A simple method to measure the twist elastic constant of a nematic liquid crystal

Haiwei Chen, Ruidong Zhu, Jianxiong Zhu and Shin-Tson Wu*

College of Optics and Photonics, University of Central Florida, Orlando, FL, USA

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We demonstrate a simple method for measuring the twist elastic constant ($K_{22}$) of a nematic liquid crystal (LC). By adding some chiral dopant to an LC host, the LC directors rotate 180° in a homogeneous cell, which is known as 180° super-twisted nematic (STN) cell. By preparing two such STN cells with different chiral concentrations and measuring their Fréedericksz threshold voltages, we can obtain the $K_{22}$ and helical twisting power simultaneously. In the whole process, there is no need to measure the pitch length. Our obtained $K_{22}$ values agree well with those reported by using other methods.

Keywords: liquid crystal display; fringe field switching; twist elastic constant

1. Introduction

Fringe-filed switching and in-plane switching (IPS) liquid crystal displays (LCDs) have been widely used in mobile displays, like smart phones and tablets.[1–9] In these LCDs, the electric field-induced LC reorientation takes place primarily in the horizontal direction. Therefore, their electro-optical characteristics, such as operation voltage and response time, are mainly governed by the twist elastic constant ($K_{22}$) instead of splay ($K_{11}$) or bend ($K_{33}$) elastic constants. However, it is not easy to measure $K_{22}$ precisely. For $K_{11}$ and $K_{33}$, a common measurement technique has been established.[10,11] But for $K_{22}$, even though several methods have been proposed, [12–21] each approach has its own merits and demerits.

An effective method for measuring $K_{22}$ is to use magnetic field.[12] The accuracy is reasonably high with careful alignment of the device relative to the magnetic field. However, a big electromagnet is required in order to generate high magnetic field (~1 Tesla). Meanwhile, the magnetic susceptibility anisotropy ($\Delta \chi_m$) [22] should be determined beforehand. Another approach is to use IPS cell, in which twist deformation can be induced by an electric field.[13,14] However, specific designs, like wall-shaped electrode or aluminium electrodes, are required to ensure pure twist rotation, otherwise the non-uniform LC reorientation would cause a large uncertainty in $K_{22}$ measurement. Raynes et al. proposed another technique using a wedge LC cell filled with a chiral dopant.[15,16] Because of the thickness gradient, the LC directors experience from an untwisted state to a 180° twisted state. Through fitting the threshold voltage at the disclination line, $K_{22}$ can be obtained. This method is quick to perform, but the accuracy is not good. Other methods, like guiding mode technique or conoscopic observation technique,[17–20] may have good accuracy but the complexity from both experimental set-up and elaborate fitting routine inhibits their wide acceptance.

In this paper, we propose a simple method for measuring $K_{22}$. The basic idea is to add some chiral dopants into an LC host, leading to a 180° twist in a homogeneous cell, which is known as 180° super-twisted nematic (STN) cell. Next, we assume the helical twisting power (HTP) of chiral dopant is also unknown, same as $K_{22}$. To solve two unknowns, we need two independent equations. To do so, we prepare two samples with different chiral concentrations. By measuring the Fréedericksz threshold voltages of these two 180° STN cells, both $K_{22}$ and HTP can be obtained simultaneously. In the whole process, there is no need to measure the pitch length. This method exhibits several advantages: (1) no sophisticated instrument is required, except two 180° STN LC cells; (2) simple experimental set-up: we only need to measure the voltage-dependent transmittance of the STN cells; (3) simple algorithm: we need two linear equations to solve two unknowns.

2. Working mechanism

The electro-optical properties of LC cells with a general planar alignment geometry have been investigated.[23–25] Once the applied voltage exceeds the Fréedericksz transition threshold (also known as critical voltage), the LC directors are reoriented by the electric field. Under strong surface anchoring, this critical voltage ($V_c$) can be expressed as [24,25]

*Corresponding author. Email: swu@ucf.edu

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$V_c = \pi \sqrt{\frac{K_{11} + \frac{d}{\pi} [K_{33} - 2K_{22}(1 - \frac{2d}{\pi P})]}{\varepsilon_0 \Delta \varepsilon}}$ \hspace{1cm} (1)

where $\phi$ is the total twist angle of LC directors, $\varepsilon_0$ is the vacuum permittivity, $\Delta \varepsilon (\varepsilon_1 - \varepsilon_2)$ is the dielectric anisotropy, $d$ is the cell gap and $P$ is the pitch length of the LC. For a homogeneous cell, $\phi = 0$ as shown in Figure 1(a), Equation (1) is simplified to

$$V_c = \pi \sqrt{\frac{K_{11}}{\varepsilon_0 \Delta \varepsilon}}$$ \hspace{1cm} (2)

Based on Equation (2), $K_{11}$ can be determined once $V_c$ and $\Delta \varepsilon$ are known. These two parameters can be obtained relatively easily from the measured voltage-dependent transmittance (VT) or capacitance curves. \cite{26,27}

To extract the $K_{22}$ value from Equation (1), here we propose to dope some chiral compound to the LC host and form a 180° STN cell ($\phi = \pi$) with $0.25 < d/P < 0.75$, as depicted in Figure 1(b). In Equation (1), if we substitute $\phi = \pi$ and pitch length $P = 1/(HTP \cdot c)$ (where $c$ is chiral concentration), then the critical voltage can be rewritten as

$$V_c = \pi \sqrt{\frac{K_{11} + [K_{33} - 2K_{22}(1 - 2d/P)]}{\varepsilon_0 \Delta \varepsilon}}$$

$$= \pi \sqrt{\frac{K_{11} + [K_{33} - 2K_{22}(1 - 2d \cdot c \cdot HTP)]}{\varepsilon_0 \Delta \varepsilon}}$$ \hspace{1cm} (3)

From Equation (3), in principle it is possible to determine $K_{22}$ by measuring the critical voltage. However, the accurate determination of $d/P$ is not easy. This is because for a given chiral dopant (e.g. R811), its HTP could vary noticeably depending on the LC host and measurement conditions.\cite{28-30} Thus, the measured $d/P$ result may not be consistent.

