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Twisted wedges for the measurement of long pitch lengths in chiral nematic liquid crystals

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A new method is described for the measurement of long pitch lengths in chiral nematic liquid crystal materials using wedges with twisted alignments on the two surfaces.

1. Introduction

Chiral nematic liquid crystals possess a director with a helical rotation in space described by the pitch length P, the distance over which the director rotates by an angle of 2π. Chiral nematic liquid crystals can show a pitch length of less than 0.1 µm, and by diluting these materials into a standard nematic liquid crystal, mixtures with a range of pitch lengths from 0.1 µm to an infinite value can be formulated. The relationship between P and the concentration x (by weight) of the chiral nematic liquid crystal in the mixture is given by

$$P^{-1} = x(\mathrm{HTP}), \tag{1}$$

where HTP is known as the *helical twisting power* of the chiral additive. Similar results can be achieved with non-liquid crystalline chiral materials providing the concentrations used are small.

The standard method for measuring long pitch lengths up to 1 mm involves the use of a thick layer of liquid crystal of smoothly varying thickness confined between two surfaces treated to produce parallel planar anchoring. This so-called Grandjean–Cano wedge [1] geometry shows a series of parallel disclination lines orthogonal to the direction of increasing layer thickness when observed using a polarizing microscope. These disclination lines correspond to a sudden change of π in the total twist angle across the layer and occur when the liquid crystal layer thickness, d, is related to the pitch length by

$$d_m = (2m-1)\frac{P}{4}\,(m = 1, 2, 3, \ldots), \tag{2}$$

and P can therefore be calculated from the observed values of d_m. However, the sensitivity of this method is limited to $P \leqslant 1$ mm by the practical difficulties involved when using layers much thicker than 0.25 µm and the large quantity of liquid crystal material required.

A new method for measuring long pitches has recently been reported [2] that uses thin cells and depends on the bowing of reverse twist disclination lines in 90° twisted nematic devices. The method can be used to easily measure pitch lengths of 10 mm, and has potential for measuring pitch lengths up to about 50 mm.

2. Theory of twisted wedges

A twisted wedge has an angle between the planar anchoring on the two surfaces. This twist angle produces a difference in the free energy density of the twist domains, so that the disclination lines between the various twist domains now occur for a different ratio of d/P to that given by equation (2). The alignment geometry is shown in figure 1 and, for convenience, the angle between the two alignment directions is defined as $(\pi/2+\delta)$. The two lowest twist angles, $\phi_{1,2}$, possible across the layer are given by

$$\phi_1 = \left(\frac{\pi}{2} + \delta\right) \text{ and } \phi_2 = -\left(\frac{\pi}{2} - \delta\right).$$

The twist energy F per unit volume of a layer of thickness d and twist angle ϕ can be derived from the continuum energy [3]:

$$F = \frac{k_{22}}{2}\left(\frac{\phi}{d} - \frac{2\pi}{P}\right)^2. \tag{3}$$

Equating the energies for the two states with twist angles ϕ_1 and ϕ_2 shows that the disclination line between

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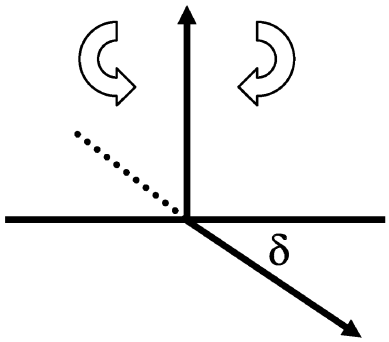

Figure 1. Alignment on the two surfaces within a twisted wedge.

these two states occurs at:

$$\frac{P}{d} = \left(\frac{2\pi}{\delta}\right). \tag{4}$$

We note that $\delta=\pi/2$ corresponds to parallel surface alignment, as used in a Grandjean–Cano wedge, in which the disclination line is at $P/d=4$. However, for the more general case, we see that as δ is reduced below $\pi/2$, the wedge becomes more sensitive to longer pitches. For example, if $\delta=9°$, the twisted wedge is an order of magnitude more sensitive than the Grandjean–Cano wedge. The sign of P can also be determined from the sign of δ.

3. Experiments using twisted wedges

Twisted wedges were constructed using cleaned glass slides coated with polyvinyl alcohol spun from an aqueous solution and rubbed unidirectionally. Spacer strips of 70 µm thickness were used to define the thickness at one end of the wedge, with no spacer at the other end. The wedges were held together with clips, filled and left for some time (generally around a day) to allow the disclination line to reach its equilibrium position.

The twisted wedge was tested using a standard nematic liquid crystal mixture, E70A doped with 0.06% of the chiral dopant CB15, to induce a pitch of around 200 µm. Figure 2 shows the thickness of the liquid crystal layer for the equilibrium position of the disclination line for wedges with a range of angle δ up to the value of 90° which corresponds to the Grandjean–Cano wedge. The results are linear, in agreement with equation (4), and illustrate the benefit of using smaller values of δ to reduce the layer thickness. The HTP of CB15 deduced from the gradient is shown in table 1.

