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(72) Inventors WILLIAM ALDEN CROSSLAND, JOSEPH HOURIGAN MORRISSY and DAVID COATES

(54) SMECTIC DISPLAY CELL

(71) We, STANDARD TELEPHONES AND CABLES LIMITED, a British Company of 190 Strand, London W.C.2., England, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to liquid crystal display cells, and in particular to such cells filled with a smectic material that exhibits positive dielectric anisotropy.

In this specification reference will be made to tilt angle in respect of parallel non-homeotropic alignment of a liquid crystal layer. For the purposes of this specification this tilt angle is defined as the acute angle between the liquid crystal molecular axis at the surface of the layer and the plane of that surface.

According to the present invention there is provided an internally electroded liquid crystal display cell having a layer of a smectic material that exhibits positive dielectric anisotropy sandwiched between two electroded plates having electrodes that overlap at least in part, at least one of which plates is transparent, wherein the surfaces of the plates are such that, when the layer is taken into a smectic phase from a less-ordered non-smectic phase by cooling in the absence of an applied electric field the layer is caused to assume parallel non-homeotropic alignment with too large a tilt angle for the formation of focal conic domains observable by optical microscopy in polarised light.

There follows a description of a smectic liquid crystal display cell embodying the invention in a preferred form. The description refers to the drawings accompanying the Provisional Specification in which:

Figure 1 depicts a schematic perspective view of the cell, and

Figure 2 depicts diagrammatically the two extreme types of state that the cell can assume.

Two glass sheets 1, 2 are secured together with a perimeter seal 3 to form an envelope for a layer 5 of liquid crystal to be hermetically sealed within the cell. The cell is filled via an aperture formed by an interruption in the perimeter of the seal 3, and, after the cell has been filled, this aperture is sealed off with a plug 4, for instance of indium. Alternatively, if the perimeter seal 3 is a fused glass frit seal, the aperture may be metallised prior to the filling of the cell, in which case the aperture can be sealed off by soldering.

Before they are secured together, the inwardly facing surfaces of the two sheets are provided with transparent electrodes (not shown) of appropriate layout for the required display to enable an electric field to be applied across the thickness of at least selected portions of the liquid crystal layer. For this purpose portions of the electrodes extend beyond the region of the seal 3 to permit external connection.

The inwardly facing major surface of at least one, and preferably both, of the sheets 1 and 2 are provided with a coating or other surface treatment that will cause the liquid crystal molecules to assume parallel non-homeotropic alignment when the cell is taken by cooling into a smectic phase from a less ordered non-smectic phase in the absence of any applied electric field. In order to obtain the desired parallel non-homeotropic molecular alignment it appears necessary to use an alignment method that provides a substantial tilt angle. Thus for instance an oblique evaporation of silicon monoxide at an angle of about 25° to the substrate will, with the nematic phase of 4-cyano-4^1-n-octylbiphenyl, produces parallel homogeneous (non-homeotropic) alignment with no tilt angle, but with the smectic phase it produces a focal-conic state with relatively long slender cones (typically with an aspect ratio of about 10 to 1) that are oriented in the alignment direction. These domains are revealed by the appearance of characteristic elliptical patterns when the cell is observed by optical microscopy in polarised light. Similarly oblique evaporation of silicon monoxide at an angle of between 5° and 10° to the substrate produces parallel homogeneous alignment of the nematic phase with a tilt angle of about 25°, whereas with the smectic phase it again produces an aligned focal conic state. However if the resulting tilt angle is sufficiently increased by further treatment of the evaporated surface with a homeotropic alignment inducing surfactant, it is possible to go through a threshold value of tilt angle beyond which the parallel non-homeotropic alignment is preserved even in the smectic state. An example of this is provided by treating the 5° to 10° silicon monoxide evaporated layer with a 0.1% solution of hexadecyl-trimethyl-ammonium bromide in methanol. This produces a conoscopically measured tilt angle of 68°.

