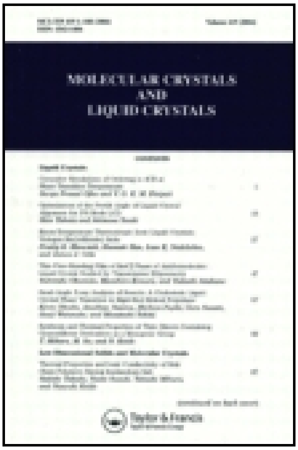

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Determination of the Temperature Dependent Smectic C Biaxial Permittivity Tensor and Elastic Constants

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The direct measurement of the smectic C bend (B_1) and splay (B_2) elastic constants and the three permittivities ε_1, ε_2 and ε_3 for the commercial material SCE8R is described. A new technique has been employed in which some of the assumptions inherent in previous measurements[1,2]have been removed and the inaccuracies have been reduced. This involves fitting the a.c. field dependence of the permittivity in the surface stabilised chevron (C2U) geometry using continuum modelling. Data from the fitting process is combined with measurements of the homeotropic permittivity and electro-optical measurements of the layer tilt angle and smectic cone angle.

Keywords: Smectic C Liquid Crystals; Dielectric Permittivity; Elastic Constant

1 INTRODUCTION

Optimisation of the electro-optic performance of a ferroelectric liquid crystal (FLC) display requires a quantitative knowledge of the material properties of the FLC mixture which is used. For displays operating in the τV_{min} mode the value of the dielectric biaxiality, $\partial\varepsilon$, has particular importance for both the voltage where the minimum in the switching response occurs and also the effectiveness with which a.c. stabilisation improves the brightness of the display[3,4]. The smectic C elastic constants also play an important role in determining electro-optic device behaviour[5].

Characterisation of the bend and splay elastic constants of FLC materials from optical measurements has been reported previously[6,7,8,9]. However, measurement of the three permittivities of the FLC phase has usually required certain assumptions in order to give the three geometries required. Jones and Raynes[1] used a linear extrapolation of the average permittivity against the reciprocal of the temperature. This ignores any effects due to dipole correlations and is limited to low frequencies. Gouda *et. al.*[2] applied a d.c. bias to couple to the spontaneous polarisation and unwind the ferroelectric helix to give one of the geometries. At the field strengths required for complete unwinding of the helix layer disruption may occur. This method also required a high frequency to quench the fluctuations due to the ferroelectric Goldstone and Soft modes.

In the current work measurements of the dielectric permittivity of a smectic C material in two different alignment geometries are interpreted using continuum theory allowing simultaneous measurement of smectic C elastic constants and the biaxial permittivities. This technique should be applicable to both chiral and racemic materials over a wide frequency range.

2 ALIGNMENT GEOMETRIES

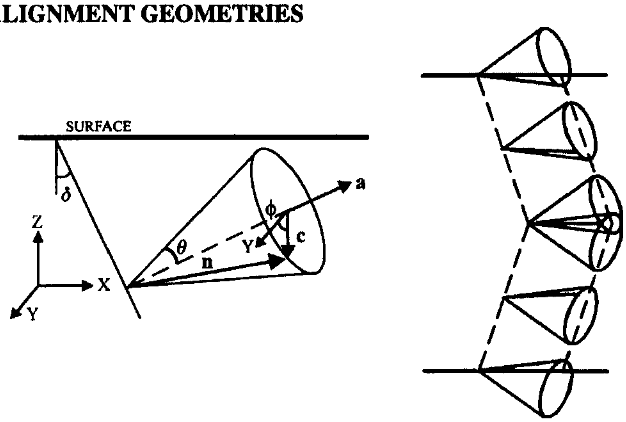

FIGURE 1 The C2U smectic C alignment geometry

In the smectic C and ferroelectric C* phases the liquid crystal forms layers within which the molecular director **n** lies on a cone of half angle θ. If the material is confined between appropriate parallel rubbed polyimide layers the

C2U alignment configuration occurs as shown in figure (1). A characteristic chevron structure is formed with layers in the top and bottom half of the cell inclined at a tilt angle $\pm\delta$ with a chevron interface at the centre.

