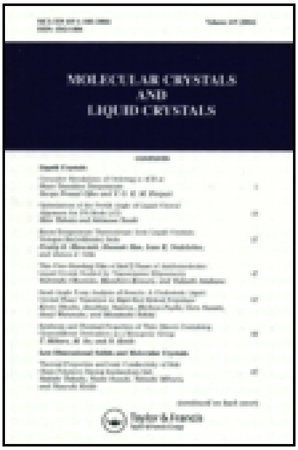
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Measurement of Twist Elastic Constant in Nematic Liquid Crystals using Conoscopic Illumination

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A method of imaging the birefringence and optic axis orientation of a sample as a function of angle of incidence using conoscopic illumination and a rotating input polariser has previously been demonstrated on polymerized liquid crystals. In this work, we apply this technique to a planar nematic device with in-plane electrodes, which cause a twist in the director profile. The conoscopic images are compared with theoretical predictions based on a combination of a 1D nematic and an extended Jones optical method. The comparison allows values for the twist elastic constant K_{22} and the azimuthal surface anchoring energy to be determined.

Keywords: birefringence; conoscopy; elastic constant; liquid crystal; nematic; twist

INTRODUCTION

Conoscopy is a technique used widely in the field of liquid crystal work [1,2], particularly in the identification of phase sequences of new materials [3]. In conventional conoscopy, in which the sample is viewed between crossed polarisers, it is often difficult to distinguish between a uniaxial phase and one that is slightly biaxial, because the central

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part of the conoscopic image is masked by the characteristic cross of extinction or isogyres.

To avoid this difficulty, it is possible to use a slightly different system, in which the sample is viewed between a linear input polariser and a circular analyser. By recording the conoscopic image as a function of the angle of the linear polariser, it is possible to extract the birefringence and optic axis orientation of the sample as a function of the angle of incidence of light, even very close to normal incidence. This system (the "Metripol" system [4]) has already been demonstrated on a number of different samples [5], including one study of polymerized cholesteric films [6]. In this work, we aim to study a planar nematic liquid crystal device under the application of an applied in-plane electric field, with a view to measuring the twist elastic constant K_{22}.

EXPERIMENTAL METHOD

A side view of the liquid crystal device used for the experiment is shown in Figure 1. The glass substrate is coated in a transparent conductor (ITO) on one surface, apart from a 0.5 mm stripe which has been etched away down the centre, thereby creating two electrodes with which to apply an in-plane electric field to the liquid crystal. The superstrate is a non-conducting glass coverslip of about 200 μm thickness: this is to allow the high numerical aperture objective used in the optical system to get sufficiently close enough to the liquid crystal layer to form a conoscopic image. Both glass surfaces are coated with a thin layer of PVA (poly-vinyl alcohol) and rubbed in the same direction to produce planar alignment along the direction of the stripe in the electrodes (i.e. perpendicular to the direction in

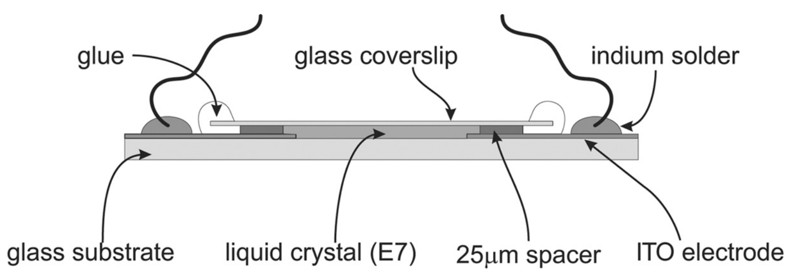

FIGURE 1 Geometry of the liquid crystal cell used for this work. The device has planar, parallel alignment perpendicular to the direction in which an electric field can be applied, via the in-plane electrodes.

which the electric field will be applied). The final assembled cell was made by separating the glass plates with a film spacer of approximately 25 μm thickness, filling with the nematic mixture E7 from Merck, and sealing with glue.

