Electro-Optical Properties of Quasi-Twisted Nematic Cell with Spontaneous 90° Twist Liquid Crystal

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ABSTRACT

A twisted hybrid aligned nematic orientation turns to a TN orientation, that is a quasi TN (Q-TN), by weakening the anchoring on only one side of the substrate. The driving voltage can be reduced in the Q-TN. The relationship between elastic constants, anchoring strengths and electro-optical properties are numerically clarified when using the spontaneous 90° LC cell.

1 Introduction

A hybrid aligned nematic (HAN) LC mode in which one substrate alignment is planar and another is homeotropic has no threshold voltage, since the LC director in the bulk is already tilted to an electric field. Moreover, it has been reported that the HAN orientation changes to a homogeneous orientation when the anchoring strength of the homeotropic alignment surface decreases to a critical anchoring [1]. The homogeneously aligned LC cell which we call cells as a quasi homogeneous (Q-Homo) have no threshold voltages, as well as the HAN cell.

As the same manner, a twisted hybrid aligned nematic (THA) [2, 3]" also turns to a TN orientation when the anchoring strength is less than the critical one [4, 5], that is called a quasi TN (Q-TN). Q-TN cell has a drive voltage below 1 volt. As a condition in these reports of the Q-TN cells, the azimuthal anchoring was assumed to be infinite. However, the LC with spontaneous 90° twist have been used in the previous THA cells. Therefore, in this paper, the spontaneous 90° twist is introduced in the Q-TN. Relationships between LC elastic constants and the critical anchoring strength (*W*c) are estimated and the electro-optical property is numerically clarified.

2. Principle

Figure 1 shows a schematic LC orientation model of THA and Q-TN cells. The planar alignment surface has infinite strong polar anchoring strength ($W_{\mathrm{p\_0}}$). Azimuthal easy axes of a pair of substrates is perpendicular and the azimuthal anchoring strength is infinite in both substrates.

A total free energy per unit area *F* in the LC cell is represented,

$$F = F_{\mathrm{surface}} + F_{\mathrm{bulk}} + F_{\mathrm{electric}}$$

$$F_{\mathrm{surface}} = \frac{1}{2} W_{\mathrm{p\_d}} \sin^2(\theta_{\mathrm{d}} - \theta(d))$$

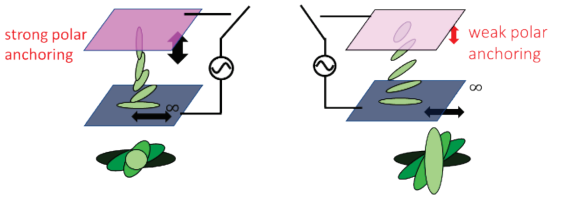
$$F_{\mathrm{bulk}} + F_{\mathrm{electric}} = \int_0^d \frac{1}{2} \left\{ (K_{11}\cos^2\theta + K_{33}\sin^2\theta)\left(\frac{d\theta}{dz}\right)^2 \right.$$

$$+(K_{22}\cos^2\theta + K_{33}\sin^2\theta)\cdot\cos^2\theta\left(\frac{d\phi}{dz}\right)^2$$

$$\left. -2K_{22}\frac{2\pi}{P_0}\cos^2\theta\left(\frac{d\phi}{dz}\right) + K_{22}\left(\frac{2\pi}{P_0}\right)^2 - \varepsilon_0(\varepsilon_\perp + \Delta\varepsilon sin^2\theta)\left(\frac{dV}{dz}\right)^2 \right\} \quad (1)$$

where K_{11}, K_{22} and K_{33} are splay, twist and bend elastic constants, P_0 is a spontaneous helical pitch of the LC, θ is the tilt angle, ϕ is the twist angle, *d* is the thickness of the LC layer, and W_p is the polar anchoring strength of each substrate. The LC director distribution is estimated by minimizing a total free energy *F* by a finite difference method. In this study, the cell thickness *d* is set to be 10 μm. In order to achieve the spontaneous twist of 90°, the pitch length is 40 μm.

3. Results



(a) THA (b) Q-TN

Fig. 1 Schematic model of (a) THA, (b) Q-TN cells.