It is assumed that the director **n** is fixed at the top and bottom of the smectic cones at the upper surface and lower surfaces respectively. At the chevron interface the director is also infinitely anchored at the intersection between two cones in the X-Y plane. When there is no applied field the director profile described by $\phi(z)$ varies almost linearly from the values $\phi_s = \pm 90°$ at the surfaces to $\phi_{ch} = \arcsin(\tan\delta/\tan\theta)$ at the chevron interface[10].

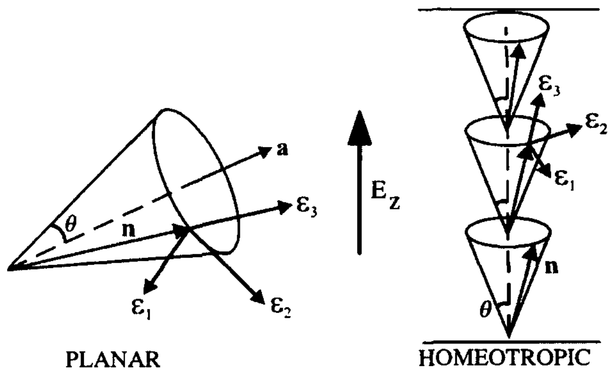

FIGURE 2 Permittivity components for two measurement geometries

The directions of the permittivity components are shown in figure (2) for the planar C2U and homeotropic alignment geometries. Equations (1) and (2) give the z-components of the permittivity in each case using the definitions of uniaxial anisotropy $\Delta\varepsilon = \varepsilon_3 - \varepsilon_1$ and dielectric biaxiality $\partial\varepsilon = \varepsilon_2 - \varepsilon_1$[1].

$$\text{Homeotropic:} \quad \varepsilon_h = \varepsilon_1 + \Delta\varepsilon\cos^2\theta \quad (1)$$

$$\text{Planar:} \quad \varepsilon_{zz}[\phi(z)] = \varepsilon_0\left[\varepsilon_1 + \Delta\varepsilon(\sin\theta\cos\delta\sin\phi - \cos\theta\sin\delta)^2 + \partial\varepsilon\cos^2\delta\cos^2\phi\right] \quad (2)$$

For uniformly tilted, incompressible layers smectic C continuum modelling can be used to calculate the director orientation $\phi(z)$ through the cell in response to applied a.c. electric fields[11] as shown in figure (3). With no applied field the director profile is approximately linear in both halves of the cell. An applied a.c. field couples to the biaxial permittivity causing the director to rotate around the cone giving a voltage dependent distorted director profile. The voltage torque is opposed by the restoring torque which is dominated by the bend and splay elastic constants B_1 and B_2 in the C2U geometry. Director distortions characterised by these elastic constants are shown in Figure (4). The anisotropy between the values of the elastic constants determines the exact shape of the $\phi(z)$ profile.

