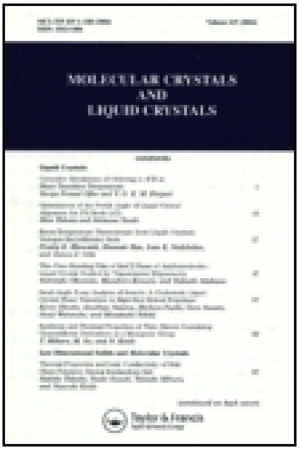

Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl19

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Version of record first published: 24 Sep 2006.

Mol. Cryst. Liq. Cryst., 1992, Vol. 220, pp. 99–104
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Printed in the United States of America

Observation of Dielectric Biaxiality in a Ferroelectric Liquid Crystal by the Excitation of Optic Modes†

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(Received July 26, 1990)

The method of AC stabilization to enhance the contrast of a ferroelectric liquid crystal (FLC) device is well established, however the actual process taking place is not well understood. Here a careful analysis of propagating optic mode data for an AC stabilized cell leads to the conclusion that the AC stabilization process involves a torque around the smectic cone, very similar to the DC/dipole interaction. This shows that the dielectric tensor of a FLC is BIAXIAL. The degree of this biaxiality is measured by comparison between AC and DC interaction energies.

Keywords: ferroelectric liquid crystals, dielectric biaxiality, AC stabilization

INTRODUCTION

Surface stabilized ferroelectric liquid crystal (SSFLC) cells have many possible applications in light shutters and display devices.[1] There are however a number of problems in the practical development of such devices, one of these being the instability of the switched states in FLC cells. It is generally observed that after a switching pulse is removed the angle of extinction for a cell placed between crossed polaroids is seen to decrease considerably.[2] One of the ways in which this difficulty can be reduced is to stabilize the switched states by the application of a high frequency (hf) AC field across the cell.[3] This leads to the so called AC-stabilized system, and it is the mechanism of this which is investigated here. Previously it has been thought that the process involved was due to the negative dielectric anisotropy of FLC materials,[3] but recent work has indicated otherwise.[4,5]

If the average molecular axis of the FLC lies in the plane of the cell surfaces in a thin FLC cell as indicated by the chevron structure[6,7] and a careful analysis of optic mode data for zero surface tilt cells,[8] then the mechanism of the AC-stabilization cannot be due to negative dielectric anisotropy in the FLC material. Since

†Presented at the 13th International Liquid Crystal Conference, Vancouver, B.C., Canada, 22–27, July 1990.

the director lies in the plane of the cell surfaces it will already be at an energy minimum and no response to a hf AC field should be seen. There must therefore be some other process involved.

TECHNIQUE

Here the technique of examining the optic tensor configuration in a thin dielectric layer by the propagation of optic modes will be used. This has previously been used to demonstrate that the relaxed state in a FLC cell is largely equivalent to a uniform slab of material rotated out of the surface alignment direction[8] and also to investigate the optic tensor profile under the application of a forward bias DC field.[9]

A sample is formed as shown in Figure 1, with a thin aligned layer of FLC (in this case the BDH material SCE3) contained between silver coated glass pyramids. This structure allows the excitation of guided modes in the silver/liquid crystal/ silver system and the propagation of surface plasmon-polaritons (SPPs) at the silver/ liquid crystal interface.[10] The former are modes with various field distributions across the FLC layer which allow the bulk dielectric tensor configuration to be examined. The latter are surface localized modes which are sensitive to optic properties (and hence optic tensor configuration) near the cell surfaces. These modes are excited by light incident in one of the glass pyramids and are observed as dips in the reflectivity monitored as a function of the angle of incidence at the glass/liquid crystal interface. Comparison of the reflectivity data with theoretically generated curves[11] allows models of the optic tensor configuration in the FLC layer to be evaluated.

Here we examine the optic tensor profile under a hf AC field to determine the dielectric induced reorientation process taking place. The frequency used must be well above the relaxation frequency due to the sensitivity of this method to small perturbations in the liquid crystal orientation (~50 kHz is used).

