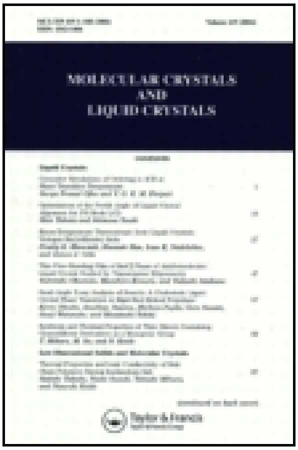

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A Study of Elastic Deformation During Voltage Switching of a Ferroelectric Liquid Crystal Cell

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A Study of Elastic Deformation During Voltage Switching of a Ferroelectric Liquid Crystal Cell

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Ferroelectric liquid crystal devices are primarily of interest owing to their truly bi-stable operation and fast switching times. At present our understanding of the switching processes in ferroelectric liquid crystal cells is incomplete. In order to develop a more complete understanding it is necessary to have a detailed knowledge of the optical tensor configuration adopted by liquid crystalline materials in cells. In this paper we present results of a half-leaky guided mode study of voltage induced elastic deformations of the director profile in a cell containing a homogeneously aligned 40% chiral mixture of the ferroelectric liquid crystal SCE8. The experimentally deduced changes in the director structure are highly accurate and may be used to test theoretical models of surface stabilised ferroelectric liquid crystal devices.

Keywords: guided-mode; ferroelectric liquid crystal; chevron; switching

INTRODUCTION

Polarised microscopy is, perhaps, the most common and convenient method of examining a liquid crystal cell. However, results from optical microscopy experiments are fundamentally limited as they are deduced from the integrated optical response of any given cell. A more detailed study of the spatial variation of the optic tensor configuration (director profile) within a liquid crystal cell can only be made using a non-integral technique. Guided mode techniques are the primary non-integrating probe and are ideally suited to detailed studies of the director profile within liquid crystal cells.

A typical liquid crystal device has a thickness of several microns. In order to excite guided modes in such a waveguide the wavelength of the probing radiation has to be less than about twice the optical thickness of the guide. Radiation of 632.8 nm from a standard HeNe laser fulfils this criteria and is commonly used to excite in guided mode studies of cells with thicknesses down to ~ 1 μm. Generally the incident light is momentum coupled into the cell via a coupling prism (or alternatively a grating method[1] may be used).

By varying the component of momentum of the incident light along the waveguide it is possible to excite a range of guided modes associated with a given system. This is achieved by altering the incident angle of the probing radiation. A convenient angle scan arrangement is shown in figure 1 where the sample is set on a rotating stage.

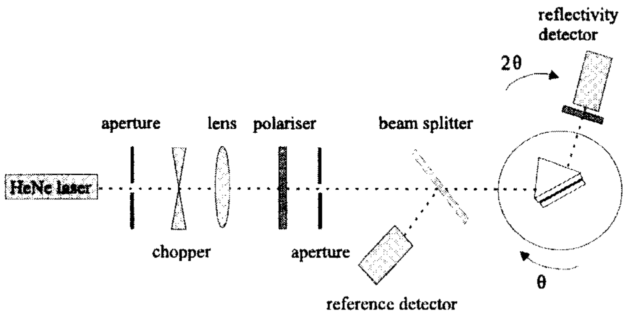

FIGURE 1: The standard guided mode experimental set-up.

Essentially the guided mode experiment involves monitoring the angle dependent signal from a given cell geometry. The form of the angle dependent reflectivity is governed by the director profile of the liquid crystal and the optical properties of the cell, (including alignment layers). Comparing experimentally recorded reflectivity with the predicted reflectivity from multi-layer optics theory[2] yields information pertaining to the entire liquid crystal cell.

The fully-guided mode technique was the first to be used to study the director profile in SSFLC's[3]. The cell geometry used in that technique incorporates two thin layers of silver which form a highly efficient optical cavity. Consequently the angle dependent reflectivity features recorded are very sharp enabling the director profile to be studied in great detail. However, such a technique is not ideally suited to studies of cells which incorporate rubbed polyimide alignment layers as the thin silver layers are damaged during the rubbing process.

The fully-leaky technique (with high index cells[4]) and later the development of the half-leaky guided mode technique[5] in 1993 enabled the director profile in cells with rubbed polyimide alignment layers to be studied in detail. The main feature of the half-leaky guided mode geometry (shown in figure 2) is that it is fabricated from a high refractive index superstrate and a low refractive index substrate pair. The typical form of the angle dependent reflectivity features can be divided into two distinct angular regions occurring either side of a critical edge feature whose angular position is related to the refractive indices of the prism/top plate and substrate via Snell's law. At angles of incidence before the critical edge the liquid crystal waveguide is lossy and the reflectivity features are broad. This region is termed the "fully-leaky" region. Beyond the critical edge the low index glass substrate acts as a perfect mirror and hence the reflectivity features are more intense and are highly featured. The higher angle region is often referred to as the "half-leaky window" and is particularly sensitive to details of the director profile in liquid crystal cells. It is worth noting that the polarisation conversion signals, (R_{sp} and R_{ps}), recorded using the half-leaky guided mode technique are stronger than those associated with the fully-guided mode technique in which the polarisation conversion signal is surpressed by the silver layers. This is important because the polarisation conversion signal is likely to be highly sensitive to the twist and tilt profiles of the optically anisotropic liquid crystal layer.

