

The invention relates to a liquid crystal display (LCD) cell comprising a twisted nematic liquid crystal layer which is disposed between two plates and polarizers having electrodes and surface orientations and which has a positive dielectric anisotropy.

The invention relates more particularly to an LCD cell of the kind set out wherein the nematic liquid crystal layer has a low optical path difference.

If they are to have a high multiplex ratio, LCD cells must of course have a steep electro-optical characteristic. The corresponding development was concentrated on highly twisted nematic structures. The term "highly twisted nematic structures" is to be understood as denoting structures having a twist of more than 90° . Of course, doping with chiral additives is usually necessary to produce such a twist.

The advantages of liquid crystal cells having highly twisted nematic structures are a very steep electro-optical characteristic and a wide viewing angle range. the steep electro-optical characteristic leads to high multiplex ratios which are necessary to provide displays of high information density.

However, little regard was had for the fact that the main requirement for some purposes is not a high multiplex ratio but the possibility of providing a highly differentiated grey scale. This is more particularly the case, for example, for television applications.

The importance of a grey scale for the projection of colour images is apparent from EP-A 23 796. This specification describes a projection system in which a projection beam in a liquid crystal cell is modulated by means of an image information contained in a second beam incident on the other side of the cell. This is, therefore, a relatively complex system in which the theoretical simplicity of LCD cells is no longer applicable.

It is therefore the object of the invention to provide an LCD cell having an electro-optical characteristic with a very low slope.

According to the invention, this object is achieved by an LCD cell of the kind hereinbefore mentioned which is characterized by the combination of: a twist angle ϕ of

from 10° to 80° ; an angle θ between the surface orientation direction and the polarization direction of the plate on the light incidence side of from -30° to 60° ; an angle ψ between the polarization directions of the two polarizers of from 80° to 110° ; and an optical path difference $\Delta n \cdot d$ of from 0.2 to $0.7 \mu\text{m}$.

For the purposes of this description the angles indicated are to be understood as follows: The twist angle ϕ is the angle included between the planes which are defined by the two nematic directors on the front plate - i.e., the plate on the light incidence side - and on the rear plate and which are perpendicular to the plates - i.e., in other words the angle by which the nematic directors are offset from one another. This definition corresponds to the conventional definition.

The angle θ is the angle between the surface orientation on the front plate or on the nematic director n_1 on the plate and the polarization direction of the polarizer associated with the last-mentioned plate. Positive values of the angle θ indicate that the polarization direction is outside the angle ϕ while negative values of θ indicate a polarization direction between the nematic directors.

The angle ψ is the angle by which the polarizers are offset from one another. The polarizers are called crossed when they substantially bar the passage of light without any light-influencing means between them. This means that the term "crossed" covers all the corresponding values of ψ and is not limited exclusively to a 90° offset.

The resulting cell provides a positive contrast display and, surprisingly, is not coloured for low values of $d\Delta n$ and $\theta \neq 0$.

In positive contrast displays electrically energized segments appear dark on a bright background whereas in negative contrast displays the situation is the converse.

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

Figure 1 is a diagrammatic exploded view of an LCD cell according to the invention;

Figure 2 is a diagram showing the arrangement of angles, the surface orientations and the polarizers relatively to one another, and

Figure 3 illustrates a voltage-contrast curve of a preferred embodiment.

The LCD cell according to the invention is of very similar construction to known cells, such as Twisted Nematic LCDs (Schadt and Helfrich, Appl. Phys. Lett. 18, 127 [1971]), so that there is no need here to go into constructional details. The cell according to the invention comprises a liquid crystal layer 1 isposed between two plates 3, 4 which are disposed substantially plane parallel to one another and which are made of a transparent material such as glass or acrylic glass or plastic foils or the like. A polarizer 4 is disposed before the front plate 3 and is preferably connected thereto, for example, by sticking. A polarizer 5 is similarly associated with the rear plate 4. The plates are separated from one another by a spacing or gap d.

On their surfaces facing the liquid crystal the plates 2, 3 have conventional electrode coatings 6 segmented for the display of symbols or dots. Also, the surfaces are so treated as to exert a directional effect on the adjacent liquid crystal molecules and thus determine the direction of the nematic director n. The treatment resides, for example, in rubbing the surface in one direction or in the oblique evaporation of orienting layers etc.; it is not necessary, but neither is it disadvantageous, to provide a tilt angle. The result of this treatment will be called surface orientation for the purpose hereof. An arrow 7 indicates the surface orientation on the front plate 2. The surface orientation on the rear plate 3 is offset from that of the front plate and is indicated by an arrow 8.