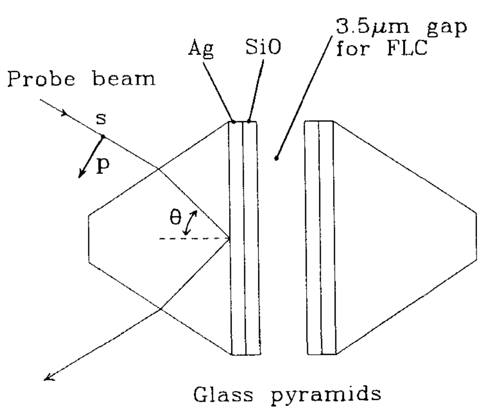

FIGURE 1 The FLC cell used in the work here, formed from glass pyramids. These are coated with 45 nm of Ag and a 20 nm low surface tilt aligning layer of SiO. The cell is formed with a gap of ~3.5 μm, and reflectivity data are taken as a function of the angle of incidence θ.

RESULTS

Monitoring the reflectivity for p-polarized (Transverse Magnetic) light with the surface alignment direction of the sample oriented perpendicular to the plane of light propagation, with the cell in the relaxed (no field applied) state, leads to a curve shown by the dashed line in Figure 2. Previously we have shown that such data is well modelled by a uniform slab,[8] which is consistent with the chevron structure in the smectic layering. Application of a field across the FLC layer results in a distortion of the optic tensor configuration in the cell and a resulting change in the reflectivity curve is seen. This leads to information about the reorientation taking place in the cell.

Application of ≃10 V rms AC at 50 kHz across the cell leads to the reflectivity curve shown by the crosses in Figure 2. This can no longer be reproduced by modelling the FLC layer as a uniform slab, indicating that a complex distortion is taking place. Iterative modelling has shown that tilt out of the surface plane is taking place under the application of an AC stabilizing field. Careful analysis of the reflectivity data shows that the distorted optic tensor profile is very similar to that observed under the application of a DC field.[9] Modelling the profile in this way, with a pinned point at the chevron interface, and allowing the optic tensor to rotate around the cone within a chevron type structure in the smectic layering,

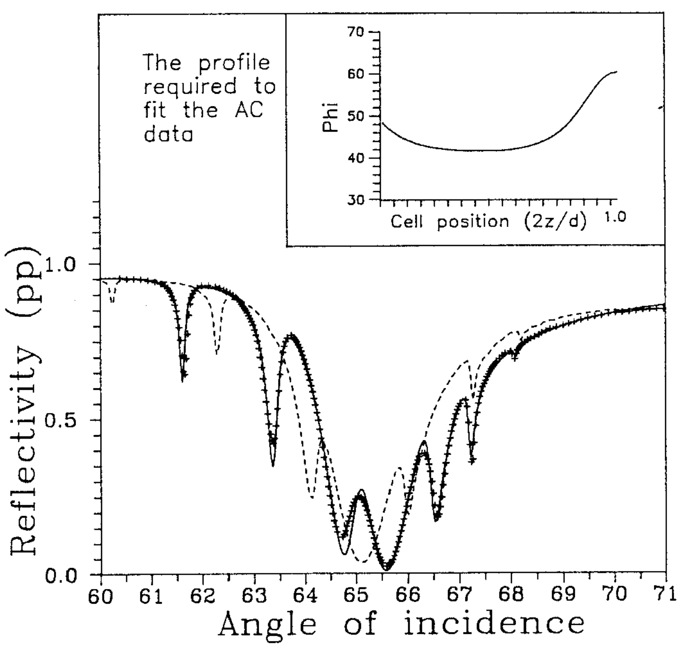

FIGURE 2 The dashed line shows a reflectivity curve with the cell in the relaxed state, for p-polarized light, with the surface alignment direction of the cell oriented perpendicular to the plane of light propagation. The crosses are data when ≃ 10V rms AC at 50 kHz is applied. The continuous line is a fit to this data, which required a director profile (in each half of the cell) as illustrated in the inset, where the angle ϕ is as shown in Figure 3.

leads to a fit to the data shown by the continuous line in Figure 2. The distorted optic tensor profile present in the cell is illustrated in the inset of Figure 2.

This shows that under a hf AC field the distortion causes out-of-the-plane tilt in a FLC cell. There must therefore be a torque around the smectic cone similar to that present under the application of a forward bias DC field. Since the material lies flat in the surface plane in the relaxed state, and has negative dielectric anisotropy this indicates that the dielectric tensor is BIAXIAL.

