Stressed liquid crystals for large phase shift modulation

Sigma Pi Sigma Undergraduate Research Award
Final Report

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Summary

This Undergraduate Research Award allowed us to continue our work on development of stressed liquid crystals. These are new revolutionary light modulating materials that decouple the thickness of the liquid crystal layer and the switching speed. The material comprises interconnected microdomains of a liquid crystal dispersed in a stressed polymer structure. The stress deformation imposes unidirectional orientation of the liquid crystal. The new material is optically transparent and provides electrically controllable phase modulation of the incident light.

The new phase retarder can provide ~50 micron phase retardation within 10 milliseconds, which is the largest phase shift available today within shortest time frame. In principle, there is no limit on the thickness of the SLC film, i.e. phase retardation.

Description of the samples preparation

We provided a detailed description of the materials preparation in our intermediate report. In short, we mixed the photopolymerizable monomer NOA65 and the LC 5CB and sandwiched the mixture between two glass substrates that contain electrodes disposed on the facing surface of each of the substrates; the gap between these substrates was controlled using plastic sphere spacers. The concentration of the polymer is optimized to be high enough to maintain the mechanical stress induced by the shear (we assume by adhering to the substrate) while being as low as possible to maximize the electro-optic performance (maximum phase retardation and minimal light scattering). The cell was cured under UV irradiation at isotropic phase. The UV intensity and cure time was optimized according to the requirement for specific applications. For thick SLC phase retarder, high UV intensity and double side irradiation was necessary to achieve uniform polymer structure across the cell thickness. For photopatterned SLCs, lensed or prismatic gradient mask was inserted between the UV light source and the cell in order to produce corresponding size distribution of LC domains. After photopolymerization, the cell was cooled down to room temperature. Shear force can then be applied to one substrate with the other substrate fixed. The shear deformation stretches the polymer network in the shear direction and aligns the LC domains (figure 1). The observation of the cell between crossed polarizers shows that this cell possesses anisotropy in the direction of the

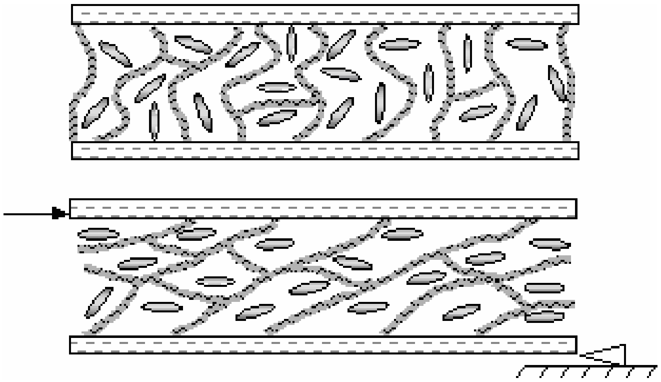

Figure 1: schematic structure of an SLC cell: a) before application of shearing deformation; b) after application of shearing deformation.

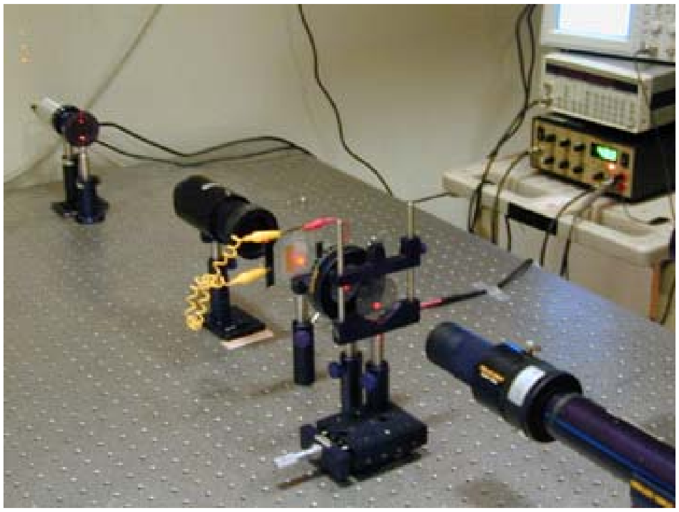

Figure 2: electro-optic measurement system for evaluation of switching characteristics of SLC cells.

shear the substrates.

The electro-optic characteristics of the cells were measured by a standard method in the art (Figure 2). The cells were placed between crossed polarizers. The optical axis of the cells was set at 45 degree to the polarization direction of the polarizers. An electric field was applied to the electrodes of the cells and the dependence of the shift of the phase retardation produced by the film on the applied voltage, *V*, was measured. In addition, the dynamics of the phase retardation shift after abrupt switching ON and switching OFF of the electric field was measured.

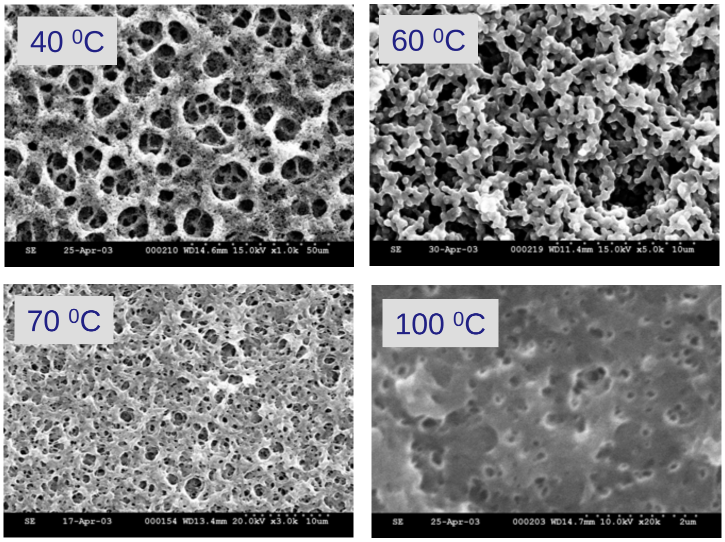

Figure 3: scanning electron microscope (SEM) images of SLC films made at different temperatures.

