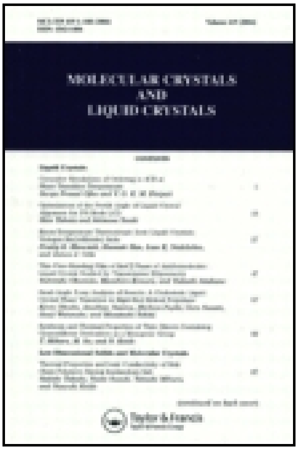

Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

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Version of record first published: 18 Oct 2010

Mol. Cryst. Liq. Cryst., Vol. 409, pp. 293–299, 2004

ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421400490431444

A NOVEL METHOD FOR THE MEASUREMENT OF THE NEMATIC LIQUID CRYSTAL TWIST ELASTIC CONSTANT

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A novel technique has recently been developed for the determination of the twist elastic constant K_{22} in nematic liquid crystals. The method is based on the measurement of the threshold voltages of the unwound and π-twisted regions in a wedge cell geometry. It has the advantage that the chiral nematic pitch and the cell spacing do not need to be accurately known. In this paper the value of K_{22} is determined using this method for the material MLC6424. This is compared with the value derived from measurements in the conventional twist geometry in a cell with uniform spacing.

Keywords: chiral nematic; liquid crystal; nematic; twist elastic constant; wedge cell

1. INTRODUCTION

The importance of elastic constants measurements is unquestionable for the production of high performance displays, particularly in regard to frame rate and power dissipation. For the splay constant K_{11} and the bend constant K_{33} after Frank [1], sufficiently accurate and simple measurement methods exist, commonly based on the work of Gruler *et al.* [2]. However, the literature methods for the determination of the twist constant K_{22} are far more involved and require more complicated experimental set-ups.

The method of Gerber and Schadt [3], is based on the Freedericksz transition within a magnetic field. Gerber and Schadt's method is applicable to

The authors gratefully acknowledge M. Francis and M. Goulding at Merck NB-SC UK for the supply of substrates and materials of known pitch. JFS also gratefully acknowledges Merck NB-SC UK and EPSRC for funding.

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materials with low dielectric anisotropy. However it requires separate susceptibility and cell thickness measurements, and access to equipment that provides relatively high magnetic fields. Methods like those of Ikeda *et al.* [4], that make use of in-plane electrical fields to determine the twist constant are difficult to interpret because the geometry leads to inhomogeneous field profiles. Other methods based on light scattering [5,6] or guided mode techniques [7], require complex set-ups and data analysis and can be difficult and time consuming.

Because of the reasons outlined above there are very few materials for which all three elastic constants have been determined. However, a novel and straightforward technique has recently been proposed to remedy this situation [8]. In this paper the value of K_{22} is measured using this method for the material MLC6424 [9] and the value obtained is compared with the value derived from more conventional techniques.

2. BACKGROUND THEORY

The measurements reported here are based on the threshold voltage phenomena, a re-orientation of the liquid crystal molecules in response to an electrical field after Freedericksz and Zolina [10]. Consider a long pitch chiral nematic liquid crystal confined between two planar aligned surfaces where the liquid crystal is twisted by an angle ϕ. If a voltage is applied across this layer then re-orientation starts to occur if the voltage [11] is above a threshold given by equation(1).

$$V_c(\phi)^2 = V_c(0)^2\left\{1 + \left(\frac{\phi}{\pi}\right)^2\left(\frac{K_{33}}{K_{11}} - \frac{2K_{22}}{K_{11}}\left[1 - \frac{2\pi d}{P\phi}\right]\right)\right\} \tag{1}$$

$$V_c(0)^2 = \frac{\pi^2 K_{11}}{\varepsilon_0 \Delta\varepsilon} \tag{2}$$

Here d is the distance between the substrates, P is the natural pitch of the chiral nematic, and $\Delta\varepsilon$ is the dielectric anisotropy. $V_c(0)$ is given in Eq. (2) and this is the threshold voltage for a long pitch chiral nematic material when the twist of the director though the cell is zero ($\phi = 0$). If the amount of chiral dopant is sufficiently small ($< 1\%$) there is no significant effect on the magnitude of the elastic constants [2,12].

