any preceding claim, wherein the substrates are spaced apart by spacers such as polyethyleneterephthalate films, polyimide films or glass microspheres.

8. A device as claimed in any preceding claim, wherein a nematic discotic material with negative dielectric anisotropy such as a compound of the formula shown in figure 7, figure 8 or figure 9 is employed.

9. A device as claimed in any preceding claim, wherein the nematic discotic material employed is selected from any substance having negative dielectric anisotropy such as hexakis ((4-nonylphenyl)ethynyl)benzene of the formula shown in Figure 7 of the drawings, undecenyl, pentakis[(4-pentylphenyl)ethynyl]phenyl ether of the formula shown in figure 8 of the drawings, and α,ω-bis[penta(4-pentylphenylethynyl)phenoxy]phenoxy]alkane of the formula shown in figure 9 of the drawings, and derivatives of triphenylene of the formulae shown in figures 10(a) and (b) of the drawings.

10. A device as claimed in any preceding claim, wherein an optical reflector is provided at the bottom surface of the device for its use in a reflective mode.

11. A device as claimed in any preceding claim, wherein a discotic pleochroic dye such as derivatives of anthraquinone, phthalocyanine, porphyrin is incorporated in the nematic discotic material.

CENTRE FOR LIQUID CRYSTAL RESEARCH

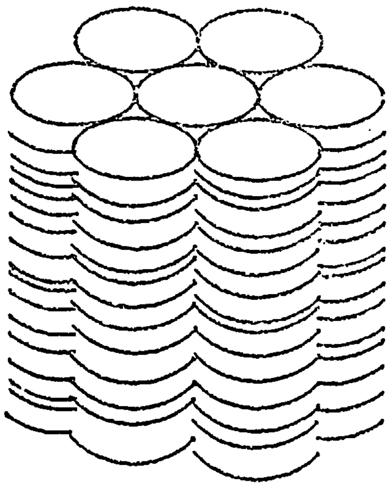

Figure 1

CENTRE FOR LIQUID CRYSTAL RESEARCH

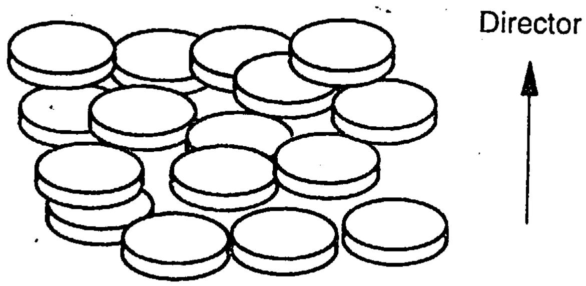

Figure 2

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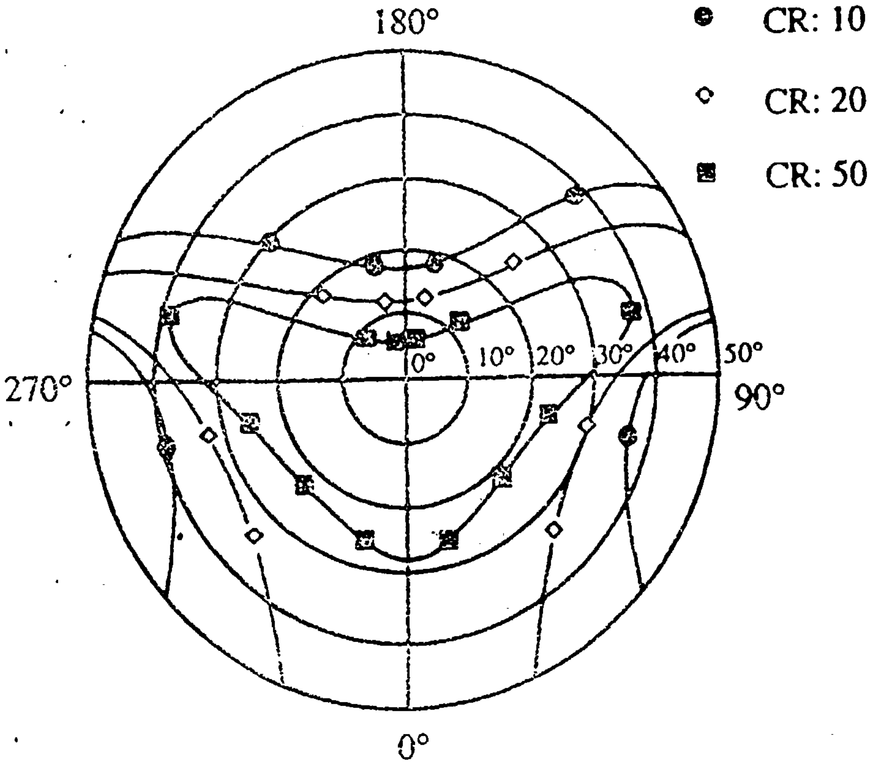