Mixtures with longer pitch lengths were measured using wedges with smaller values of δ. These mixtures were made by adding the E70A sample doped with

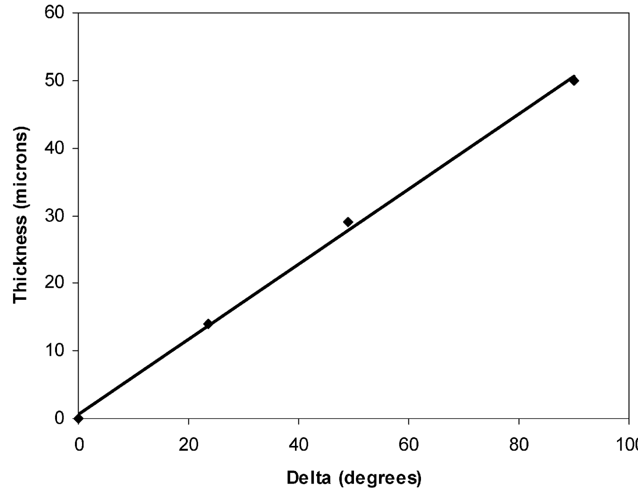

Figure 2. Dependence of layer thickness for position of disclination line on wedge twist angle using a mixture containing 0.06% CB15.

Table 1. HTP of CB15 measured using various methods.

Method	HTP/$10^6\,m^{-1}$
Twisted wedge: 0.06% CB15	8.2
Twisted wedge: 0.012% CB15	7.8
Twisted wedge: 0.0013% CB15	8.9
Bowed disclination lines [2]	9.3

0.06% CB15 into the standard nematic liquid crystal mixture E7. Figure 3 shows the LC layer thicknesses for a range of δ for a mixture containing 0.012% of

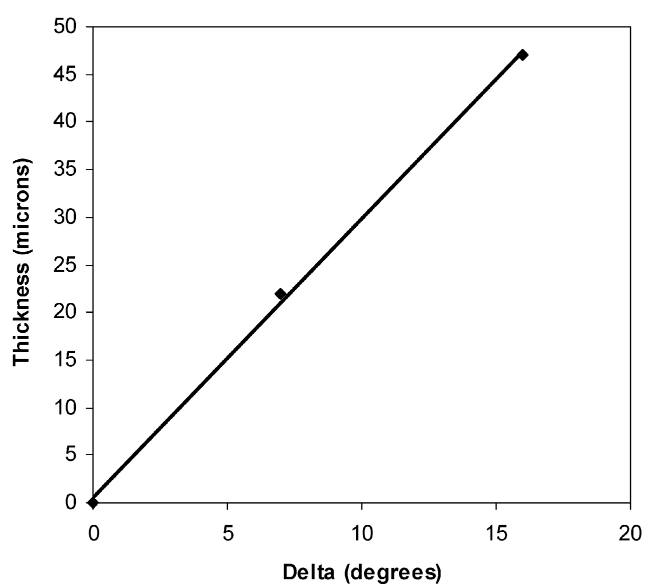

Figure 3. Dependence of layer thickness for position of disclination line on wedge twist angle using a mixture containing 0.012% CB15.

CB15, which should correspond to a pitch length of approximately 1 mm. The results are again linear and the HTP calculated from the gradient is shown in table 1. Even longer pitch lengths were measured using a combination of small δ and thicker layers.

Figure 4 shows a photomicrograph of the disclination line occurring at a layer thickness of 168 μm in a wedge with $\delta=7°$ for a mixture containing 0.0013% of CB15. This corresponds to a pitch of 8.6 mm and an HTP shown in table 1. The HTP values shown in table 1 agree with each other within experimental error and also with the value previously found from the radii of curvature of bowed disclination lines [2].

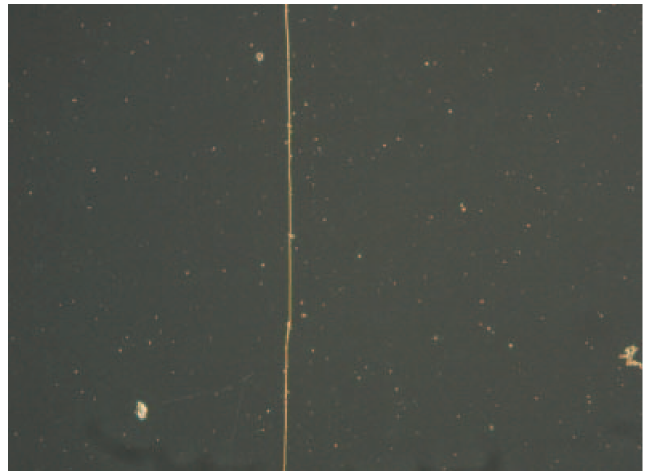

Figure 4. Photomicrograph, using approximately parallel polarizers, of the disclination line occurring at a layer thickness of 168 μm in a wedge with $\delta=7°$ using a mixture containing 0.0013% CB15.

4. Comparison of twisted wedges with other methods

Twisted wedges are at least an order of magnitude more sensitive than Grandjean–Cano wedges, allowing either the use of less material in thinner layers or the measurement of longer pitch lengths. The comparison with the method recently reported using bowed reverse twist disclination lines [2] is less clear. Both methods depend on the accurate control and measurement of the twist angle, and both benefit from a low, or preferably zero, pre-tilt angle of the surface alignment. Making reasonable assumptions for the likely limits of device construction, both methods should be capable of measuring pitch lengths of several tens of mm. However, there are some crucial differences between the two methods. The use of bowed disclination lines does not depend on the layer thickness and can successfully use thin layers down to a few μm, although it does benefit from using thicker layers to reduce the influence of other device parameters, such as the twist angle being slightly different from 90°. Secondly, the extraction of an accurate value of the pitch requires either quite complex modelling or an assumption for the form of the line tension together with the assumption of a one elastic constant approximation [2]. On the other hand the method using twisted wedges has no such computational restriction, but does require the measurement of the layer thickness, and the measurement of very long pitches requires the use of layers over 100 μm thick.

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