3. TWIST GEOMETRY MEASUREMENTS

Equation (1) implies that the elastic constant ratio K_{22}/K_{11} can be determined from the transition voltage in a twisted structure provided the pitch

P, the cell thickness d, and the elastic constant ratio K_{11}/K_{33} are all known. The threshold voltage will depend on K_{22}/K_{11} only if the condition $2\pi d/P\phi \neq 1$ is met. For a twist of $\phi = \pi$ the contribution of the ratio K_{22}/K_{11} to the threshold $V_c(\pi)$ is largest when $|d/P| \approx 0.25$. In practice the value of $|d/P|$ must be just greater than this in order to ensure that the $\phi = \pi$ twist state is formed rather than the untwisted linear $\phi = 0$ state.

The cells used for the twist geometry threshold measurements had low pre-tilt polyimide layers (pre-tilt $< 0.5°$) that were rubbed in an anti-parallel configuration. Two different thicknesses were investigated: 56.2 μm and 21.8 μm. To minimise the inhomogeneous field effects at the edges of the electrodes, guard ring configurations were used. The cells were capillary filled with chiral nematic material in the isotropic phase. The host material MLC6424 had been doped with a very small percentage ($<0.1\%$) of the chiral additive S811 to give a suitable chiral pitch to form a π-twist texture within the cells.

Two different experimental techniques are employed for measuring the threshold voltages. The first technique places the nematic liquid crystal cell between crossed polarisers. A silicon diode detector measures the transmission response for illumination with a laser diode of 670 nm wavelength while applying a slowly increasing RMS voltage of 1 kHz frequency to the cell. In the second technique the capacitance of the cell is measured using a HP4192LF Impedance Analyser that applies a slowly increasing RMS voltage of 1 kHz frequency to the cell. For both measurement techniques it is necessary to have a wait time of over 30 seconds between each voltage step because of critical slowing down just above the threshold voltage. This effect is exacerbated for the thicker cell.

In Figure 1 the results of the optical transmission measurements on the twist cells of two different thicknesses are shown. The precise determination of the threshold voltage for certain thickness/wavelength combinations is complicated, if the form of the curve immediately above threshold lies at a maximum or a minimum. Capacitance measurement results are shown in Figure 2. The threshold voltages for a given cell are the same within experimental errors for the two measurement techniques, $V_c(0) = 1.30 \pm 0.01\,\mathrm{V}$ for $d = 56.2\,\mu\mathrm{m}$ and $V_c(\pi) = 1.33 \pm 0.01\,\mathrm{V}$ for $d = 21.8\,\mu\mathrm{m}$. The natural pitches of the mixtures used were 188.0 μm and 71.3 μm respectively.

Table 1 shows the values for the elastic constant ratio K_{22}/K_{11} that have been derived from Eq. (1) using the threshold measurements in Figures 1 and 2. The threshold voltages are estimated directly from the curve with an expanded voltage scale. An auxiliary experiment was carried out to determine the ratio K_{33}/K_{11} by fitting the shape of the capacitance voltage curve for achiral MC6424 in the planar Freedericksz geometry. At room temperature this value was found to be 1.51. The cell thicknesses were found by

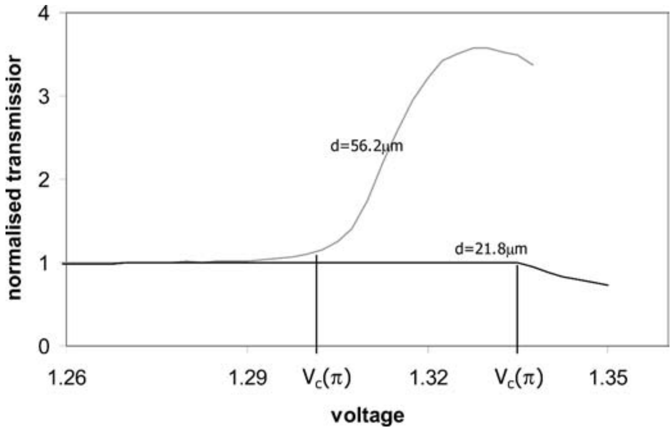

FIGURE 1 Normalised optical transmission between crossed polarisers as a function of RMS voltage for two different twist cells.

measuring the empty cell capacitance. The pitch values were found using the Cano wedge method [13].

