Taylor & Francis
Taylor & Francis Group

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

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

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

where ϕ is the total twist angle of LC directors, ε_0 is the vacuum permittivity, $\Delta\varepsilon$ ($\varepsilon_\parallel - \varepsilon_\perp$) 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

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

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. [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

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

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.[28–30] Thus, the measured d/P result may not be consistent.

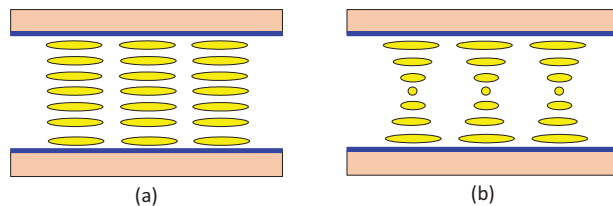The novelty of our approach is to treat the HTP of chiral dopant as a second unknown. In experiment, we prepared two LC samples with different chiral concentrations. By measuring the threshold voltages of these two cells, K_{22} and HTP could be extracted simultaneously. In the whole process, there is 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°. Two homogeneous cells with gaps $d = 5.21$ μm and 5.22 μm 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. (LC director configuration for (a) homogeneous cell and (b) 180° STN cell with $0.25 < d/P < 0.75$.
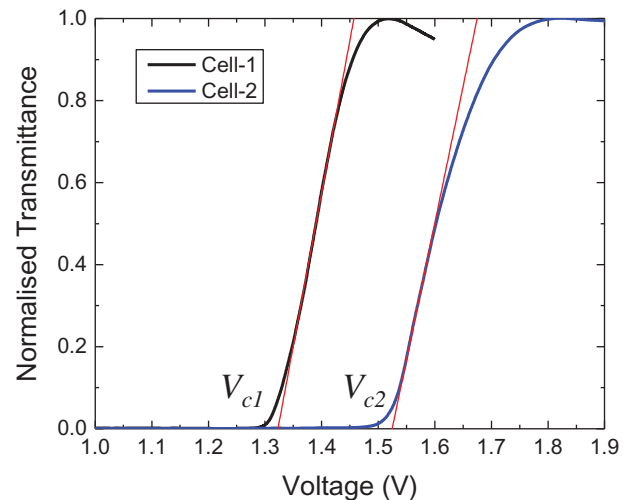

Figure 2. Measured voltage–transmittance (VT) curves for two 180° STN samples. Red lines are fitting curves.

Table 1. Comparison on the measured K_{22} of E7 from different techniques, $T = 23°C$.

	Magnetic field	Wedge cell		Dynamic light scattering	Optical guided modes	Pi-cell	Our method
K_{22} (pN)	6.5	7.6	6.8	6.2	6.5	6.4	6.8

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:

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

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

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

Table 2. Sources of error for the measurement of K_{22} of E7.

Source	Error in measured K_{22} (%)
Pretilt angle ±0.5°	±3.0
Pretwist angle ±0.5°	−3.5
Cell gap ±0.05 μm	±1.0
Chiral concentration ±0.01 mg	±1.5
V_c ±0.02 V_{rms}	±3.5
K_{11} ±2.2%	±2.6
K_{33} ±4.6%	±4.5
$\Delta\varepsilon$ ±0.9%	±1.2
Total	±8.1

Table 3. Measured dielectric constants and elastic constants of five LC mixtures and the HTP values of R811 at $T = 23°C$.

	$\varepsilon_{\parallel}$	$\varepsilon_{\perp}$	$\Delta\varepsilon$	K_{11} (pN)	K_{22} (pN)	K_{33} (pN)	HTP of R811 (μm^{-1})
E7	19.2	5.2	14.0	10.8	6.8 (6.5)[a]	17.5	9.7
BL038	20.7	5.3	15.4	13.3	8.6	27.1	11.2
ZLI-1132	16.5	4.5	12.0	9.5	6.5 (6.3)[a]	18.2	12.4
DIC-LC2	4.5	2.8	1.7	12.5	6.3 (6.5)[b]	13.5	9.4
HAI-653265	5.0	2.6	2.4	13.0	7.4 (7.8)[c]	14.2	9.8

Note: [a]See Ref. [18], [b]data from DIC (Japan), [c]data from HCCH (China).

