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PATENT SPECIFICATION

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(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 negative dielectric anisotropy.

According to the present invention there is provided an internally electroded liquid crystal display cell having a layer of a smectic material that exhibits negative dielectric anisotropy sandwiched between two electroded plates having electrodes that overlap at least in part at least one of which plates is transparent, and 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 substantially homeotropic alignment.

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

Figure 1 depicts a schematic perspective view of the cell,

Figure 2 depicts diagrammatically the two types of stable state and the intermediate metastable state that regions of the cell may assume, and

Figure 3 is a graph showing, for a particular smectic composition, how, at a particular frequency, the switching threshold voltage varies with temperature.

Two glass sheets 1, 2 are secured together with a perimeter seal 3 to form an envelope for a layer 5 of liquid crystal filling 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 had been filled, this aperture is sealed off with a plug 4, for instance of indium. Alternatively solder is used, the aperture having been metalised prior to the filling of the cell.

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 perimeter seal in order 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 substantially homeotropic alignment when it is taken by cooling into a smectic phase from a less ordered non-smectic phase in the absence of any electric field applied across the thickness of the layer.

A preferred surface treatment is that provided by coating the glass surfaces with lecithin or hexadecyltrimethyl ammonium bromide solutions. If a fused frit perimeter seal is used for the cell, as is generally preferred on account of its innertmess, this surface treatment is applied after firing of the frit by first filling the assembled cell with the required solution and then draining it. Then the cell is filled with a suitable smectic material. This may be for instance 4-octyloxyphenyl trans-4-butyl-cyclohexyl-l-carboxylate, which has a small negative dielectric anisotropy, and is a smectic A material in the temperature range 28°C to 49.1°C. Tests with this material in a 20μm thick cell revealed that, in the region of overlap between electrodes, this display went from clear to a transient schlieren texture as a

30Hz signal voltage was increased to the region of 150 volts. This appearance is believed to be produced by a tilting of the smectic layers as diagrammatically illustrated at *a* in Figure 2, or it may be that the field induces a pseudo smectic C phase as diagrammatically illustrated at *b*. Whichever of these two is the correct interpretation, it seems that the arrangement is very metastable, and even a slight increase in field strength induces the formation of focal-conic domains. At a certain threshold voltage the spread of these domains is very rapid and the cell assumed a milky appearance which is not attributable to any form of dynamic scattering effect. An increase in signal frequency was observed to increase the switching threshold voltage.

If the cell is placed between crossed polarisers the transition is more pronounced. Initially the display is black. When the metastable state is reached the domains of the schlieren texture show substantially the same Newtonian fringe colour but with different saturations according to the orientation of the domains with respect to the principle axes of the polarisers. In some cases the schlieren texture is too transient to be detected. Then, when the focal-conic domain generation threshold is reached, the display appears birefringent.

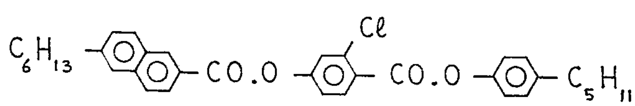
The focal-conic regions can be restored to homeotropic alignment by heating the cell sufficiently to go through the smectic-nematic phase change. The focal-conic structure is not sustained in the nematic phase and hence, when the cell is cooled sufficiently to cause the smectic phase to be restored, it will be restored in homeotropic alignment provided that, at that time, there is no applied electric field.

Since the cell is switched into the homeotropic state by the action of heat selective switching into the homeotropic state can be achieved by the use of localised heating. This may be achieved by the 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 medium or by a material dissolved in or adjacent to it, such as the material of one of the electrode layers.

It has been found that a cell with some portions in the homeotropic alignment state and the remainder in the focal-conic state will remain for long periods without apparent degradation, and hence it is believed that the storage is indefinite.

It is believed that the schlieren textured appearance of the metastable state can be eliminated by providing a unidirectional bias to the substantially homeotropic alignment so that it produces a tilt angle of slightly less than 90°. Provided that this tilt angle is in the same direction over the whole surface, the application of the alternating potential will cause all the smectic molecules to begin to lie over in the same direction instead of in random directions. This bias might be provided by first treating one of the surfaces so that it would, at least weakly, tend to promote homogeneous alignment of a nematic phase in a particular direction, and then covering the treated surface with a suitable thickness of coating that tends to promote homeotropic alignment.

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 crossover frequency, and negative dielectric anisotropy at higher frequencies above the cross-over frequency. With 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 nematic phase into the smectic phase this cross-over effect persists, but at much higher threshold voltages

TABLE

	Temperature	Cross-Over Frequency	Switching Voltage Applied
	77°C	29 KHz	22V
	72°C	20 KHz	22V
	67°C	13 KHz	22V
	65°C	11 KHz	22V
	63°C	9.8 KHz	18V
	61°C	7.2 KHz	22V
	59°C	6.2 KHz	21.1V
	57°C	5.5 KHz	20.8V
	55°C	4.8 KHz	20.2V
	54.5	4.6 KHz	20.4V
	54.0°C	4.6 KHz	20.1V
S_A—N ——	53.5°C	4.2 KHz	78V
	53.2°C	4.2 KHz	112V
S_A	52.0°C	4.2 KHz	182V
	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 be switched from substantially homeotropic alignment to focal-conic by the application of an alternating electric potential at a frequency above 4.2 KHz, and then can be switched back to substantially homeotropic alignment again by the application of an alternating electric potential at a frequency beneath 4.2 KHz.