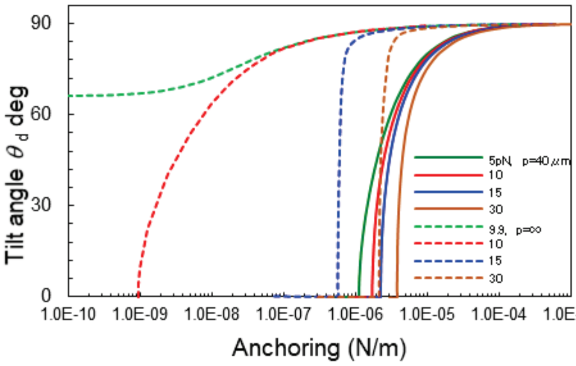


Fig. 2 Polar anchoring vs. tilt angle on the homeotropic surface with the parameter of K_{11} and the pitch length. K_{22}=K_{33}=10 pN.

θ_{d} which is the tilt angle on the homeotropic surface is estimated as a function of the polar anchoring $W_{\mathrm{p\_d}}$ with the parameter of K_{11}, as show in Fig. 2. Here, K_{22} and K_{33} are 10 pN. θ_{d} decreases with decreasing the anchoring strength and is to 0° at each critical anchoring *W*c. When the pitch length is infinite, the Q-TN is not obtained with K_{11} less than 10 pN since θ_{d} never becomes zero even if the *W*c decreases. On the other hand, when the pitch length is 40 μm, the Wc can be found with any values of K_{11}. Fig. 3 shows *W*c as a function of K_{11}. *W*c almost linearly increases with K_{11} for both pitch lengths.

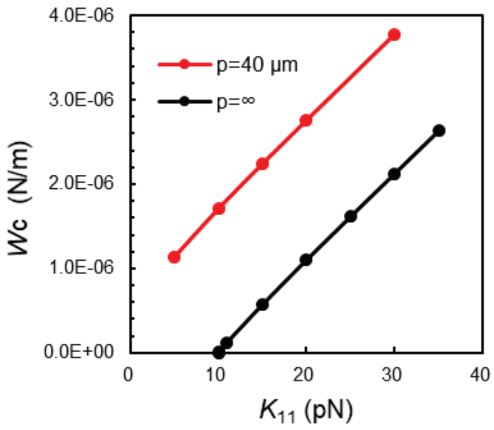


Fig. 3 *W*c as a function of K_{11}. K_{22}=K_{33}=10 pN. *d* is 10 μm.

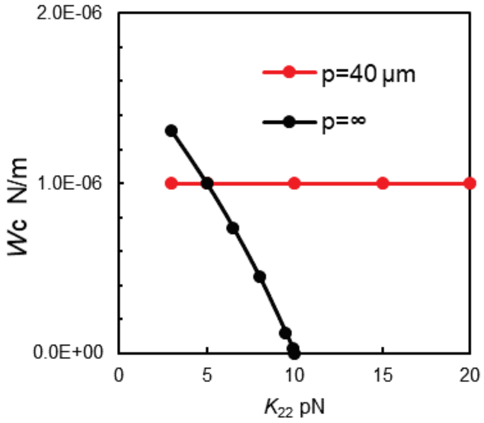


Fig. 4 *W*c as a function of K_{22}. K_{11}=K_{33}=10 pN. *d* is 10 μm.

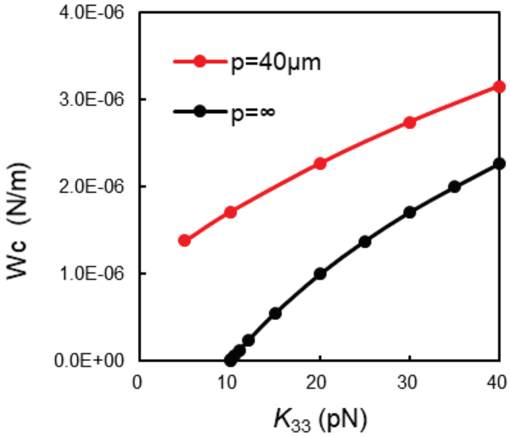


Fig. 5 *W*c as a function of K_{33}. K_{11}=K_{22}=10 pN. *d* is 10 μm.

Fig. 4 shows *W*c as a function of K_{22}. K_{11} and K_{33} are 10 pN. *W*c decreases with K_{22} if the pitch is infinite and the Q-TN is not obtained with K_{22} more than 10 pN. When the pitch length is 40 μm, the *W*c is independent of K_{22} and is approximately 1.71×10-6 N/m. This is because there is no torsional torque in the cell due to the spontaneous twisting of the LC.