Figure 3

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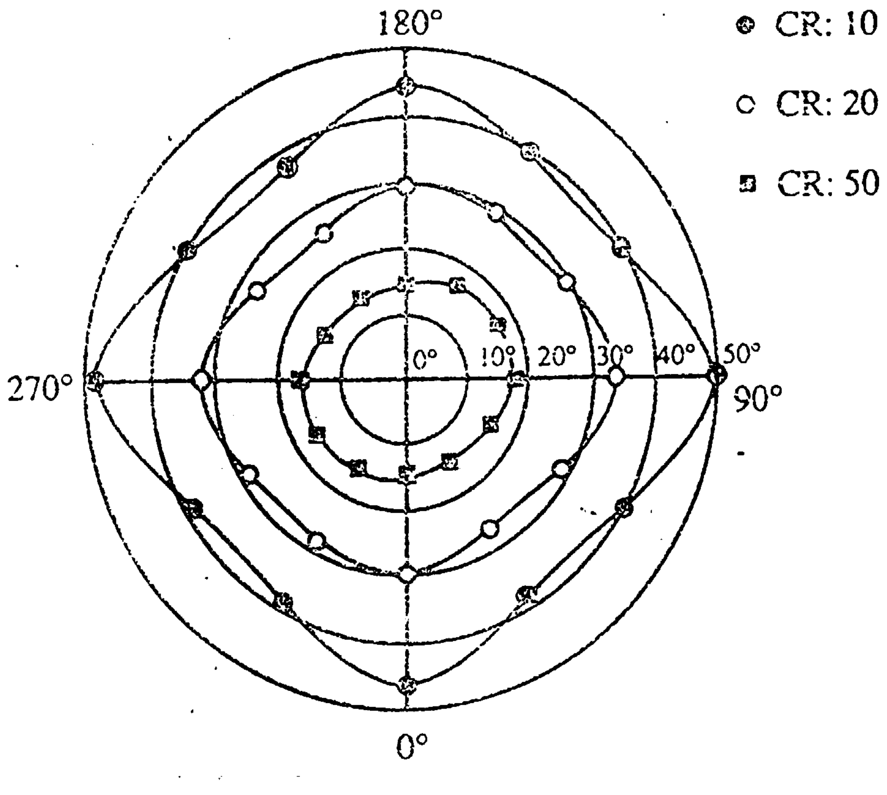

Figure 4

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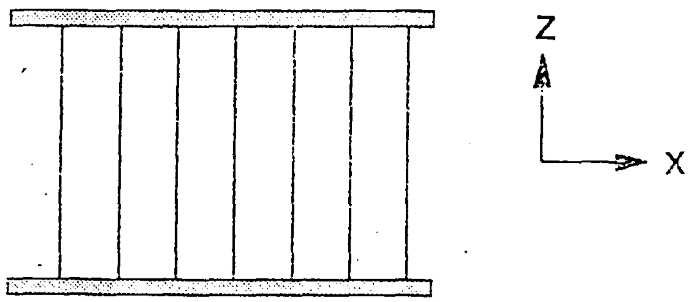

Figure 5

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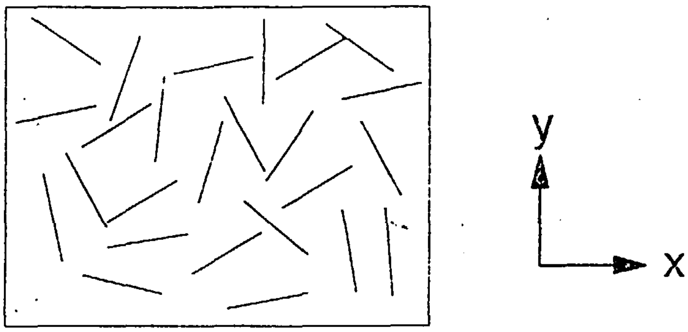

Figure 6

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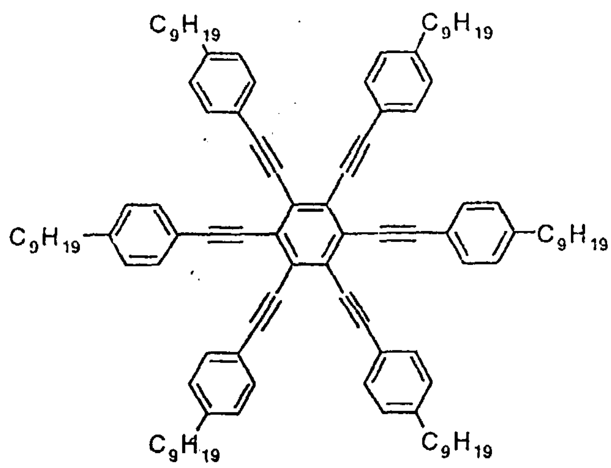