In the manufacture of a test cell this treatment with the surfactant was applied before the two sheets were secured together with the perimeter seal. The treatment consisted of dipping the sheets into the solution, removing them, and allowing them to dry. In commercial production we would prefer if possible to apply the surfactant after the envelope has been assembled as this would allow the use of a perimeter seal mode of fused glass frit. We contemplate that the assembled cell would be filled with the surfactant, emptied, and the residue allowed to dry on the interior surfaces of the cell. In either instance the cell needs to be assembled so that the alignment directions are parallel having particular regard to tilt angle.

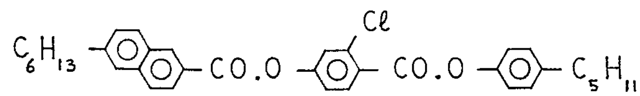
The conoscopic measurement of tilt angle has not revealed whether the tilt is due to the molecules tilting in the smectic layers with the layers themselves being parallel with the glass sheets (i.e. pseudo smectic C as depicted at *a* in Figure 2, or whether the molecules are normal to the layers and the layers tilted as depicted at *b*. However more recent tests using a neutron scattering technique appear to indicate that with this material it is the smectic layers that are tilted. (Figure 2b and d). If a gradually increasing alternating electric field is applied across the cell the tilt angle, as observed by its conoscopic figure, gradually increases to a limiting value of about 88° (i.e. substantially homeotropic alignment as depicted at *c* or *d* in Figure 2.) Preferably the excitation frequency is about 1KHz because below about 800 Hz the conoscopic figure appears diffuse, probably as a result of some electro-hydrodynamic instability.

When viewed in transmission between crossed polarisers the cell appears coloured, and the effect is at a maximum when the alignment direction is mid-way between the two polarisation directions. To obtain an even colour over the whole surface of the cell the thickness of the liquid crystal layer needs to be very uniform. With a 20μm thickness layer the cell appears a brown-yellow when observed normal to the glass surface. This agrees with the theoretical retardation of 450nm for a 20 micron thick liquid crystal aligned at 68° from the glass surfaces and of birefringence $n_o = 1.52$, $n_e = 1.675$ (quoted indices for 4-cyano-4'-n-octylbiphenyl). The application of the alternating field changes the appearance through yellows, white, and greys to black as the applied voltage is progressively increased to about 150—180 volts r.m.s. By choosing a different thickness of liquid crystal layer it would be possible to arrange for the cells to have different initial colours. In particular thicker cells with start at a higher order colour in the Newton spectrum, and thus be able to be swept through a greater range of colours. For instance a cell with a 30 micron thick liquid crystal layer will initially appear blue. Cells of the same thickness can also be arranged to exhibit different colours by the use of different smectic materials having different birefringences, or by the use of different alignment techniques producing differing initial tilt angles.

When the tilt is increased from the initial value it is found that the increase is sustained after removal of the exciting field. If the tilt angle is less than maximum the tilt angle can be increased still further by the application of a stronger exciting field. Therefore it is possible by suitable switching to provide a display with more than two contrasting colours. The cell is switched back to the original lower limit of tilt angle by heating it into the nematic phase out of the smectic phase, then allowing it to cool again.

Selected portions of the display can have their tilt angle reduced in this way by the use of localised heating. This can be provided by intensity modulation of a focused laser beam as it is scanned over the surface of the cell. For this purpose the wavelength of the laser would be chosen so that it is absorbed either by the liquid crystal or by material dissolved in or adjacent to the liquid crystal, such as the material of one of the electrode layers.

The above described cell is capable of being switched in only one direction by the application of an alternating electric potential, while thermal cycling is used for switching in the opposite direction. However certain smectics have the property of exhibiting a cross-over frequency effect in which the material exhibits positive dielectric anisotropy at low frequencies beneath the cross-over frequency, and negative dielectric anisotropy at higher frequencies above the cross-over frequency. With the such materials electric switching in both directions is possible. One example of such a material is given by 4-n-pentylphenyl 2′-chloro-4′-(6-n-hexyl-2-naphthoyloxy) benzoate



a monotropic liquid crystal with the following phase transition temperatures, C—N, 68.6°C; [S_A—N, 53.5°C]; N—I, 178.9°C.