The device was imaged using a 50× lens with a numerical aperture of 0.95 with the Metripol system, ensuring that the light path was passing through the gap in the ITO electrodes. The measurements were taken at a wavelength of 600 nm which was achieved by using a halogen lamp for illumination and a filter with a 10 nm bandwidth. The experimental set-up is illustrated in Figure 2. The system records the conoscopic image of the device (between the linear input polariser and the circular analyser) as a function of the angle α of the input polariser. At each angle of incidence, the resulting data is then fitted to the following formula:

$$I = \frac{1}{2} I_0 [1 + \sin 2(\alpha - \varphi) \sin \delta],$$

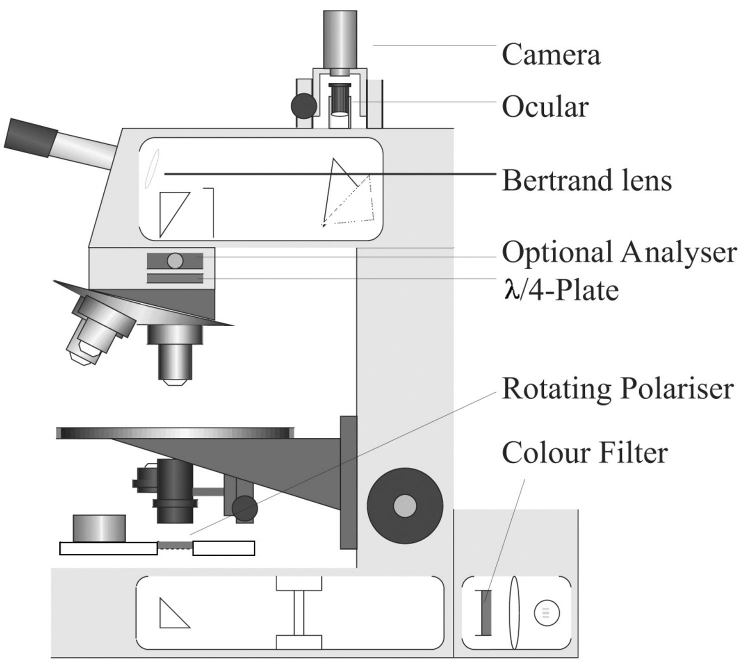

FIGURE 2 Experimental set-up of the Metripol optics system. A microscope is adapted so that monochromatic light is incident on the sample via a rotating linear input polariser. The output is detected by a camera via a high numerical aperture lens and circular analyser.

where α is the angle of the linear polariser, φ is the orientation of the optical indicatrix and δ is related to the birefringence via:

$$\delta = \frac{2\pi\Delta nd}{\lambda}.$$

The system therefore calculates (amongst other things) the birefringence of the device as a function of the angle of incidence of light (both zenithal and azimuthal). An example of this is illustrated in Figure 3(a), which shows the value of $|\sin\delta|$ as a function of incident angle for the device used in this experiment, with no voltage applied. Note that the images shown in Figure 3 (and also Figs. 4 and 5) are not the raw conoscopic images obtained at any one particular angle of the linear input polariser, but rather a specific piece of information (in this case related to the birefringence) obtained from all the conoscopic images obtained at all angles of the linear input polariser and plotted as a function of the angle of incidence.

Figure 4 shows equivalent images of $|\sin\delta|$ for the case when a voltage is applied to the liquid crystal cell, via the in-plane electrodes. To avoid ionic migration, a high frequency square wave was applied to the liquid crystal, rather than a DC signal. The figures show a clear Freedericksz transition, i.e. below a critical voltage (between 10 and 15 V) there is no change in the liquid crystal structure and hence the conoscopic image. Above the threshold there is a clear rotation of the optic axis of the system (accompanied by a rotation of the conoscopic image). In addition, the number of "fringes" or orders observed

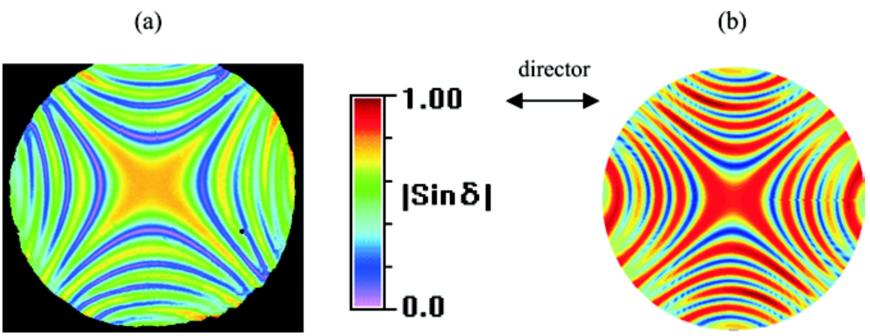

FIGURE 3 (a) Typical example of an output from the Metripol optics system: this image shows (in false colour) the value of $|\sin\delta|$ as a function of incident angle for a planar nematic device at zero volts. (b) Theoretical equivalent generated using a 1D model and an extended Jones optical technique.