Figure 7

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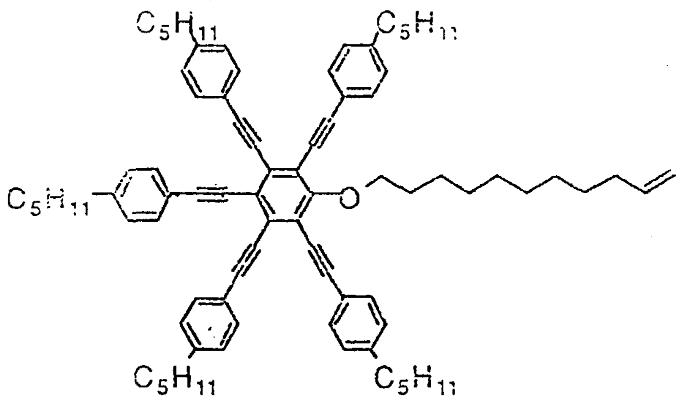

Figure 8

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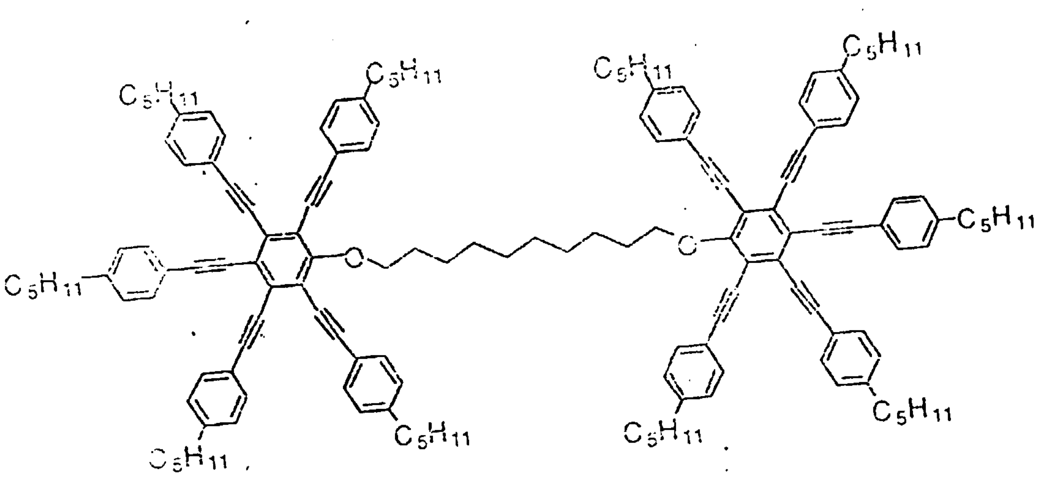

Figure 9

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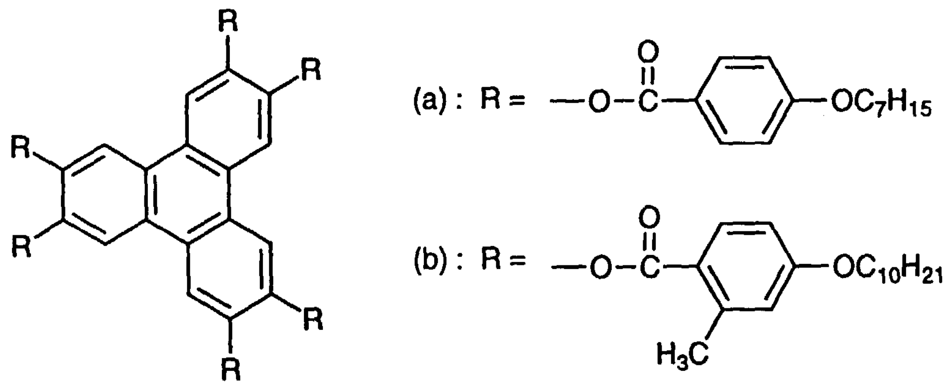

