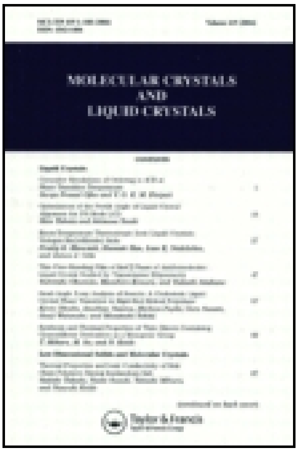

Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl19

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Version of record first published: 04 Oct 2006

To cite this article: Jianlin Li, James E. Anderson, Charles D. Hoke, Toshiaki Nose & Philip J. Bos (1997): The Effect of Polymer Networks on the Electrodistortional Characteristics of Nematic Liquid Crystals, Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals, 301:1, 261-266

To link to this article: http://dx.doi.org/10.1080/10587259708041776

Mol. Cryst. Liq. Cryst., 1997, Vol. 301, pp. 261–266
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THE EFFECT OF POLYMER NETWORKS ON THE ELECTRO-DISTORTIONAL CHARACTERISTICS OF NEMATIC LIQUID CRYSTALS

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Abstract The effect of polymer networks is studied for highly twisted nematic liquid crystals. A numerical relaxation technique was used to minimize the free energy density of a liquid crystal medium. Assuming the networks are distributed uniformly, an polymer network contribution to the system free energy is added in the form of $-\frac{1}{2}K_a(\underline{n} \bullet \underline{N})^2$, where K_a, $\underline{n}$ and $\underline{N}$ are polymer network coefficient, liquid crystal director and polymer network unit vector, respectively. Ignoring the polymer networks elasticity, the liquid crystal director configuration and elastic energy under the influence of an external electric field are calculated numerically. The obtained electro-distortional characteristics are found to depend on the value of K_a and $\underline{N}$. The results are compared to the electro-optic threshold and hysteresis behaviors of a set of highly twisted nematic cells with different monomer concentrations. The elastic energy of the liquid crystal medium is used to describe its bistability.

INTRODUCTION

Recently, polymer networks formed in the liquid crystal mixtures have been shown to improve the electro-optic performances of liquid crystal displays.[1,2,3,4,5] This study investigates the influence of polymer networks in highly-twisted nematics. Even though the exact mechanism is still unclear and under investigation, a polymer network field-like contribution, maybe coupled with the interaction between the nematic elasticity and network elasticity,[6,7] seems to explain the electro-optic behaviors of a polymer stabilized cell. Since the flexibility of a polymer network is unknown at this point, only the field-like contribution to the system free energy is considered in our present calculation. However, the method proposed here can take into account the elasticity of the polymer networks once it is known. The highly-twisted nematics are studied to take advantages of their steep threshold and possible hysteresis.

THEORY

From the continuum theory, the free energy density in a liquid crystal medium (neglecting the surface divergence terms for K_{13} and K_{24}) has the form:

$$F=\tfrac{1}{2}\{K_1(\nabla\bullet\underline{\mathbf{n}})^2+K_2[\underline{\mathbf{n}}\bullet(\nabla\times\underline{\mathbf{n}})-q_0]^2+K_3[\underline{\mathbf{n}}\times(\nabla\times\underline{\mathbf{n}})]^2\}-\tfrac{1}{2}(\underline{\mathbf{D}}\bullet\underline{\mathbf{E}})-\tfrac{1}{2}(\underline{\mathbf{B}}\bullet\underline{\mathbf{H}}) \quad (1)$$

where K_1, K_2 and K_3 are splay, twist and bend elastic constants, respectively; $\underline{\mathbf{n}}$ is the director; $\underline{\mathbf{D}}$, $\underline{\mathbf{E}}$, $\underline{\mathbf{B}}$ and $\underline{\mathbf{H}}$ are the electric displacement, electric field, magnetic induction and magnetic field, respectively; q_0 is the wave vector which is equal to $2\pi/P$ and P is the nature pitch. The positive and negative values of q_0 correspond to the left and right handed helix, respectively.

For a system which has the coordinates as in Figure 1, where θ and ϕ are the polar and azimuthal angles of the director; θ_N is the angle of polymer network director makes with the z axis, and ϕ_N is the angle of the projection of polymer network director makes with the x axis.