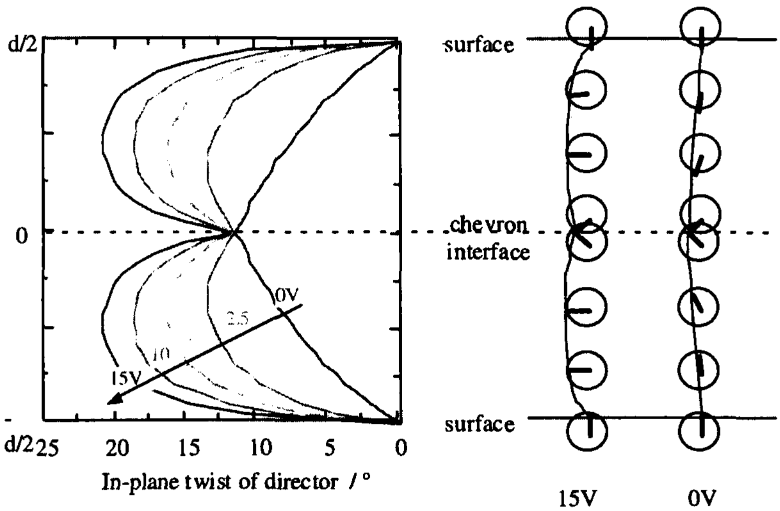

FIGURE 3 Distortion of the director profile by an applied a.c. field

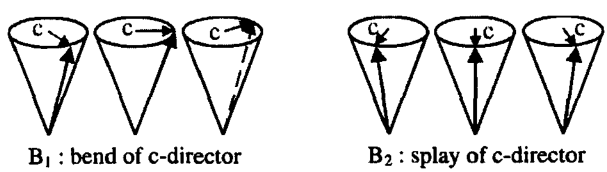

FIGURE 4 Elastic distortions characterised by B_1 and B_2.

3 EXPERIMENTAL MEASUREMENTS

Dielectric frequency measurements were performed on cells filled with the commercial smectic C material SCE8R using an HP 4284A precision LCR meter. The ITO electrodes in the cells were circular with an earthed guard ring and up to 12 Volts a.c. were applied at the measurement frequency of 1 kHz. The planar geometry cell had rubbed polyimide alignment (Ciba-Geigy PI-32) layers and the homeotropic aligned cells used the polymer ZLI3334. A nitrogen gas circulation bath was used for the temperature controlled environment.

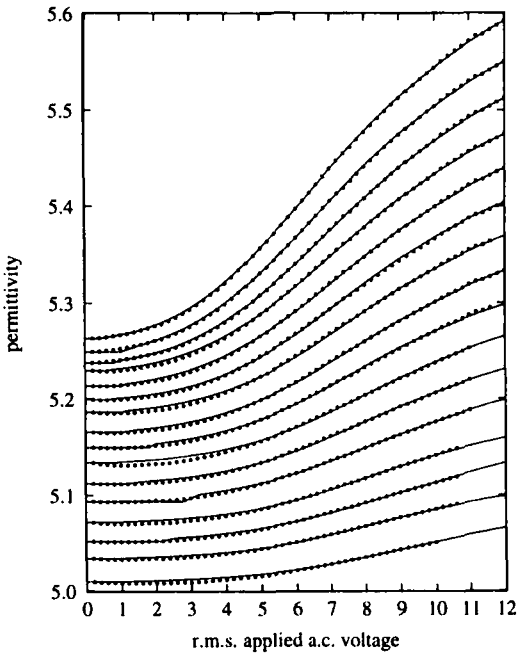

FIGURE 5 Temperature and voltage dependence of the C2U permittivity

Results from measurements of the planar geometry as a function of temperature and applied a.c. voltage are shown in figure (5). The filled circles are the experimental points and the lines show the numerical fit to the data. The temperature was increased from 10°C (upper data set) to 47.5°C (lower data set) in 2.5°C steps. Fitting curves were generated by calculating the director orientation $\phi(z, V_{a.c.})$ for a number of slices N through the cell using continuum theory for a given applied a.c. voltage V[11]. The planar permittivity ε_p is calculated from $\phi(z)$ using equations (2) and (3) :

$$\frac{1}{\varepsilon_p} = \frac{1}{(N-1)} \sum_{i=1}^{N} \frac{1}{\left[\varepsilon_{zz}(\phi_i, V)\right]_i} \tag{3}$$

The value of the cone angle θ for SCE8R given in equation (4) was measured using an Abbé refractometer at a wavelength of 543.5 nm. The layer tilt angle δ in equation (5) was then inferred from this measurement and optical wavelength dependent extinction angle data[10]. The smectic C to smectic A transition temperature for SCE8R is $T_C = 58$ °C.