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.

Disclosure statement

No potential conflict of interest was reported by the authors.

References

[1] Lee SH, Lee SL, Kim HY. Electro-optic characteristics and switching principle of a nematic liquid crystal cell controlled by fringe-field switching. Appl Phys Lett. 1998;73:2881–2883. doi:10.1063/1.122617

[2] Lee SH, Kim HY, Lee SM, et al. Ultra-FFS TFT-LCD with super image quality, fast response time, and strong pressure-resistant characteristics. J Soc Inf Disp. 2002;10:117–122. doi:10.1889/1.1827852

[3] Yun HJ, Jo MH, Jang IW, et al. Achieving high light efficiency and fast response time in fringe field switching mode using a liquid crystal with negative dielectric anisotropy. Liq Cryst. 2012;39:1141–1148. doi:10.1080/02678292.2012.700078

[4] Chen Y, Luo Z, Peng F, et al. Fringe-field switching with a negative dielectric anisotropy liquid crystal. J Display Technol. 2013;9:74–77. doi:10.1109/JDT.2013.2242844

[5] Chen H, Peng F, Luo Z, et al. High performance liquid crystal displays with a low dielectric constant material. Opt Mater Express. 2014;4:2262–2273. doi:10.1364/OME.4.002262

[6] Xu D, Peng F, Chen H, et al. Image sticking in liquid crystal displays with lateral electric fields. J Appl Phys. 2014;116:193102. doi:10.1063/1.4902083

[7] Chen H, Luo Z, Xu D, et al. A fast-response A-film-enhanced fringe field switching liquid crystal display. Liq Cryst. 2015;42:537–542. doi:10.1080/02678292.2015.1014873

[8] Xu D, Chen H, Wu S-T, et al. A fringe field switching liquid crystal display with fast grayscale response time. J Display Technol. 2015;11:353–359. doi:10.1109/JDT.2015.2398315

[9] Oh-e M, Kondo K. Electro-optical characteristics and switching behavior of the in-plane switching mode. Appl Phys Lett. 1995;67:3895–3897. doi:10.1063/1.115309

[10] Uchida T, Takahashi Y. New method to determine elastic constants of nematic liquid crystal from C-V curve. Mol Cryst Liq Cryst. 1981;72:133–137. doi:10.1080/01406568108084049

[11] Morris SW, Palffy-muhoray P, Balzarini DA. Measurements of the bend and splay elastic constants of octyl-cyanobiphenyl. Mol Cryst Liq Cryst. 1986;139:263–280. doi:10.1080/00268948608080132

[12] Madhusudana NV, Pratibha R. Elasticity and orientational order in some cyanobiphenyls: part IV. Reanalysis of the data. Mol Cryst Liq Cryst. 1982;89:249–257. doi:10.1080/00268948208074481

[13] Ikeda K, Okada H, Onnagawa H, et al. Twist elastic constants of liquid crystals using in-plane electrode structure. J Appl Phys. 1999;86:5413–5416. doi:10.1063/1.371539

[14] Parka J, Dąbrowski M, Kowerdziej R. Investigations of twist elastic constant K_{22} of new nematic liquid crystal materials using threshold IPS method. Opto-Electron Rev. 2011;19:114–118. doi:10.2478/s11772-010-0074-z

[15] Strömer JF, Brown CV, Raynes EP. Method for the measurement of the K_{22} nematic elastic constant. Appl Phys Lett. 2002;82:13–15.