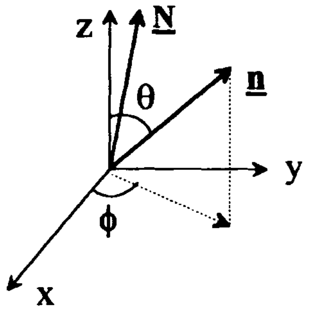

FIGURE 1 Coordinates for liquid crystal director $\underline{\mathbf{n}}$

In a system which has a polymer network in the direction of $\underline{\mathbf{N}}$ and has no magnetic field present, using the representation of the director in terms of angles θ and ϕ,

$$\underline{\mathbf{n}} = (\sin\theta\cos\phi, \sin\theta\sin\phi, \cos\theta) \text{ and } \underline{\mathbf{N}} = (\sin\theta_N\cos\phi_N, \sin\theta_N\sin\phi_N, \cos\theta_N)$$

the energy density has the form of

$$\begin{aligned} F = \tfrac{1}{2}\{&K_1(\sin^2\theta)\bullet(\theta')^2 + K_2[(\sin^4\theta)\bullet(\phi')^2 + 2q_0(\sin^2\theta)\bullet(\phi') + q_0^2] \\ &+K_3[(\cos^2\theta)\bullet(\theta')^2 + (\sin^2\theta\cos^2\theta)\bullet(\phi')^2]\} - \tfrac{1}{2}(\underline{\mathbf{D}}\bullet\underline{\mathbf{E}}) - \tfrac{1}{2}K_a(\underline{\mathbf{n}}\bullet\underline{\mathbf{N}})^2 \end{aligned} \tag{2}$$

where K_a is the polymer network coefficient.

Using the numerical relaxation technique outlined in an earlier paper[8], the coupled equations

$$\begin{aligned} \gamma\frac{\partial\theta}{\partial t} = {} & [K_1(\sin^2\theta) + K_3(\cos^2\theta)]\bullet(\theta'') + [K_1 - K_3](\sin\theta\cos\theta)\bullet(\theta')^2 \\ & -\{[2K_2\sin^2\theta + K_3(\cos 2\theta)]\bullet(\phi')^2 - 2K_2q_0(\phi') \\ & +\frac{D_z^2}{\varepsilon_0}\left[\frac{\Delta\varepsilon}{(\varepsilon_{//}\cos^2\theta + \varepsilon_\perp\sin^2\theta)^2}\right]\}(\sin\theta\cos\theta) \\ & +K_a(\sin\theta\cos\theta\cos^2\phi\sin^2\theta_N\cos^2\phi_N + \sin\theta\cos\theta\sin^2\phi\sin^2\theta_N\sin^2\phi_N \\ & +2\sin\theta\cos\theta\sin\phi\cos\phi\sin^2\theta_N\sin\phi_N\cos\phi_N + \cos^2\theta\cos\phi\sin\theta_N\cos\theta_N\cos\phi_N \\ & -\sin^2\theta\cos\phi\sin\theta_N\cos\theta_N\cos\phi_N + 2\sin\theta\cos^2\theta\sin\phi\sin\theta_N\cos\theta_N\sin\phi_N \\ & -\sin\theta\cos\theta\cos^2\theta_N - \sin^3\theta\sin\phi\sin\theta_N\cos\theta_N\sin\phi_N) \end{aligned} \tag{3}$$

and

$$\begin{aligned} \gamma\sin^2\theta\frac{\partial\phi}{\partial t} = {} & [K_2(\sin^4\theta) + K_3(\sin^2\theta\cos^2\theta)]\bullet(\phi'') + 2[K_2q_0\sin\theta\cos\theta]\bullet(\theta') \\ & +2[2K_2\sin^2\theta + K_3(\cos 2\theta)](\sin\theta\cos\theta)\bullet(\theta'\phi') \\ & +K_a(-\sin^2\theta\sin\phi\cos\phi\sin^2\theta_N\cos^2\phi_N + \sin^2\theta\sin\phi\cos\phi\sin^2\theta_N\sin^2\phi_N \\ & +\sin^2\theta\cos^2\phi\sin^2\theta_N\sin\phi_N\cos\phi_N - \sin^2\theta\sin^2\phi\sin^2\theta_N\sin\phi_N\cos\phi_N \\ & -\sin\theta\cos\theta\sin\phi\sin\theta_N\cos\theta_N\cos\phi_N + \sin^2\theta\cos\theta\cos\phi\sin\theta_N\cos\theta_N\sin\phi_N) \end{aligned} \tag{4}$$

can be solved numerically by letting $\theta(z)$ and $\phi(z)$ relax to equilibrium.

RESULTS AND DISCUSSIONS:

A diacrylate monomer, Desolite 2002-33 from DSM Desotech Inc., was added in different concentrations to the liquid crystal mixture of ZLI-1694 with 1.8% chiral CB15. Polyimide alignment layer Nissan-SE3510 was spin-coated onto ITO coated glass at 2550 RPM. The polyimide coated glass was soft-baked on a 90°C hot-plate for 2 minutes and then hard-baked in a 250°C oven for 60 minutes. Pretilts of about 8° were obtained by using the hand-rubbing technique. 7 μm glass spacers were used. The cells, vacuum filled with the liquid crystal mixture, were exposed to a metal halide lamp exposure system from nuArc Company, Inc., after they were squeezed and sealed. A curing voltage was applied to the cells during the exposure process.

The data of reduced voltage and hysteresis width as a function of polymer concentration for a set of 360° twist cells, cured at 10 V, is presented in Figure 1. When the concentration was less than 1.0 percent, there was no change on the drive voltage. When the polymer concentration was larger than 2.6 percent, the effect of the polymer networks stabilized the mid-cell director to perpendicular to the surface. They were 'homeotropic' at zero field, and there was very little birefringence change when an electric field was applied. In the range between, the higher the polymer content was, the lower the drive voltage and wider the hysteresis curve were.