Both smectic materials so far exemplified above have been smectics exhibiting an S_A phase. It is to be noted however that a corresponding switching operation can be obtained with a cell containing a S_B phase. An example of such a material is given by 4-n-octyloxyphenyl trans-4-n-pentylcyclohexyl-1-carboxylate, an enatiotropic liquid crystal with the following phase transition temperatures, C—S_B, ~ 42°C; S_B—S_A, 49.4°C; S_B—N, 64.6°C; N—I 79°C. Figure 3 depicts how the switching threshold voltage at a frequency of 30 Hz varies with temperature for a cell having a 20 micron thick layer of this material. With this material the substantially homeotropic alignment is restored by thermal cycling.

The appearance of the cell may be modified by incorporating a pleochroic dye with the smectic material. For example a typical filling may use approximately 1.3% of the dye 1-(4'-Butyloxyaniline)-4-hydroxyanthraquinone together with approximately 0.05% of Waxoline Yellow A. The Waxoline Yellow, which, is an isotropic dye, is added to compensate the residual blue of the display in its homeotropic state caused by the ordering within the smectic host being less than 100%. The presence of the yellow converts this residual blue to a substantially neutral grey. The optical density of the grey is relatively slight so that by eye its appearance is scarcely distinguishable from transparent. When the cell is in the focal-conic state the colour of the pleochroic dye is shown because of the substantially random orientation of the molecules in this state.

WHAT WE CLAIM IS:—

1. An internally electroded liquid crystal display cell having a layer of smectic material that exhibits negative dielectric anisotropy sandwiched between two electroded plates having electrodes that overlap at least in part at least one of which plates is transparent, and 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 it in the absence of an applied electric field, the layer is caused to assume substantially homeotropic alignment.

2. A display cell as claimed in claim 1 wherein both plates of the cell are transparent and the liquid crystal layer is located between crossed polarisers.

3. A display cell as claimed in claim 1 or 2 wherein the layer of smectic material includes a pleochroic dye.

4. A display cell as claimed in claim 1, 2 or 3 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.

5. A display cell substantially as hereinbefore described with reference to the accompanying drawings.

6. A display cell as claimed in claim 1, 2 or 5 wherein the smectic material does not incorporate a pleochroic dye, and is of a kind that does not exhibit positive dielectric anisotropy.

7. A method of operating a cell as claimed in any preceding claim including the steps of applying an electric potential across the cell electrodes to cause the smectic layer, or one or more portions thereof, to assume a focal-conic scattering state, of removing the applied field, and of restoring, by heating into a less ordered non-smectic phase and in the absence of an applied field cooling back into the smectic phase, some of all of the smectic material then in a focal-conic state back to the homeotropic state.

8. A method as claimed in claim 7 wherein the heating is effected by scanning an intensity modulated focused beam of radiation.

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

Sheet 1

Fig.1.

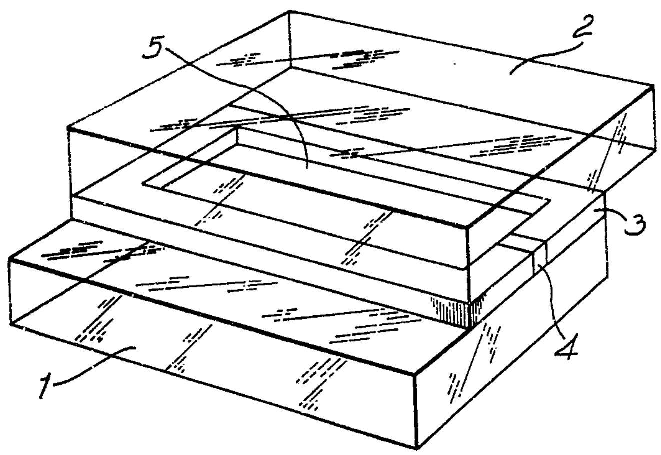
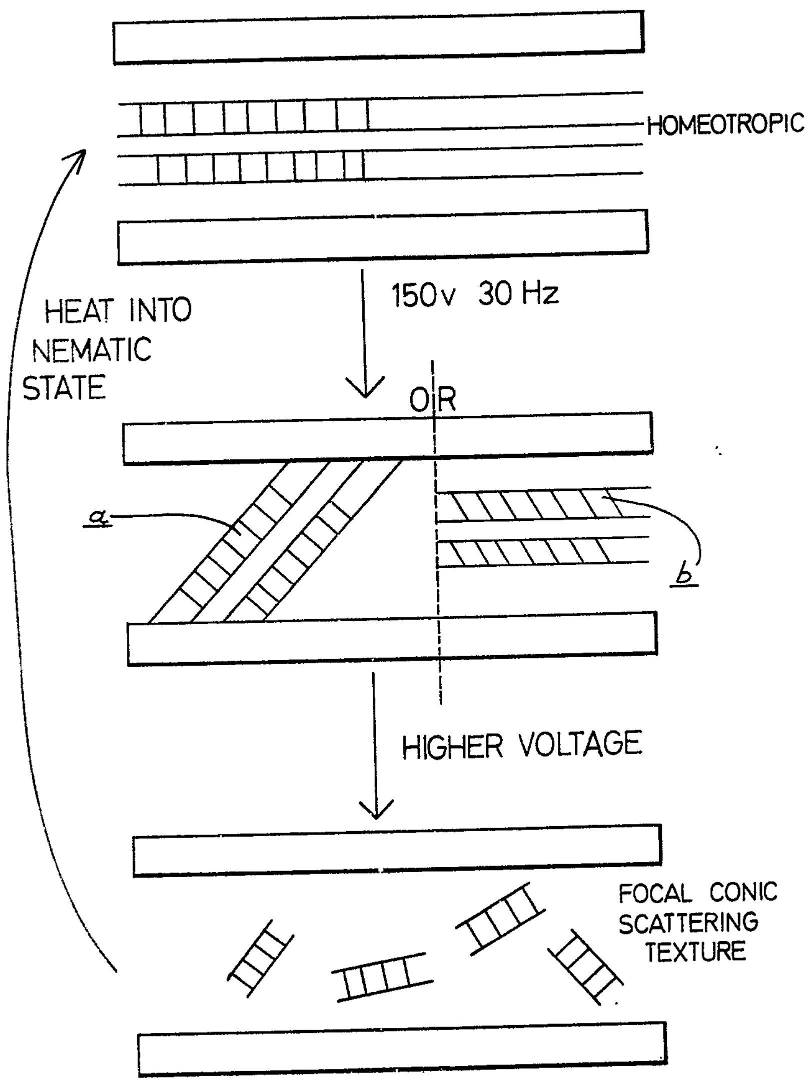