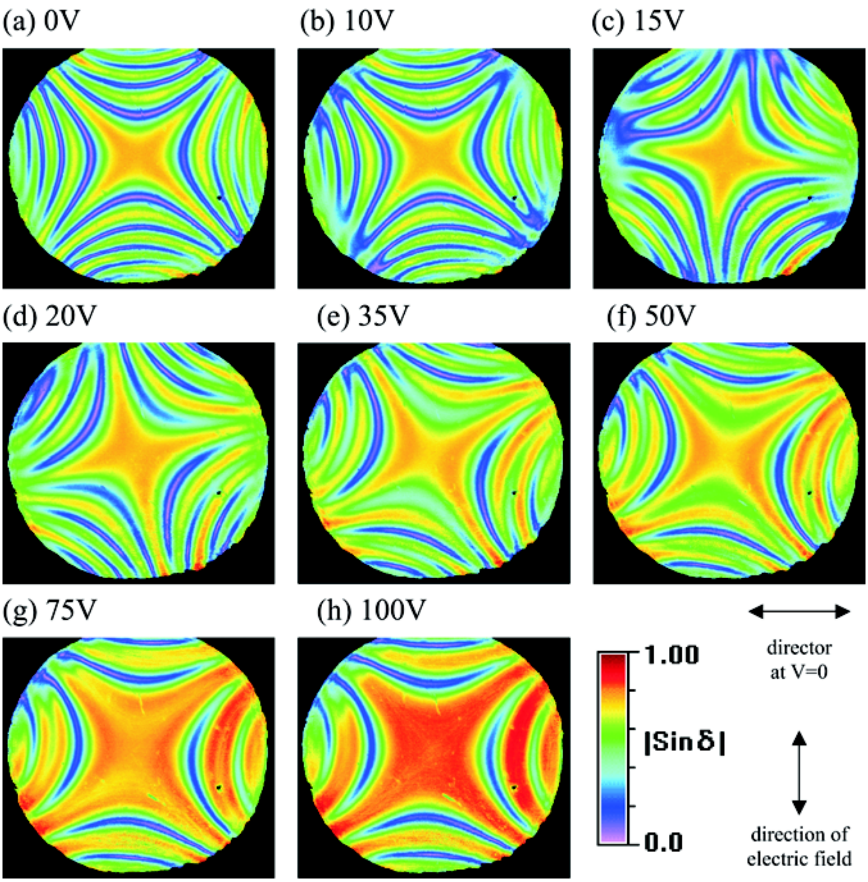

FIGURE 4 Experimental results for the planar nematic cell. The output from the Metripol system (for $|\sin\delta|$) is shown as a function of the applied in-plane voltage.

in the conoscopic image decreases with applied voltage. This is thought to be because at high voltage, the director profile in the device is highly distorted, and the average birefringence of the device at normal incidence becomes quite low. Therefore there are fewer oscillations in $|\sin\delta|$ as the angle of incidence is increased from zero towards 90°.

THEORETICAL PREDICTIONS

In order to create theoretical predictions to mimic those produced by the Metripol system, the following approach was used.