Fig. 5 shows *W*c as a function of K_{33}. K_{11} and K_{22} are 10 pN. *W*c increases with K_{33} for both pitch lengths of 40 μm and infinite, as shown in Fig. 5, however are not linear properties as well as the function of K_{11}.The Q-TN is not obtained with K_{33} less than 10 pN and *W*c can be found with any values of K_{33} with the pitch length of 40 μm.

Figure 6 shows electro-optical properties are calculated with the parameter of K_{33} in Q-TN cells. K_{11} and K_{22} are10 pN. The cell thickness is =10 μm and Δ*n* is 0.1065, giving the 2nd minimum condition at the wavelength of 550 nm. Each anchoring strength is the critical anchoring given by Fig. 5. It is well known that the threshold voltage V_{90} and the driving voltage V_{10} increase with K_{33} in the conventional TN cell. Almost the same changes are obtained in the Q-TN. Furthermore, the addition of chiral agents is also known to increase the driving voltage. When the pitch length is changed from infinite to 40 μm, V_{10} becomes approximately three times higher.

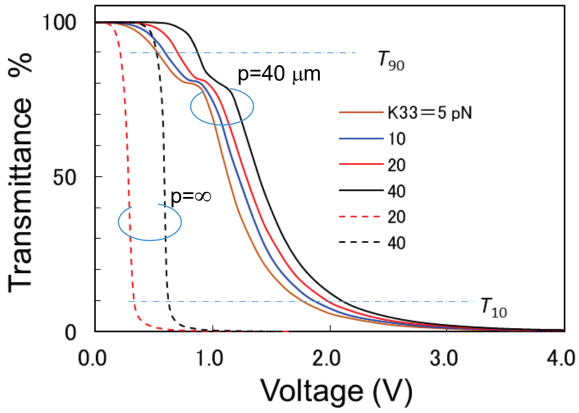


Fig. 6 VT curves in Q-TN cells with the parameter of K_{33}. K_{11}=K_{22}=10 pN. *d* is 10 μm.

The electro-optical properties are calculated with the parameters of K_{11}=10, K_{22}=7 and K_{33} =14 pN, $\varepsilon_{//}$=15 and $\varepsilon_{\perp}$=5, which are typical values for a nematic LC for a display. The cell thickness is =5 μm and Δ*n* is 0.095, giving the 1st minimum condition at the wavelength of 550 nm. The pitch length is 20 μm (=4*d*) and *W*c is estimated to be 3.9×10^{-6} N/m. If the pitch length is infinite, *W*c is 2.0×10^{-6} N/m. It is also well known that the driving voltage becomes higher with a shorter pitch length in conventional TN cells. The driving voltage V_{10} increases from 1.96 to 2.36 V. In the Q-TN with an infinite pitch length, V_{10} is extremely low at 0.37 V. V_{10} increases to 1.34 V if the pitch length is 20 μm.

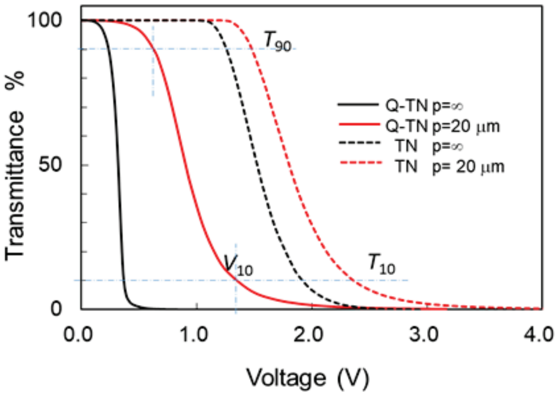


Fig. 7 VT curves in TN and Q-TN cells. K11=10, K22=7 and K33 =14 pN. *d* is 5 μm.

4. Conclusions

The spontaneous 90° twist is introduced in the Q-TN. The critical anchoring strength *W*c for the transition from THA to Q-TN orientations is highly dependent on the three elastic constants of the NLC and. Furthermore, it was clarified that Q-TN is realized for any elastic constant when the liquid crystal has a 4*d* pitch length. The driving voltage increases due to the addition of pitch length. However, it is lower than that of the conventional TN cell.

References

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