Figure 10

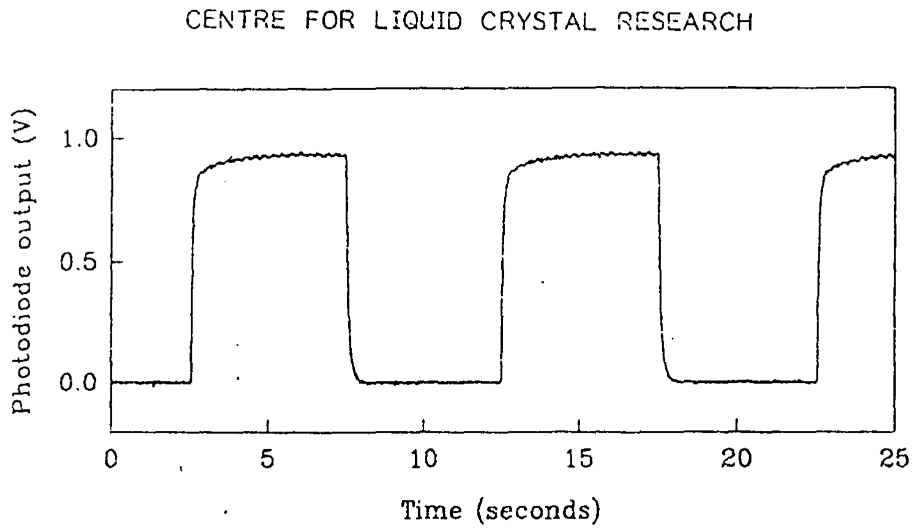
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Figure 11

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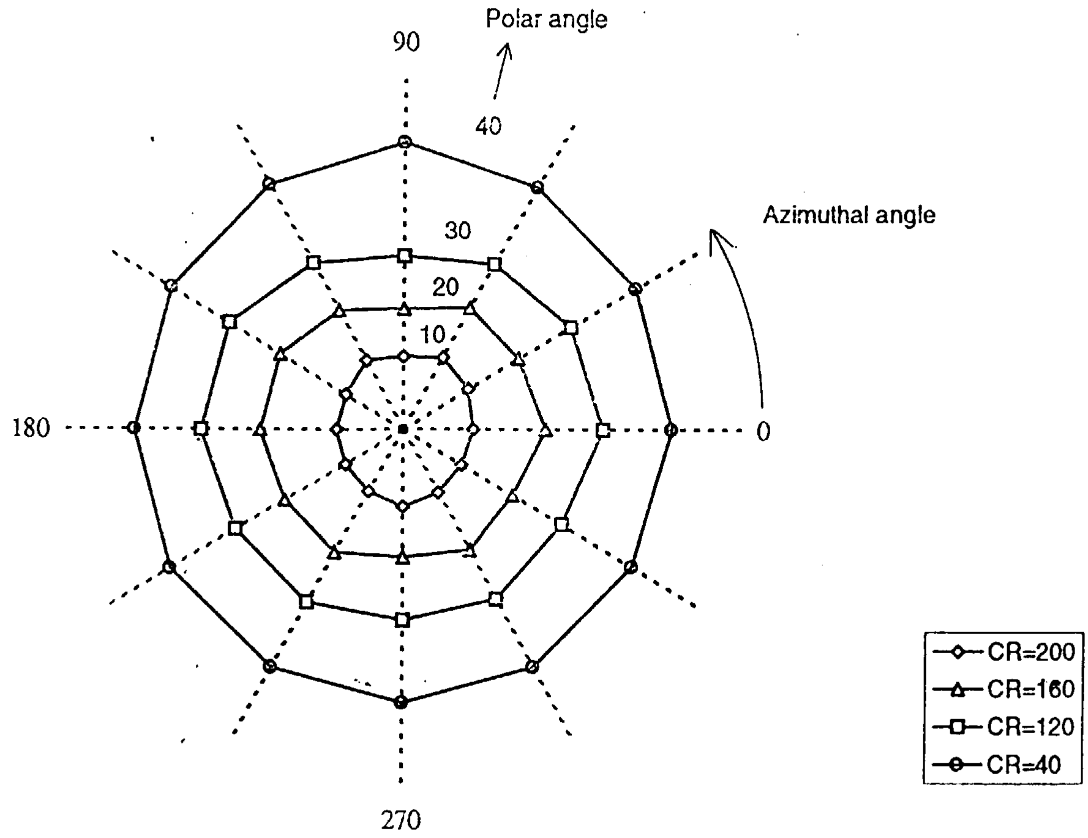

Figure 12

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 98 30 7996

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	EP 0 030 879 A (THOMSON CSF) 24 June 1981 * page 5, line 29 - page 6, line 34 * ---	1-11	G02F1/137
X	EP 0 093 035 A (CENTRE NAT RECH SCIENT) 2 November 1983 * page 9, line 05 - line 19 * * page 25, line 08 - line 19 * -----	1-12	

TECHNICAL FIELDS SEARCHED (Int.Cl.6)
G02F

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	22 February 1999	Diot, P

CATEGORY OF CITED DOCUMENTS

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