ANALYSIS

An axes system is set up as shown in Figure 3. In this sytem the cone angle θ, layer tilt angle (chevron angle) δ and azimuthal angle ϕ are labelled as normal. In addition the dielectric tensor of the system (ε_1, ε_2, ε_3) is set up with ε_1 along the molecular long axis, ε_2 along the spontaneous polarization and ε_3 perpendicular to these. Now assuming uniaxiality (i.e., $\varepsilon_2 = \varepsilon_3$) the manufacturers quote $\Delta\varepsilon = -1.6$. However for a torque to exist around the smectic cone (leading to out of plane tilt) we must have $\varepsilon_2 > \varepsilon_3$ here in a BIAXIAL system.

In order to obtain a measure of the biaxiality we note that the distortion profiles observed are very similar under AC and DC fields.[4] Thus it should be possible to apply an AC stabilizing signal, causing distortion in the optic tensor profile with changes in the corresponding reflectivity curve (Figure 2), and then to remove this distortion by the simultaneous application of a reverse bias DC field. Knowing the spontaneous polarization of the material and comparing the applied AC and DC fields allows the determination of the AC induced torque, and hence the biaxiality of the FLC.

Doing this works well for small fields, but the reverse bias DC fields destabilize the system when they become greater than ~0.3 V. The resulting AC field applied verses DC back-off field is shown in Figure 4. Here the open circles are the data and the continuous line is a best fit to this using a power law. The expected exponent is 0.5, since the DC interaction energy is $\propto$ E and the AC interaction energy is $\propto$

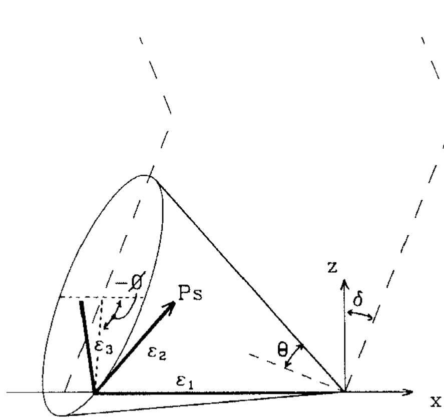

FIGURE 3 The axes set up to define the tensor in the FLC. Conventional labels are used for the cone angle etc.

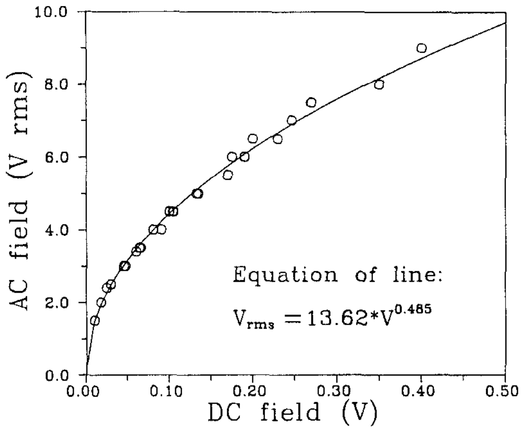

FIGURE 4 Plot of data (open circles) for the required reverse bias DC field to cancel the effect of an AC stabilizing field at 50 kHz, found by examining the reflectivity curve. A fit to this yields a relationship between the AC and DC field effects, and hence a value for the biaxiality in the FLC dielectric tensor.

E^2. The exponent of the best fit line is 0.485 ± 0.02, which is within experimental error of this (though the measured exponent may be expected to be smaller due to the additional dielectric interaction with the DC field).

Comparison of the normalized interaction energy densities for the AC and DC cases,[4] using the data shown in Figure 4 leads to:

$$\varepsilon_2 - \varepsilon_2 = 0.3 \pm 0.05$$

for SCE3 at room temperature.

CONCLUSIONS

It is seen that to explain the reflectivity data observed for a FLC cell under the application of a hf AC field an optic tensor profile which involves out of plane tilt must be introduced. Since the largest dielectric constant of the material lies along the molecular long axis this indicates that the dielectric tensor is BIAXIAL. Application of a reverse bias DC field to remove the distortion caused by an AC field allows the value of $\varepsilon_2 - \varepsilon_3$ (=0.3) to be derived.

Acknowledgment

SJE acknowledges the support of the Wolfson trust and the SERC through a CASE award with Prof. M. G. Clark of GEC.

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