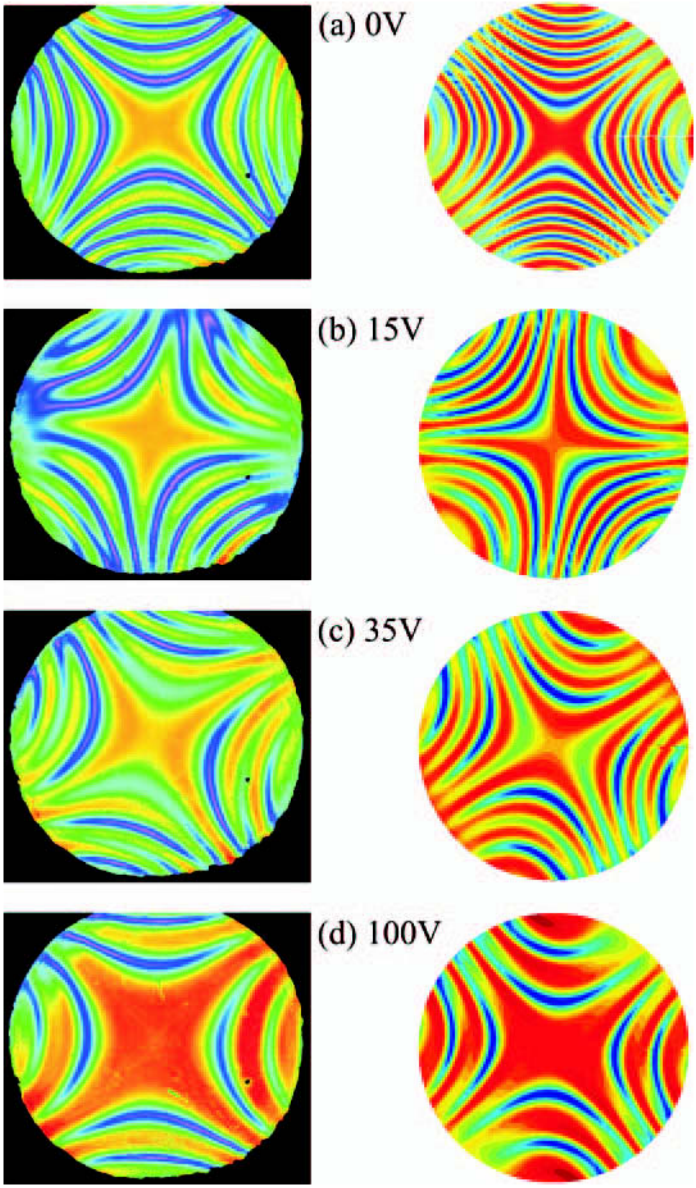

FIGURE 5 Comparison between experimental results and theoretical predictions, for the best-fit parameters of $K_{22} = 5.0\,pN$ and $W_0 = 5 \times 10^{-6}\,J/m^2$.

Firstly, a one-dimensional director profile was generated using a simple model of a nematic liquid crystal. The director was constrained to lie in the plane of the glass plates, so that the only free variable was the twist of the director ϕ in the plane of the device. This approach assumes that there is zero pretilt of the directors at the rubbed polymer surfaces, and also that the applied electric field is in the plane of the device. This latter assumption is valid because the aspect ratio of the active area is about 1:20 (the electrodes are 500 μm apart and the cell is 25 μm thick). The equilibrium director profile at a given applied voltage was determined by minimizing the following free energy across the device:

$$F = \frac{K_{22}}{2}\left(\frac{d\phi}{dz}\right)^2 - \frac{1}{2}\varepsilon_0 \Delta\varepsilon E^2 \sin^2\phi,$$

i.e. the sum of an elastic and a dielectric term. The boundary conditions used in the model are those of finite azimuthal anchoring, i.e. the director is not constrained to lie along the rubbing direction, but deviations from it cost an energy F_s given by:

$$F_s = W_0 \sin^2\phi,$$

where the rubbing direction is defined to be at $\phi = 0$.

The conoscopic image of a device between a linear polariser and a circular analyser is then calculated using an extended Jones technique [7,8]. By calculating the transmitted intensity for two different angles of the input linear polariser, it is possible to extract $|\sin\delta|$ as a function of incident angle. These are then plotted in false colour in the same manner as the output from the Metripol system, an example of which is shown in Figure 3(b), for the case of zero applied voltage.

DISCUSSION

In comparing the experimental and theoretical results for zero applied voltage in Figures 3(a) and (b), respectively, it is clear that the patterns agree well with each other. The most noticeable difference is that the experimental data does not reach $|\sin\delta| = 1$ at any angle of incidence, unlike the theoretical prediction. This is attributed to the fact that in reality, the part of the liquid crystal device observed will have a small spread in cell thickness, which will prevent $\sin\delta$ reaching unity because the measurements are averaged over a range of cell thicknesses. Since this is not the case with the theoretical model, this must be bourn in mind when comparing experimental and theoretical results.

Figure 5 shows a selection of the experimental results, together with the best-fit theoretical results. It can be seen that the theoretical predictions reproduce the same twist in the axis of the conoscopic image, together with the reduced number of fringes with increased voltage.

The best fit between the experimental results and theoretical predictions were obtained when the model used the following values for its adjustable parameters: $K_{22} = 5.0\,pN$ and $W_0 = 5 \times 10^{-6}\,J/m^2$. Both values compare well with previous measurements of these parameters [9–11].

To conclude, we have shown that the Metripol system can be used to great effect in studying the electric field dependent behaviour of liquid crystals, and that measurements of elastic constants and anchoring energies are consistent with previously published values.

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