EXPERIMENTAL

A high quality cell is a necessary pre-requisite to any guided mode experiment. In particular it is important that the cell thickness is uniform over the area probed by the incident radiation and that the liquid crystal region forms a monodomain. The cell geometry used in this study is illustrated in figure 2. Both glass plates are ITO coated and have rubbed polyimide alignment layers which are arranged to give parallel homogeneous alignment of the director at the surface boundary. Cell thickness and flatness are established using a UV-cured glue containing 3 μm glass beads.

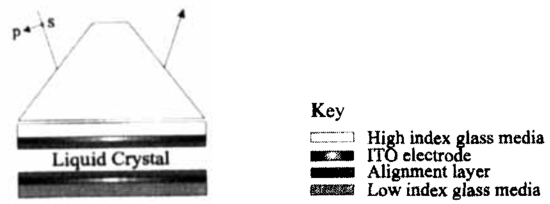

FIGURE 2: The half-leaky guided mode cell geometry.

The cell is initially filled under vacuum at 100 ^{0}C (at which temperature SCE8 is in the isotropic phase) and then cooled through the S_A*/S_C* phase transition into the S_C* phase at a rate of 4 ^{0}C per hour resulting in a uniform monodomain sample at room temperature.

THE CONE AND CHEVRON GEOMETRY

The co-ordinate geometry used for modelling the liquid crystal director profile is illustrated in figure 3.

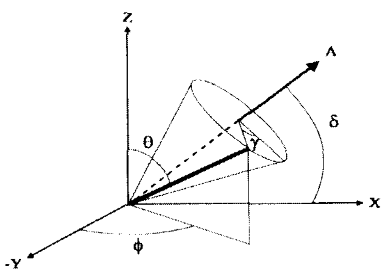

FIGURE 3: The cone and chevron co-ordinate geometry.

Equation (1) relates the Euler angles twist (ϕ) and tilt (θ) to the layer tilt (δ) and cone angle (θ_C) parameters used in the cone and chevron model. This equation can be re-arranging to give a quadratic equation in sin δ.

$$\cos(\theta_C) = \sin(\phi)\cos(\delta)\sin(\theta) + \sin(\delta)\cos(\theta) \qquad \text{Eq (1)}$$

Solving this equation yields the layer tilt variation through the cell. Careful fitting to R_{sp} data recorded with no voltage applied across the cell yields the Euler angle description of the director profile which is used to calculate the layer tilt variation. Calculations (based upon a cone angle of 23^0) reveal a symmetric C2 cone and chevron model in which the smectic layers are tilted by 20.5^0 with respect to the surface layer normal. Substituting interpolated layer tilt angles and Euler angles into equation (2) yields the rotation (γ) of the director around each of the smectic cones. The rotations describe the usual triangular director profile anticipated for low P_S materials in the chevron geometry.

$$\cos(\theta) = \cos(\theta_C)\sin(\delta) - \sin(\theta_C)\cos(\delta)\cos(\gamma) \qquad \text{Eq (2)}$$

APPLIED VOLTAGE DATA ACQUISITION

Care must be taken to avoid charge build-up within the cell when applying DC voltages over the time period required to record the angle dependent reflectivity data. Previously workers have overcome the potential problem of charge build-up by applying a triggered "staircase" function pulse across the cell at each angular step of the rotating table.

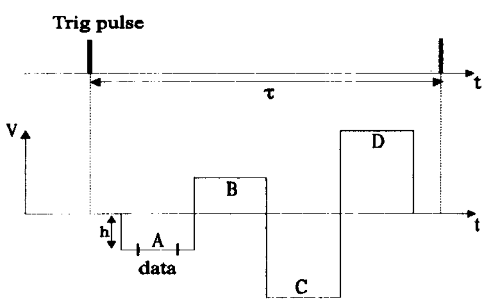

FIGURE 4: Timing sequence of the "staircase function."

The staircase function shown in figure 4 is designed such that areas of blocks A, B, C and D average to zero. Each block in the staircase function is 100 ms long and data acquisition occurs within block A. The final 2V pulse ensures recovery of the initial switched state.

FITTING APPLIED VOLTAGE DATA

Voltage induced changes in the director profile are modelled by modifying the rotation of the director around the C2 cone and chevron model deduced. In fitting the data it is assumed that deformation of the smectic layers may be ignored and that the chevron interface remains centrally located within the cell.

