

Ferroelectric liquid crystal display cell

The invention relates to a liquid crystal display cell having: a chiral ferroelectric smectic liquid crystal layer whose helix structure is so influenced by the action of an electric field that its optical anisotropy alters; a pair of transparent plates between which the liquid crystal is disposed and which have a surface structure aligning the molecules of the liquid crystal and are provided with electrodes to produce an electric field therein; and one polariser each before and after the liquid crystal.

The effect of distortion of a helix structure of the kind hereinbefore set out by an electric field has been described in Ostrovski, B.I., *Advances in Liquid Crystal Research and Applications*, Oxford/Budapest, 1980, pp. 469 et seq. The effect is sometimes referred to in the literature by the abbreviation DHF for "distorted helix ferroelectric". The article considers the possibility of modulating a light beam at a frequency of 1 kHz and using an electric field of less than 6×10^{-3} V/cm. Subsequently, however, it was apparently found that this effect does not lead to an electro-optical cell which is usable in practice.

A known effect, but of a different kind, is Lagerwall and Clark's surface stabilized ferroelectric liquid crystal (SSFLC) in which ferroelectric liquid crystals are used in an untwisted configuration. This effect has been described in *Mol. Cryst. Liq. Cryst.* 94 (1983), 213-234 and 114 (1984), 151-187.

It is the object of the invention to provide a DHF cell which has not only the known advantages of the DHF effect but also the properties necessary for practical use as a light shutter or display cell.

According to the invention, this is achieved by a DHF cell of the kind hereinbefore set out wherein the ratio d/p of the thickness d of the liquid crystal layer to the pitch height p of the helical twisting is greater than 5, the smectic tilt angle θ_0 is between 22.5° and 50° and the product $d \cdot \theta_0^2 \cdot \Delta n \cdot 1/\lambda$ is greater than $0.1 \mu\text{m}$. Δn denotes the birefringence and λ denotes the wavelength of light.

Embodiments of the invention will be described hereinafter with reference to the accompanying drawings wherein:

Fig. 1 is a diagrammatic perspective illustration of a small part of a liquid crystal cell according to a preferred embodiment of the invention, and

Fig. 2 is a graph in which storage time is plotted against applied voltage.

As shown in Fig. 1, the liquid crystal cell according to the invention comprises a liquid crystal layer 1 disposed between two plates 2, 3 which are disposed in substantially plane-parallel relationship to one another and which are made of a transparent material such as glass, acrylic glass, plastics foils or the like. A polariser 4 is disposed before the front plate 2 and is preferably connected thereto, for example, by sticking. A polariser 5 is correspondingly associated with the rear plate 3. The plates are spaced apart from one another by a distance d .

The plate surfaces facing the liquid crystal have conventional electrode coatings which are segmented to represent characters or image dots. Referring to the cell part shown in the drawing, just a single electrode segment 6 is shown on the plate 2 and an opposite electrode segment 7 is shown on the rear plate 3.

Also, the surfaces facing the liquid crystal are so treated as to exert a directional effect on the adjacent liquid crystal molecules and thus to determine the direction of the director. This treatment consists, for example, of rubbing the surface in one direction to produce a planar orientation. Other possibilities are the oblique vapour coating of orienting layers etc. The result of such treatment will be referred to for the purposes of this description as surface orientation. The surface orientation on the two plates is indicated by arrows. The surface orientation on the rear plate 3 is parallel to that on the front plate. As well as planar surface orientation homeotropic orientation or combinations of both can be considered.

The polariser 4 associated with the front plate is so disposed as to include an angle β with the direction of the surface orientation or with the helix axis. The polariser associated with the rear plate is at a 90° offset from the front polariser. This arrangement of the polarisers is a preferred embodiment. Other polariser arrangements which also gives satisfactory results are possible. Appropriate polarizer

arrangements can readily be determined by simple optimizing.