Fig.2.


HOMEOTROPIC
HEAT INTO
NEMATIC
STATE
150v 30 Hz
OR
a
b
HIGHER VOLTAGE
FOCAL CONIC
SCATTERING
TEXTURE

1569687 COMPLETE SPECIFICATION

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

Sheet 3

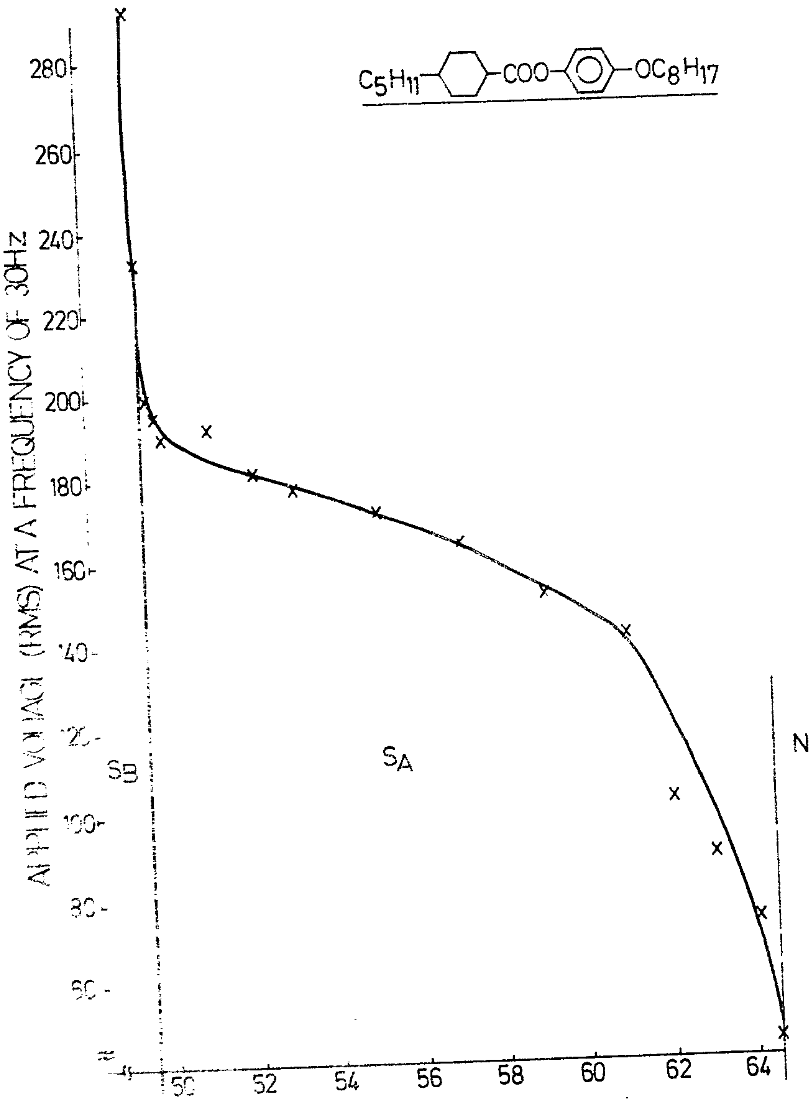


Fig.3