The following table shows that with this material the cross-over effect also exists in the nematic phase. On cooling the material from the mematic phase into the smectic phase this cross-over effect persists, but at much higher threshold voltages.

	Temperature	Cross-Over Frequency	Switching Voltage Applied
	77°C	29 KHz	22V
	72°	20 KHz	22V
	67°	13 KHz	22V
	65°	11 KHz	22V
	63°	9.8 KHz	18V
N	61°	7.2 KHz	22V
	59°	6.2 KHz	21.1V
	57	5.5 KHz	20.8V
	55	4.8 KHz	20.2V
	54.5	4.6 KHz	20.4V
	54.0	4.6 KHz	20.1V
S_A—N	53.5	4.2 KHz	78V
	53.2	4.2 KHz	112V
	52.0=	4.2 KHz	182V
S_A	50.0	3.9 KHz	204V

A cell of the same basic construction as that described above, filled with this material (instead of the other liquid crystal material previously referred to) and maintained at 52°C can have the tilt angle of its liquid crystal layer increased by the application of an alternating electric potential at a frequency beneath 4.2 KHz, and then have the tilt angle reduced to its lower limit again by the application of an alternating electric potential at a frequency above 4.2 KHz.

WHAT WE CLAIM IS:—

1. An internally electroded liquid crystal display cell having a layer of smectic material that exhibits positive dielectric anisotropy sandwiched between two electroded plates having electrodes that overlap at least in part, at least one of which plates is transparent, wherein the surfaces of the plates are such that when the layer is taken into a smectic phase from a less ordered non-smectic phase by cooling in the absence of an applied electric field the layer is caused to assume parallel non-homeotropic alignment with too large a tilt angle for the formation of focal conic domains observable by optical microscopy in polarised light.

2. A display cell as claimed in claim 1 wherein the surfaces of the plates are provided by an oblique evaporation performed under conditions which promote parallel homogeneous alignment with a non-zero tilt angle and wherein said surfaces are further treated with a homeotropic alignment inducing surfactant to increase said tilt angle.

3. A display cell as claimed in claim 2 wherein the surfaces of the plates are provided by obliquely evaporated silicon monoxide.

4. A display cell as claimed in claim 2 or 3 wherein the surfactant is hexadecyl-trimethyl-ammonium-bromide.

5. A display cell as claimed in any preceding claim wherein the layer of smectic material is a layer of material that in its smectic phase exhibits a cross-over frequency above which it exhibits negative dielectric anisotropy and beneath which it exhibits positive dielectric anisotropy.

6. A display cell substantially as hereinbefore described with reference to the drawings accompanying the Provisional Specification.

7. A display cell as claimed in any preceding claim except claim 5 wherein the smectic material is a material that does not exhibit negative dielectric anisotropy.

S. F. LAURENCE
Chartered Patent Agent
For the Applicants

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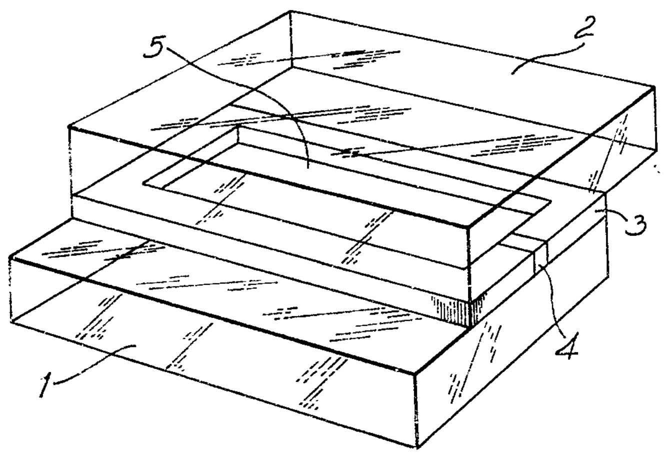
1569686 PROVISIONAL SPECIFICATION

2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

Fig.1.



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2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 2

Fig2.