The liquid crystal 1 is a chiral smectic ferroelectric liquid crystal often referred to in literature as smectic C. Liquid crystals of this kind are known from the literature. Their distinguishing feature is that their molecules are arranged relatively to the smectic planes not perpendicularly but at a particular angle known as the smectic tilt angle θ_0 . The chirality resides in that the molecule directions are not parallel to one another in all the layers but are twisted relatively to one another from layer to layer to give overall a helical twisting. In the case of a planar surface orientation the axis of this helical twisting is aligned parallel to the plates. Fig. 1 shows one molecule 8 per smectic layer and illustrates the helical twisting of the molecules relatively to one another along a helix axis 9, the twisting continuing from layer to layer. The smectic tilt angle θ_0 is the angle between the molecule longitudinal axis and the helix axis 9. When no field is acting on the liquid crystal the pitch height of the helix is p_0 .

When a voltage is applied to the electrodes 6 and 7, an electric field is produced in the liquid crystal and reorientates the molecules. In practice the symbolically indicated voltage source 10 delivers periodic signals or trigger pulses which in the case of the present cell may be of opposite polarity, as will be described in detail hereinafter.

In its normal state - i.e., in the absence of an applied electric field - the cell has a particular light transmittance. The application of an electric field distorts the helix arrangement of the molecules so that the light transmittance alters. There is an optical contrast between the two states. Basically, the helix structure distortion produced by the electric field alters the pitch height.

Depending on the relationship between light intensity and applied voltage, two different forms of operation are possible, viz. linear operation, in which light intensity is directly proportional to the applied voltage, and quadratic in which light intensity is proportional to the square of the voltage.

The effect occurs when the light beam passing through the liquid crystalline structure encounters an aperture

a corresponding to a number of periods p_0 of the helical structure. The electrooptical output effect is transmitted in this way along the helix direction.

As compared with effects in which the helical structure is completely cancelled, such as the SSFLC effect, there are a number of important differences.

1. The operating voltage depends upon the smectic tilt angle θ_0 , the polarization P_0 in the untwisted state and the ratio d/p of layer thickness to pitch height and is usually lower than the voltage U_0 required to cancel the helix. The range of operating voltages can be widened by increasing the ratio d/p_0 and enlarging the smectic tilt angle θ_0 .

2. The effect has a satisfactory modulation depth, a high contrast ratio and a grey scale approximately proportional to the applied voltage.

3. The effect permits a storage or memory effect controlled by the amplitude of the applied voltage. The time t_0 taken for the structure to return to the original undisturbed helix shape depends upon the viscosity and the elastic constants of the liquid crystal material and upon the pitch height of the helix. The storage time is also affected by surface conditions. For low pitch height values the storage time can be varied from very low values of approximately 10 - 100 μ sec to high values of 5 - 10 sec.

4. The effect is based on minor variations of the director orientation and does not alter the disinclination walls in the display zone. Consequently, there are no delay times in display operation.

5. In the planar configuration the effect is not sensitive to wall orientation. Conventional methods of wall orientation can be used as in nematic liquid crystals.

6. The effect permits the use of bipolar signals and of harmonic fields having a characteristic frequency f .

7. By means of appropriate control signals, optical phase differences can be so produced by the effect in the liquid crystal layer as to facilitate a colour changeover.

As previously stated, d/p_0 ratio parameters of greater than 5 are preferred, those greater than 10 being particularly preferred. The smectic tilt angle is preferably from 22.5° to 50° and particularly preferably from 25° to 40° . Also, the value of the so-called phase factor

$$\frac{d\theta_0^2 \cdot \Delta n}{\lambda}$$

is more than 0.45 and, particularly preferably, more than 1.

In the present example the liquid crystal consists of the following mixture: 26.1 wt.% 5-octyl-2-[p-(octyloxy)phenyl]pyrimidine, 17.1 wt.% 5-octyl-2-[p-(nonyloxy)phenyl]pyrimidine, 24.5 wt.% 5-octyl-2-[p-(decyloxy)phenyl]pyrimidine and 32.3 wt.% of a chiral additive which induces a high spontaneous polarization in the liquid crystal mixture and is chemically stable, colourless and readily soluble in conventional liquid crystal materials, more particularly in ferroelectric smectic liquid crystals.