A representative fit to R_{sp} data recorded with 500 mV applied across the cell is shown in figure 6. The director profile used to generate this fit is obtained through a process of hand fitting and is represented by the circles in figure 5. The second director profile, represented by the continuous line in figure 5, is derived from the incompressible, continuum theory developed by C. V. Brown et al in which the form of the bulk elastic free energy density equation is given by the expression:

$$W_B = [(B_1\sin^2\phi + B_2\cos^2\phi)\cos^2\delta + B_3\sin^2\delta - B_{13}\sin\phi\,\sin 2\delta]\phi'^2$$

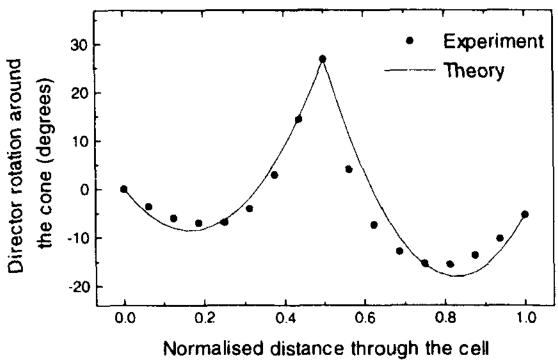

FIGURE 5: Director profiles derived theoretically and through hand fitting.

Essentially the director profile generated theoretically is a best line fit to the one determined experimentally. R_{sp} features generated using the director profile predicted by the continuum theory are compared in figure 7 with R_{sp} data recorded experimentally.

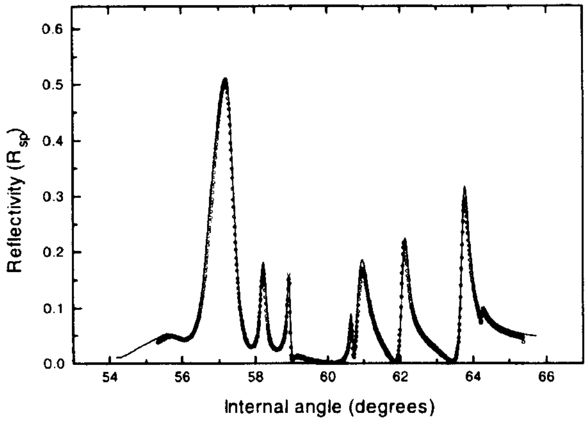

FIGURE 6: Fitted R_{sp} data with 500 mV applied across the cell.

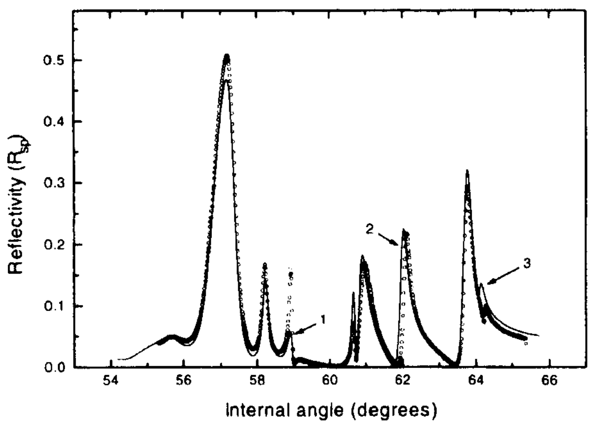

FIGURE 7: Continuum theory fit to R_{sp} data with 500mV applied across the cell.

A clear difference in the quality of the two fits shown in figures 6 and 7 demonstrates the sensitivity of the R_{sp} signal. This enables us to distinguish between the two director profiles proposed and also indicates the level of accuracy achieved by hand fitting. Arrowheaded regions 1, 2 and 3 highlight areas where there are significant discrepancies between the angular positions and/or amplitudes of the experimentally observed R_{sp} data and the features predicted by the director profile derived from the continuum model. The observed discrepancies are sufficient to justify the conclusion that the continuum theory used here is incomplete.

CONCLUSIONS

Careful fitting to R_{sp} data recorded using the half-leaky guided mode technique reveals the director profile within liquid crystal cells in great detail. In this paper the elastic distortion in the director profile has been established during the switching process of a surface stabilised ferroelectric device. Asymmetry in the director profile deduced from fitting suggests a mechanism for switching which involves the formation of a voltage induced twisted state.

Simple modelling of alternative director profiles have been included and demonstrate a high level of sensitivity of the R_{sp} features to small changes in the director profile. Elastic deformation of the director profile deduced using this technique may be used to rigorously test the validity of continuum models which have been developed to describe the switching process in surface stabilised ferroelectric liquid crystal devices.

Acknowledgements
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References

[1] E. L. Wood, J. R. Sambles, *J.Mod.Opt.*, **40**, pp493–502 (1993).
[2] D. Y. K. Ko and J. R. Sambles, *J.Opt.Soc.Am.A,* **5,** 1863 (1988).
[3] S. J. Elston, J. R. Sambles and M. J. Clark, *J.Mod.Opt.*, **36,** 1019, (1989).
[4] C. R. Lavers and J. R. Sambles, *ferroelectrics*, **113**, 339 (1991).
[5] Y. Fuzi and J. R. Sambles, *J.Opt.Soc.Am.B,* **10**,5 (1993).
[6] C. V. Brown, P. E. Dunn and J. C. Jones, *Euro.Jnl. of Applied Mathematics,* **8,** pp281–291 (1997).