4. MEASUREMENTS IN THE WEDGE CELL GEOMETRY

Consider a long pitch chiral nematic in a wedge cell with planar surface alignment, with the director aligned parallel to surface. An unwound

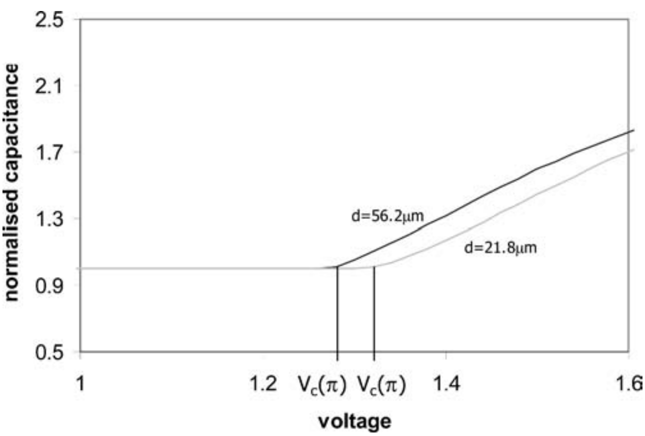

FIGURE 2 Normalised capacitance as a function of RMS voltage for two different twist cells.

TABLE 1 Elastic Constant Values Derived from Measurements in the Twist Geometry for Two Different Flat Cells and from a Wedge Cell

Type of cell	d	d/P	$V_c{}'(\pi)/V_c(0)$	K_{22}/K_{11}	K_{22}
Uniform gap, π twist	56.2 µm	0.30	1.42	0.61	4.6 pN
Uniform gap, π twist	21.8 µm	0.31	1.45	0.51	3.8 pN
Wedge cell		0.25	1.41	0.52	3.9 pN

nematic texture is formed at the thin side of the wedge cell and a π-twist texture at the thick side and these are separated by a disclination at $|d/P| = 0.25$. Other twist textures form in areas with higher d/P ratios. The threshold voltage in the nematic texture region is given by Eq. (2) and is independent of thickness. The threshold at the π-twist texture region is thickness dependent, as shown by Eq. (1).

In the π-twist region immediately adjacent to the disclination line between the two textures the substitution of the values $|d/P| = 0.25$ and $\phi = \pi$ into Eq. (2) gives the result in Eq. (3).

$$V_c{}'(\pi)^2 = V_c(0)^2\left\{1 + \frac{K_{33}}{K_{11}} - \frac{K_{22}}{K_{11}}\right\} \tag{3}$$

This predicts that the value of the ratio K_{22}/K_{11} can be determined by measuring the value of the threshold $V_c(0)$ in the untwisted region and the threshold $V_c{}'(\pi)$ in the twisted region immediately adjacent to the disclination line. As in the measurements in Section 2, this also requires knowledge of the ratio K_{33}/K_{11}. However, this method does not require additional accurate measurements of the cell thickness d or the chiral pitch P.

The wedge cell used for the experiment has been fabricated using ITO coated glass substrates and mylar spacers with thickness varying from 13.3 µm to 20.5 µm (determined by transmission spectroscopy) over a distance of 20 mm. The glass substrates were coated with low pre-tilt planar polyimide alignment layers that were rubbed in an anti-parallel orientation along the direction of varying cell thickness. The cell was capillary filled with chiral nematic material in the isotropic phase. After a few hours the alignment stabilised to show the untwisted and π-twisted regions separated by a linear disclination line. Measurements of the optical transmission and the capacitance were made, as described in Section 2.

