Fast Birefringent Mode Stressed Liquid Crystal

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Fast birefringent mode stressed liquid crystal

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We report a stressed liquid crystal (SLC) that produce a large shift in phase retardation at submillisecond speeds. The SLC consists of uniformly aligned micro-domains of a liquid crystal dispersed in a polymer structure. Mechanical stress produces uniform alignment, essentially eliminates light scattering, and substantially improves the electro-optic performance. A 22-μm-thick SLC film switches more than 2 μm of phase retardation in less than 1 ms. The system has a linear voltage response with essentially no hysteresis. © 2005 American Institute of Physics. [DOI: 10.1063/1.1852720]
We were able to measure the pretilt angle in the cell. It revealed that the scattering distance shows the dependence of the film transmittance versus the application of any shearing stress.

The measurements were done before a higher temperature than 67 °C. The scattering is much lower for the cells polymerized at a higher temperature than 67 °C. The measurements were done before application of any shearing stress.

The transition temperature of the liquid crystal used, the transmittance curve belongs to lower branch of the curves as shown in Fig. 1. For a cell polymerized at a higher temperature than the N–I transition temperature, the initial scattering is much lower and the transmission curve belongs to the upper branch of the curves (Fig. 1). Here and later we normalize transmittance measurements on the transmittance of an empty cell.

Initially, all the cells appear optically isotropic when viewed between crossed polarizers. Therefore the unstressed cells cannot be used in a traditional birefringence mode. Also, the unstressed cells are characterized with a slow electro-optical response. For example, for a 5CB based cell polymerized at a temperature of 60 °C application of about 20 V switched it into a transparent state with the relaxation time of about 50 ms. The relaxation time is even larger for the cells polymerized at a lower temperature than 60 °C.

Mechanical shearing drastically changes the optical and electro-optical properties of the mentioned 5CB cell. The cell becomes transparent, highly anisotropic and with greatly increased switching speeds. We quantified the shearing using a specially constructed shearing device where the shearing distance \( L \) increased from 20% for \( \mu m \) to 95% for \( \mu m = 20 \). The increase of the transparency occurs between crossed polarizers; therefore the unstressed cells are characterized with a slow electro-optical response. For example, for a 5CB based cell polymerized at a temperature of 60 °C application of about 20 V switched it into a transparent state with the relaxation time of about 50 ms. The relaxation time is even larger for the cells polymerized at a lower temperature than 60 °C.

A dramatic increase of the transparency occurs upon shearing. For instance, the transparency at \( \lambda = 0.63 \mu m \) increases from 20% for \( L_{\text{shear}} = 0 \) to 95% for \( L_{\text{shear}} = 100 \mu m \). The increase of the transparency occurs because of the uniform orientation of the liquid crystal microdomains along the shearing. Unlike PDLCS, the transmittance of the SLC cell does not depend on the polarization of the probe light indicating that the light scattering resulted from a mismatch between the refractive index of the unaligned liquid crystal domains and not between the individual domains and the polymer network. This indicates that the dimensions of the polymer network are small relative to the wavelength of light.

Starting from a shearing distance of about 20 \( \mu m \) we were able to measure the pretilt angle in the cell. It revealed a value of about 3°, which changed negligibly with further shearing. To characterize the orientation of the liquid crystal at a smaller shearing we measured the absorption dichroism of the SLC film in the absorption band of 5CB at \( \lambda = 0.325 \mu m \) for different shear distances, \( L_{\text{shear}} \). From these data we calculated the dichroic ratio, \( N \), and then the liquid crystal domains ordering as \( \alpha = (N–1)/(N+1) \). In our experimental geometry, a change of \( \alpha \) with shearing reflects changes of the liquid crystal orientation in both the azimuthal and polar planes. As depicted in the inset of Fig. 2, the ordering of the liquid crystal increases drastically at small shearing \( L_{\text{shear}} < 20 \mu m \) and saturates above \( \sim 80 \mu m \).

The switching speed of the liquid crystal cell increased dramatically upon shearing. We measured the switching speed of the cell by placing it between crossed polarizers, and aligning the shearing axis 45° to the polarization axes. The transmitted intensity, \( I \), of the normally incident beam can be calculated by the following equation: 

\[
I = I_0 \sin^2 \delta, 
\]

where \( \delta = 2\pi nd/\lambda \) is the angular phase retardation and \( \Delta n \) is a function of the applied voltage. The transmitted intensity will be at a minimum when the phase retardation, \( \Delta n d \), is an even multiple of the incident light wavelength.

![FIG. 1. The scattering dispersion of the E7-based SLC films as a function of the temperature of polymerization. The N–I transition temperature for the E7 liquid crystal is 67 °C. Those cells prepared at a lower temperature have higher scattering and their characteristics belong to the lower branch of the transmittance curves. The scattering is much lower for the cells polymerized at a higher temperature than 67 °C. The measurements were done before application of any shearing stress.](Image)

![FIG. 2. The dependencies of transmittance of the 5CB-based SLC and the liquid crystal ordering (insertion) on the wavelength of the probe light and different distance of shearing.](Image)

![FIG. 3. Static electro-optic response of the SLC cell: (a) the dependence of transmittance of the SLC cell vs applied voltage measured between crossed polarizers; (b) corresponding change of the phase retardation vs applied voltage.](Image)
The relaxation of the cell after removal of 100 V is shown in Fig. 4. The relaxation of about 2 μm of phase retardation occurs within 1 ms [Fig. 4(b)]. For switching between bright and dark states, only a $\lambda/2$-shift is required. At the wavelength of $\lambda=0.632$ μm, the phase shift of 0.316 μm occurs within less than 100 μs. The turn-on time is much less than the turn-off time so the SLC can be driven with the frequency of 10 kHz.

The SLC’s electro-optic response can be varied by varying the materials used, their relative concentration, and the preparation conditions. For example, by varying concentration of the components and polymerization temperature, we have produced thin SLC cells ($\sim$5 μm) for display applications that switch about 0.5 μm within 2 ms with the driving voltage of $\sim$5 V. For other applications that require large phase shifts we have made 800-μm-thick SLC cells that produce about 60 μm shift of phase retardation within several milliseconds. As with the thinner cells these thick cells require 1 V/μm to switch.

In conclusion, stressed liquid crystals provide ultrafast response and relatively low driving voltage for devices requiring shifts in the phase retardation. SLC cells are simple to fabricate and reliable, the active area of the film may be relatively large, and the films do not require any liquid crystal orientation layers. The shearing technique can produce uniform alignment in very thick cells (up to 1 mm) allowing very large shifts in the phase retardation. The system has a linear voltage response with essentially no hysteresis.

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