The novelty of our approach is to treat the HTP of chiral dopant as a second unknown. In experiment, we prepared two LC samples with different chiral concentrations. By measuring the threshold voltages of these two cells, $K_{22}$ and HTP could be extracted simultaneously. In the whole process, there is no need to measure the pitch length. Moreover, we do not need to control the chiral concentration precisely. As long as the $d/P$ ratio is in the range of 0.25–0.75, our method works well. It offers a great flexibility for conducting the measurement.

3. Experiment

In experiment, we employed commercial homogeneous cells. The inner surface of the indium tin oxide (ITO) glass substrates were over-coated with a thin polyimide alignment layer and rubbed in antiparallel direction. The pretilt angle was about $2^\circ$. Two homogeneous cells with gaps $d = 5.21 \, \mu m$ and $5.22 \, \mu m$ were prepared.

Next, we prepared two LC mixtures with different chiral concentrations. E7 has been well-studied previously. For comparison purpose, we also chose E7 as LC host and R811 as chiral dopant. The chiral concentrations were 0.52 wt% and 1.04 wt%.

After filling the LC mixture into a homogeneous cell, we placed the LC cell between two crossed polarisers. A Soleil–Babinet compensator was employed as the phase compensator to get a good dark state. The employed light source is He–Ne laser with $\lambda = 633$ nm. And the photodetector is Model 2031 (New Focus, USA). First, we recorded the VT curves for both samples,$[31]$ and then obtained the individual threshold voltage by linear fitting, as Figure 2 depicts. The fitted results are $V_{c1} = 1.32 \, V_{rms}$ for sample 1 and $V_{c2} = 1.52 \, V_{rms}$

![Figure 1](image1.png)

Figure 1. (LC director configuration for (a) homogeneous cell and (b) 180° STN cell with $0.25 < d/P < 0.75$.

![Figure 2](image2.png)

Figure 2. Measured voltage–transmittance (VT) curves for two 180° STN samples. Red lines are fitting curves.
for sample 2. Strictly speaking, the threshold voltage no longer exists if the pretilt angle is larger than zero, although a threshold-like behaviour still exists.[32] as Figure 2 shows. Since our cells have 2° pretilt angle, it may introduce a small error while determining $V_c$. Based on a previous analysis,[20] this uncertainty is within ±0.02 V$_{rms}$, which is still acceptable.

Meanwhile, we measured the dielectric anisotropy ($\Delta \varepsilon$), $K_{11}$ and $K_{33}$ of E7 using the methods described in Ref. [33] and Ref. [10], respectively. Our results are: $\Delta \varepsilon = 14.0$, $K_{11} = 10.8$ pN and $K_{33} = 17.5$ pN. Then all the auxiliary parameters except two unknowns in Equation (3) have been obtained. By substituting these values into Equation (3), we obtained two simple equations:

$$28.3 - 2K_{22}(1 - 0.0542 \cdot HTP) = 21.88 \quad (4)$$

$$28.3 - 2K_{22}(1 - 0.1086 \cdot HTP) = 29.02 \quad (5)$$

By solving Equations (4) and (5), we can obtain the $K_{22}$ of E7 and HTP of R811 simultaneously. Results are: $K_{22} = 6.8$ pN and HTP = 9.7 µm$^{-1}$. The experimental error will be discussed later. Table 1 lists the $K_{22}$ values of E7 measured using different methods.[15,17,20,34] By comparison, our $K_{22}$ result agrees quite well with the literature values. Besides, our measured HTP of R811 in E7 is 9.7 µm$^{-1}$, which is also in good agreement with that (HTP = 10 µm$^{-1}$) reported in Ref. [35].

### 4. Discussion

In our approach, we have successfully eliminated the uncertainty of measuring the pitch length. As a result, the overall error margin is quite similar to that of π-cell technique.[20] The major errors of both methods come from the uncertainty of $K_{11}$, $K_{33}$, $\Delta \varepsilon$ and $V_c$ measurements. Based on the previous analyses in Ref. [20], we summarised the uncertainties of each parameter in Table 2. Similar to the π-cell technique, the estimated error bar of our approach is ±8%, which is still pretty good as compared to other methods.[14] To minimise experimental errors, more accurate measurements for the input parameters are required, especially for the bend elastic constant $K_{33}$. Besides, using a thicker cell gap or preparing a larger amount of sample would also reduce the total error. Considering the simplicity of our approach, widespread application of this approach is foreseeable.

Using the proposed method, we measured the elastic constants of other commonly studied LC materials. And the results are listed in Table 3. The values in the brackets are the literature results or offered by the material suppliers (e.g. DIC and HCCH). From Table 3, good agreement is achieved.

### 5. Conclusion

We have proposed a simple method to measure the twist elastic constant of nematic LCs. Compared to other measurement techniques, our method shows three advantages: (1) no sophisticated instrument is required; (2) the experimental set-up is fairly straightforward; and (3) easy algorithm: we need two linear equations to solve for two unknowns. Our measured $K_{22}$ values agree well with those using other
approaches. This simple method will enable us to characterise the $K_{22}$ of more LC materials for display applications.

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