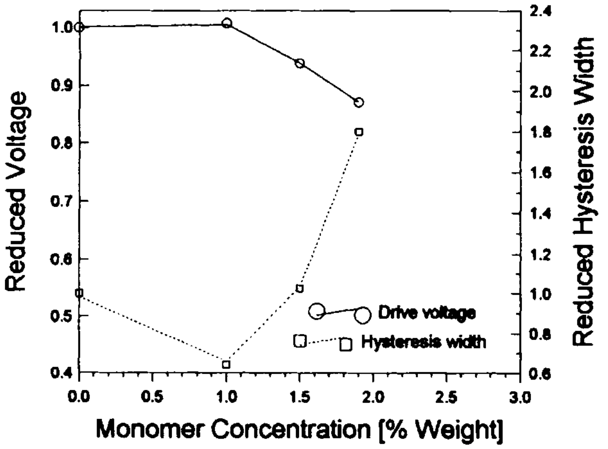

FIGURE 1 Experimental data for a set of 360° twist cells of various polymer concentration. Curing voltage was 10 V.

The same quantities as a function of polymer coefficient are calculated and presented in Figure 2. When the polymer coefficient was less than 0.3 times the twist elastic constant, there was no drive voltage change. When the coefficient was larger than this value, the drive voltage decreased linearly as a function of the coefficient. The increase of the hysteresis width as a function of the coefficient had similar characteristics to the experimental data. The surface condition for calculation was assumed as hard anchoring, commonly used in display modeling programs. The director configurations, the total Gibbs free energy and the elastic energy were obtained with the applied voltage increment of 0.1 V.

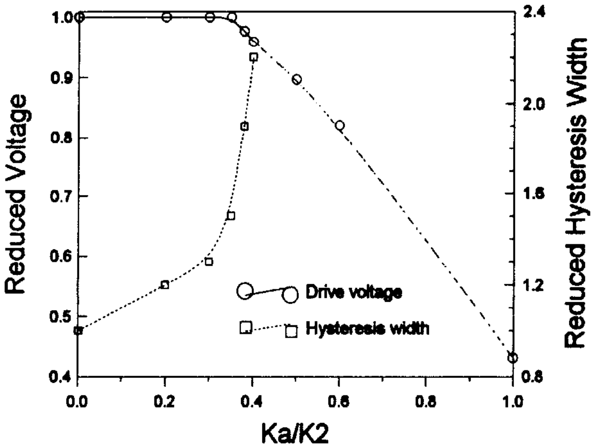

FIGURE 2 Simulation data of reduced voltage and hysteresis width as a function of polymer coefficient Ka/K_2. Polymer curing voltage was 10 V.

Shown in Figure 3 is the experimental data for a series of cells mixed with 1.9 % polymer, cured at 0, 2, 4, 6, 8, and 10 volts. When the curing voltage was zero, the drive voltage was significantly increased. This increase was exactly the same as the one with a curing voltage of 2 volts. This is expected, since the networks formed with zero volts or two volts cure were exactly the same. After the curing voltage was larger than the minimum voltage required to deform the liquid crystal cell, the drive voltage decreased and the hysteresis width increased with increased curing voltage. Fitting the theoretical model to the data is currently underway.

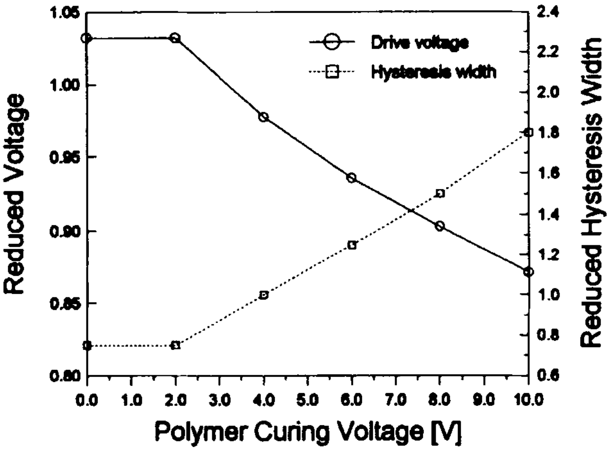

FIGURE 3 Experimental data for a set of 360° twist cells with 1.9% polymer concentration. The reduced voltage and hysteresis width are plotted as a function of polymer curing voltage.

CONCLUSIONS AND ACKNOWLEDGMENTS

The electro-optic behaviors of highly twisted nematics modified by polymer networks were studied. A numerical relaxation technique that minimizes the liquid crystal system free energy was used to calculate the elastic energy, which was used for describing the bistability. The proposed polymer network contribution to the system free energy explains the general characteristics of the experimental data. Finally, the authors wish to acknowledge the support by NSF ALCOM Center under the grant # 89-20147.

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