[16] Strömer JF, Brown CV, Raynes EP. A novel method for the measurement of the nematic liquid crystal twist elastic constant. Mol Cryst Liq Cryst. 2004;409:293–299. doi:10.1080/15421400490431444

[17] Yang F, Sambles JR, Bradberry GW. Half-leaky guided wave determination of azimuthal anchoring energy and twist elastic constant of a homogeneously aligned nematic liquid crystal. J Appl Phys. 1999;85:728. doi:10.1063/1.369153

[18] Parry-Jones LA, Geday MA. Measurement of twist elastic constant in nematic liquid crystals using conoscopic illumination. Mol Cryst Liq Cryst. 2005;436:259/[1213]-266/[1220]. doi:10.1080/15421400590955721

[19] Nych A, Voronin M, Pergamenshchik V, et al. Measurement of the twist elastic constant by phase retardation technique. Mol Cryst Liq Cryst. 2002;384:77–83. doi:10.1080/713738780

[20] Brimicombe PD, Kischka C, Elston SJ, et al. Measurement of the twist elastic constant of nematic liquid crystals using pi-cell devices. J Appl Phys. 2007;101:043108. doi:10.1063/1.2432311

[21] Xu D, Peng F, Tan G, et al. A semi-empirical equation for the response time of in-plane switching liquid crystal display and measurement of twist elastic constant. J Appl Phys. 2015;117:203103. doi:10.1063/1.4921872

[22] Wu S-T, Smith WH, Lackner AM. Diamagnetic anisotropy measurements of nematic liquid crystals. Mol Cryst Liq Cryst. 1986;140:83–93. doi:10.1080/00268948608080144

[23] Raynes EP, Tough RJA, Davies KA. Voltage dependence of the capacitance of a twisted nematic liquid crystal layer. Mol Cryst Liq Cryst. 1979;56:63–68. doi:10.1080/01406567908071968

[24] Raynes EP. The theory of supertwist transitions. Mol Cryst Liq Cryst. 1986;4:1–8.

[25] Finkenzeller U, Weber G. A simple method to estimate and optimize the optical slope of TN cells and its comparison with experimental results. Mol Cryst Liq Cryst. 1988;164:145–156.

[26] Bradshaw MJ, Raynes EP. Electric permittivities and elastic constants of the cyano bi-cyclohexanes (CCH).

Mol Cryst Liq Cryst. 1981;72:35–42. doi:10.1080/01406568108084034

[27] Chen H, Hu M, Peng F, et al. Ultra-low viscosity liquid crystal materials. Opt Mater Express. 2015;5:655–660. doi:10.1364/OME.5.000655

[28] Oswald P. Lehmann rotation of cholesteric droplets subjected to a temperature gradient: role of the concentration of chiral molecules. Eur Phys J E. 2009;28:377–383. doi:10.1140/epje/i2008-10431-3

[29] Oswald P. Leslie thermomechanical power in diluted cholesteric liquid crystals. EPL. 2014;108:36001. doi:10.1209/0295-5075/108/36001

[30] Oswald P, Poy G. Lehmann rotation of cholesteric droplets: role of the sample thickness and of the concentration of chiral molecules. Phys Rev E. 2015;91:032502. doi:10.1103/PhysRevE.91.032502

[31] Wu ST, Efron U, Hess LD. Birefringence measurements of liquid crystals. Appl Opt. 1984;23:3911–3915. doi:10.1364/AO.23.003911

[32] Nie X, Xianyu H, Lu R, et al. Pretilt angle effects on liquid crystal response time. Display Technol J. 2007;3:280–283.

[33] Wu S-T, Wu C-S. Experimental confirmation of the Osipov-Terentjev theory on the viscosity of nematic liquid crystals. Phys Rev. 1990;42:2219–2227. doi:10.1103/PhysRevA.42.2219

[34] Sefton MS. Dynamic light scattering from thermotropic liquid crystals [dissertation]. University of Manchester; 1985.

[35] Hurley SP. Liquid crystal displays for pixelated glare shielding eyewear [dissertation]. Kent State University; 2010.