$$\delta = 36.7^\circ(1 - T/T_C)^{0.26} \tag{4}$$

$$\theta = 47.1^\circ(1 - T/T_C)^{0.31} \tag{5}$$

The free parameters in the a.c. voltage dependence are then reduced to B_1, B_2 and $\partial\varepsilon$ using measurements in the homeotropic geometry at the same temperatures and applying equation (1). A quasi-Newtonian NAg least squares minimisation routine was used to obtain the actual fits to the data. This process yields the temperature dependent values of the three permittivities ε_1, ε_2 and ε_3 and the elastic constants B_1 and B_2 shown in figure (6).

The biaxial permittivities ε_2 and ε_1 converge as the temperature increases. This is to be expected since at 58 °C a phase transition occurs to the uniaxial smectic A phase. The value of ε_3 shows a marked decrease at low temperatures. Further dielectric spectroscopy studies suggest that this is due to a frequency relaxation parallel to the long molecular axis of the molecule. As a result of this the average $\bar{\varepsilon} = (\varepsilon_1 + \varepsilon_2 + \varepsilon_3)/3$ of the permittivity values does not fit the linear extrapolation from the nematic and smectic A phases below this temperature[11].

The bend and splay elastic constants show a downward trend towards the phase transition. Although there is large scatter on the results, the trends are consistent with the expected $\sin^2\theta$ dependence. The bend elastic constant B_1 is smaller than B_2 for the temperature range studied. This observation and the magnitudes of these results are consistent with results from previous studies : at 20 °C in the current work, B_1 = 5.5 pN and B_2 = 24 pN, compared to the values B_1 = 3.4 pN and B_2 = 47 pN found using optical techniques[11]. The current results should be more accurate because the values of $\Delta\varepsilon$ and $\partial\varepsilon$ are measured simultaneously.

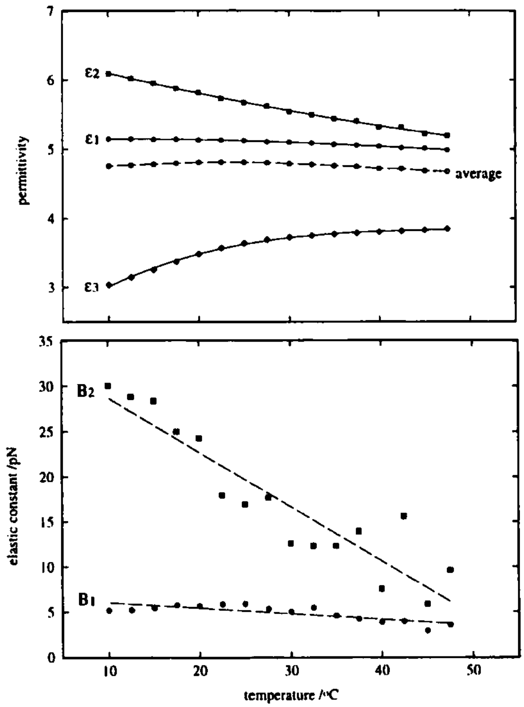

FIGURE 6 The points show the temperature dependent permittivity and elastic constant values. The lines are a guide to the eye.

4 CONCLUSIONS

The a.c. voltage dependence of the planar Smectic C permittivity is well reproduced by continuum theory. The three biaxial permittivities ε_1, ε_2 and ε_3

and the elastic constants B_1 and B_2 have been measured in SCE8R as a function of temperature by fitting the theory to the experimental data and conform to expected trends.

There is evidence for a frequency relaxation in the value of the permittivity ε_3. A more detailed investigation has shown that this Debye relaxation of fluctuations parallel to the long molecular axis occurs at a frequency of 1.7 kHz at 25°C. This work will be described in a future publication.

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