The front plate polarizer 4 is so disposed that its polarization direction includes relatively to the twist angle in the outwards direction a predetermined angle which will be described in greater detail hereinafter. The rear polarizer 5 is so disposed that its direction of polarization crosses that of the first polarizer.

The liquid crystal 1 is a nematic liquid crystal which can have chiral additives.

Figure 2 illustrates the relative angular relationships of the nematic directors and the polarization directions. As previously stated, n_1 is the nematic director on the front plate 2 and n_2 is the nematic director on the back plate 3. The angle of twist between the two nematic directors has the reference ϕ . This angle is approximately 50° in the present embodiment. However, it can vary on either side of 50° . Satisfactory results are obtained with absolute values of ϕ between 10° to 80° , preferably 20° and 60° , more particularly 30° and 50° .

The front polarizer 4 has a polarization direction P_1 . In this embodiment such direction is offset by an angle θ of 20° from the nematic director n_1 . However, the direction P_1 of the front polarizer 4 can vary by an angle θ from the nematic director n_1 in a range of from $-30^\circ < \theta < 60^\circ$. In other words, the polarizers can be arranged symmetrically of the nematic directors. The condition for this is $\theta = (90^\circ - \phi)/2$ if $\psi = 90^\circ$. Symmetry is preferable but not obligatory. The polarization direction P_2 of the rear polarizer 5 is offset from that of the front polarizer P_1 by an angle ψ which is preferably 90° . However, satisfactory results are obtained with an angle ψ of from 80° to 110° . The polarization directions P_1 and P_2 can be changed over without adverse results.

In other preferred embodiments, for example, $\phi = 30^\circ$, $\theta = 30^\circ$ and $\psi = 90^\circ$, the following liquid crystal mixture (mixture "A") being used in a layer of a thickness $d = 3.4 \mu\text{m}$:

Mixture "A"

<u>Component</u>		<u>Concentration</u>
		<u>(weight %)</u>
Ød(4)CP	p-[trans-4-(4-pentenyl) cyclohexyl]benzonitrile	8,000
5CP	p-(trans-4-pentylcyclohexyl)benzonitrile	11,000
4P(1)P	p-(5-butyl-2-pyrimidinyl)-benzonitrile	3,000
5CAPO2	p-[2-(trans-4-pentylcyclohexyl)ethyl]-ethoxybenzene	6,000

3CEC3	trans-4-propylcyclohexane carboxylic acid-trans-4- -propylcyclohexyl ester	8,000
4CEC4	trans-4-butylcyclohexane carboxylic acid-trans-4- -butylcyclohexyl-ester	11,000
5CEC3	trans-4-pentylcyclohexane carboxylic acid-trans-4 -propylcyclohexyl-ester	11,000
5CPAC4	1-[2-(trans-4-butylcyclo- hexyl)-ethyl]-4-(trans-4- -pentylcyclohexyl)benzene	9,500
5CPPAC4	4-[2-(trans-4-butylcyclo- hexyl)-ethyl]-4'-(trans-4- -pentyl-cyclohexyl)biphenyl	5,500
5CPAPAC4	4-(trans-4-pentylcyclohexyl) -4'-[2-(trans-4-butylcyclo- hexyl)-ethyl]-1,1'-ethylene- dibenzene	7,000
4CEPO2	trans-4-butylcyclohexane carboxylic acid-p-ethoxy- -phenylester	11,000
5CEP01	trans-4-pentylcyclohexane carboxylic acid-p-methoxy- hexylester	9,000

A second example was prepared with the following mixture "B":

Mixture "B"

<u>Component</u>		<u>Concentration</u>
		<u>(weight %)</u>
4P(1)P	p-(5-butyl-2-pyrimidinyl)- benzonitrile	8,820
0d(3)CP	p-[trans-4-(3-butenyl)- cyclohexyl]benzonitrile	7,390
1d(3)CP	p-[trans-4-(3E-pentenyl)- cyclohexyl]benzonitrile	7,420

Ød(4)CPP	4'-[trans-4-(4-pentenyl)-4-biphenylcarbonitrile	6,170
3CEC3	trans-4-propylcyclohexane carboxylic acid-trans-4-propylcyclohexyl ester	21,050
4CEC4	trans-4-butylcyclohexane carboxylic acid-trans-4-butylcyclohexylester	28,100
5CEC3	trans-4-pentylcyclohexane carboxylic acid-trans-4-propylcyclohexylester	21,050

The designation of the components is known to the skilled addressee. Reference is made in this connection, for example, to the publication of Schadt, M. et al in Mol. Cryst. Liq. Cryst. 122 (1985) 241ff and in Proc. Int. Displ. Res. Conf., San Diego (1985).