The liquid crystal material having a tilted smectic phase can consist of conventional materials. Materials having a smectic C-phase, such as derivatives of phenylpyrimidine, phenylpyridine, phenylbenzoate, benzoate acid biphenylester and 4-biphenylcarboxylic acid-phenylester having a smectic C-phase are preferred.

In the cell having this liquid crystal mixture the pitch height p_0 is 0.3 to 0.4 μ at 25°C and the birefringence Δn is 0.25. The smectic tilt angle θ_0 is approximately 29° at room temperature. The spontaneous polarization P_s is approximately $7 \cdot 10^{-8} \text{ c/cm}^2$ at 25°C . Rotation viscosity is approximately 1 poise. The liquid crystal layer in the cell has a thickness of 3.6 μm . The voltage U needed for complete cancellation of the helix structure is approximately 2 V. The response time of this cell is approximately 200 μsec . The response time for the entire applied voltage range $0 < U < U_u$ is approximately of the same length.

The preferred values for the angle β are $\beta = 22.5^\circ$ ($\pi/8$) or $\beta = 67.5^\circ$ ($3\pi/8$) for linear operation and $\beta = 0$; $\beta = 45^\circ$ ($\pi/8$), or $\beta = 90^\circ$ ($\pi/2$) for quadratic operation.

The resulting cell provides a contrast of more than 100 : 1. The following table lists the intensity values I for a series of voltage amplitudes. The voltage is in the form of rectangular pulses. The values are for linear operation.

Table

U[V]	I [%]
0	1
0.15	10
0.25	20
0.45	35
0.6	55
1.0	90
1.5	99
1.75	98
2.0	97
2.45	80
2.6	65
2.95	50
3.3	40
4.0	35
5.15	35

The maximum intensity value is 100%. The first values in the 0-2 volts voltage range indicate the obtainable grey scale. Contrast decreases above 2 volts due to the higher smectic tilt angle. The helix unwinds completely at voltages above 4.0 volts.



C L A I M S

1. A liquid crystal display cell having: a chiral ferroelectric smectic liquid crystal layer whose helix structure is so influenced by the action of an electric field that its optical anisotropy alters; a pair of transparent plates between which the liquid crystal is disposed and which have a surface structure aligning the molecules of the liquid crystal and are provided with electrodes to produce an electric field therein; and one polariser each before and after the liquid crystal, characterised in that the ratio d/p of the thickness d of the liquid crystal layer to the pitch height p of the helical twisting is greater than 5, the smectic tilt angle θ_0 is between 22.5° and 50° and the product $d \cdot \theta_0^2 \cdot \Delta n \cdot 1/\lambda$ (phase factor) of the thickness d , the square of the tilt angle θ_0 , the value of the birefringence Δn and the reciprocal of the wavelength λ of light is greater than $0.45 \mu\text{m}$.
2. A cell according to claim 1, characterised in that the ratio d/p is greater than 10.
3. A cell according to claim 1, characterised in that $\theta_0 = 29^\circ$.
4. A cell according to claim 1, characterised in that the phase factor is greater than 1.
5. A cell according to claim 1, characterised in that the angle β between the helix axis and the polarization direction of the input-side polariser is 22.5° or 67.5° when the cell is operated in a form in which the intensity of the transmitted light is proportional to the applied voltage.
6. A cell according to claim 1, characterised in that the angle β between the helix axis and the polarization direction of the input-side polariser is 0° or 45° or 90° when the cell is operated in a form in which the intensity of the transmitted light is proportional to the square of the applied voltage.
7. A cell according to claim 1, characterised in that the surface structure of the plates has an effect aligning the liquid crystal molecules planarly.
8. A cell according to claim 1, characterised in that the polarisers are crossed.