In Figure 3 the threshold voltages, determined by optical transmission, are shown as a function of the distance from the disclination line. Measurements closer than 2 mm to the disclination were not possible due to scattering of the laser beam. The value of the threshold closest to the disclination

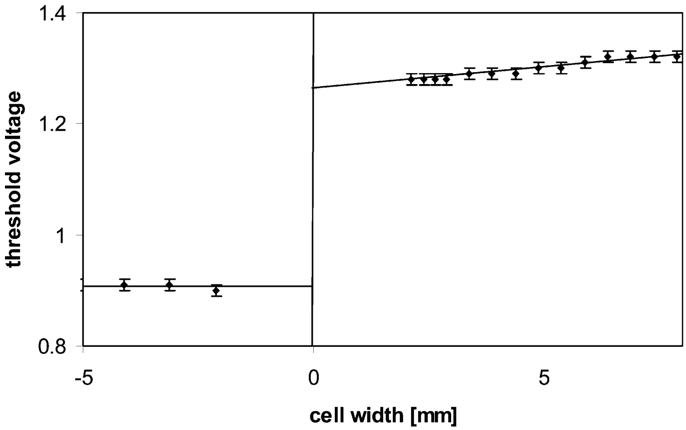

FIGURE 3 Normalised optical transmission between crossed polarisers as a function of the distance from the disclination in the wedge cell.

within the π-twisted region was 1.28 V. The untwisted region shows a constant threshold value of 0.91 V. The line in both regions depicts the cell thickness dependent threshold voltage and is intended as a guide for the eye.

A measurement of the capacitance as a function of a.c. voltage is shown in Figure 4. This shows two clear thresholds at which there is a change in gradient of the curve. Below the threshold at 0.92 V the curve is flat and no region of the device re-orients. Between the voltage 0.92 V and 1.30 V there

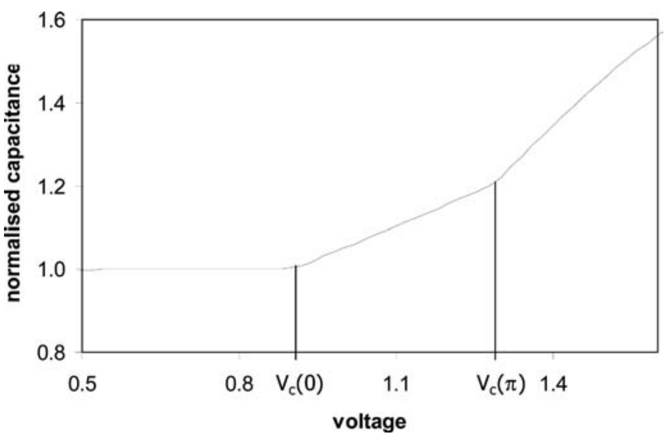

FIGURE 4 Normalised capacitance as a function of RMS voltage for the wedge cell.

is re-orientation in the untwisted region of the cell. Above 1.30 V there is re-orientation in both the untwisted and π-twisted regions.

Taking the average of the threshold values from the two measurement techniques gives $V_c(0) = 0.915 \pm 0.01\,\mathrm{V}$ and $V_c{}'(\pi) = 1.29 \pm 0.01\,\mathrm{V}$. The values of the twist elastic constant K_{22} are calculated using these results and are given in Table 1.

5. DISCUSSION AND CONCLUSIONS

Table 1 summarises the measurement results of the elastic constants ratio K_{22}/K_{11} and K_{22} for both the flat twist cells and the wedge cell. The magnitude of the error in the determination of K_{22} is likely to be of the order ± 1.0 pN for all of the cells. This error margin is derived by taking an error on the K_{33}/K_{11} measurement of about 5% and a threshold uncertainty of ± 0.01 V into account. There will be a greater experimental uncertainty for the flat twist cells due to errors in pitch and thickness determinations. A thickness change during the process of filling the cell would affect the flat cell measurements in particular. The values quoted by the material supplier are 4.5 pN from electric field measurements and 3.9 pN from magnetic field measurements [9].

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