The following Table 1 lists the relevant parameters of the two mixtures "A" and "B".

Table 1

	Mixture "A"	Mixture "B"
Clearing point T _{Cl} [°C]	72	42.5
Melting point T _m [°C]	<-20	<0
n _o	1,432	1,476
Optical anisotropy Δn	0,086	0,072
Viscosity	23	21
η (at 22°C) [m Pa. s]		

The electro-optical results compiled in the following Table 2 were obtained with these mixtures. The results achieved with the novel cell according to the invention are in each case compared with the values obtained with the same liquid crystal mixtures in a conventional twisted nematic cell and listed in the third column.

Table 2

Mixture "A"

	$\phi=30^\circ$ $\theta=30$ $\psi=90$	$\phi=60^\circ$ $\theta=15$ $\psi=90$	$\phi=90$ $\theta=0$ $\psi=90$
V_{10} (Volt)	2.165	2.058	1.971
V_{50} (Volt)	2.895	2.617	2.265
P_0	0.337	0.271	0.149
d [μm]	3.4	3.8	4.0
$d\Delta n$ [μm]	0.29	0.33	0.34

Mixture "B"

	$\phi=30^\circ$ $\theta=30$ $\psi=90$	$\phi=60$ $\theta=15$ $\psi=90$	$\phi=90$ $\theta=$ $\psi=90$
V_{10} (Volt)	1.562	1.614	1.441
V_{50} (Volt)	2.092	2.015	1.671
P_0	0.339	0.248	0.159
d [μm]	4.5	6.0	7.0
$d\Delta$ [μm]	0.32	0.43	0.50

Key to Table 2:

V_{10} denotes the optical threshold voltage at 10% extinction (or 90% transmission).

V_{50} denotes the voltage at 50% extinction or transmission.

p_0 denotes the steepness of the transmission curve at a viewing or light incidence angle $\beta = 0^\circ$ in accordance with the formula:

$$p_0 = \frac{V_{50} - V_{10}}{V_{10}}$$

Figure 3 shows the contrast curves characteristic of the electro-optical behaviour as compared with a conventional twisted nematic cell, the curves having been taken in white light at $\phi = 30^\circ$, $\theta = 30^\circ$ and $\psi = 90^\circ$ (curve I) at $\phi = 60^\circ$, $\theta = 15^\circ$ and $\psi = 90^\circ$ (curve II) and at $\phi = 90^\circ$, $\theta = 0^\circ$ and $\psi = 90^\circ$ (twisted cell, curve III). Clearly, the curve becomes steeper as the angle of twist increases.

The cell hereinbefore described can be operated in transmission and in reflection.

Claims

1. A liquid crystal display (LCD) cell comprising a twisted nematic liquid crystal (1) disposed between two plates (2, 3) and polarizers having electrodes (6) and surface orientations, the liquid crystal having a positive dielectric anisotropy, a twist angle ϕ of from 10° to 80° , an angle θ between the surface orientation direction and the polarization direction at one of the two plates (2) from -30° to 60° , negative angles of θ meaning that the said polarization direction lies within the area formed by the twist angle ϕ , characterised in that the angle ψ between the polarization directions of the two polarizers (4, 5) is from 80° to 110° , and the optical path difference being the product $\Delta n \cdot d$ of the optical anisotropy Δn and the thickness d of the liquid crystal is from 0.2 to $0.7 \mu\text{m}$.
2. A cell according to claim 1, characterized by an optical path difference $\Delta n \cdot d$ of from 0.3 to $0.5 \mu\text{m}$.
3. A cell according to claim 1, characterized by a twist angle ϕ of from 20° to 60° .
4. A cell according to claim 3, characterized by a twist angle ϕ of from 30° to 50° .
5. A cell according to claim 1, characterized in that the angle θ is defined by the condition $\theta = (90^\circ - \phi)/2$, the angle ψ between the polarizers being 90° .
6. A cell according to claim 1, characterized by an angle θ of from 0° to 60° .
7. A cell according to claim 1, characterized by an angle θ of from -30° to 0° .
8. A cell according to claim 1, characterized by an angle ψ of 90° .