Structure and performance of the new materials

In addition to electro-optic measurements, we performed SEM studies of the films prepared at different temperatures (figure 3). These studies aloowed us to identify the structure corresponding to the best electro-optical performance. In this particular case of thick films, the samples need to be prepared at ~ 70 ^{0}C.

For a phase retarder to offer 50µm phase retardation, the cell thickness of a pure LC cell has to be ~250 µm (assume $\Delta n=0.2$), which make the LC cell impractical with τ_{off} over 60 seconds. Because SLCs decouple the thickness of the film and the switching time, large phase modulation can be obtained by simply increasing the film thickness while maintaining the milliseconds fast response.

We have fabricated a series of SLCs phase retarders of different thickness. Here we list the typical electro-optical performance demonstrated by an 820 µm thick SLC phase retarder. It was made of the LC 5CB and UV curable monomer NOA65 with the weight concentration of the components 90 % and 10 %, respectively. The cell was consist of two ITO-glass substrates, filled with the 5CB/NOA65 mixture, and irradiated with UV light (~ 30 mW/cm^2) from double sides for 2 hours at 50 ^{o}C. After irradiation, the cell was cooled down to room temperature and placed in a home made shear device where the shear distance can be controlled with the accuracy of 5 µm.

We measured the dependence of the transmittance as a function of an applied voltage for the 820 µm SLC film at 650 µm shear distance. The polarizers were crossed and align 45 ^{o} to the shear direction of the SLC film. The variation of the transmitted light intensity between two successive minima demonstrates the switch of the phase retardation equal to the wavelength of the probing light, λ = 1.55 µm, or $\delta = 2\pi$ in terms of the angular phase retardation. The relationship of the phase shift versus applied voltage was calculated and graphed in Figure 4. It is clear that to produce the phase shift of 36$\lambda \approx$ 56 µm the SLC cell requires about 800 V. The voltage may seem high. However, the electric field is only ~1V/µm. As one can see, the cell can be driven in a linear regime (~250V to ~600V) when the induced shift of the phase retardation (~36µm) changes linearly with the applied voltage. Such a behavior is unique in SLCs and may be due to a strong confining geometry in which LC is placed. Such a feature can greatly simplify the driving schemes in many practical devices.

Application of the shear deformations to a SLC cell stretches the polymer chains/sheets and elongates the LC domains, forming ellipsoidal shape. Due to strong anchoring at the LC/polymer interface and the shape anisotropy, the molecules of the LC become oriented along the shear directions.

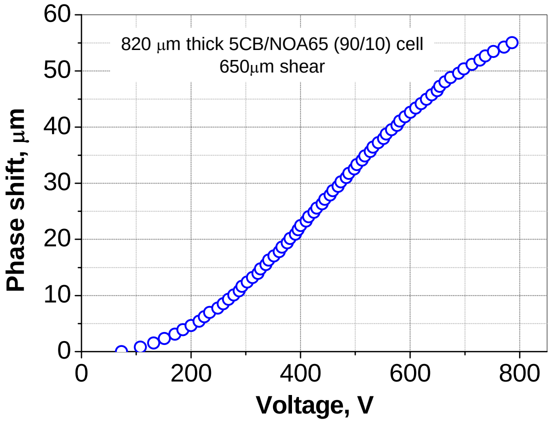

Figure 4: Phase retardation as a function of applied voltage

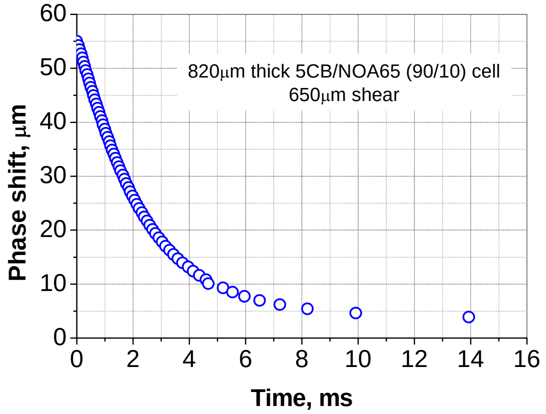

Figure 5: Relaxation time of a thick SLC film.

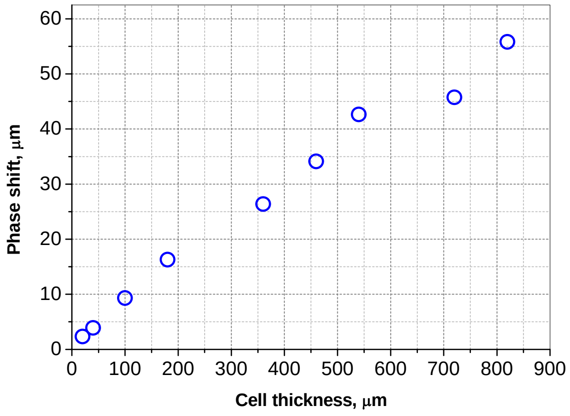

Figure 6: dependence of the maximum achievable phase shift on the thickness of an SLC cell.

Figure 5 shows the relaxation time response of the previous mentioned 820 μm thick cell. The decay time for ~50 μm phase shift is only about 10 ms, 5 μm per 1 ms.

To summarize, we continued development of novel LC materials with ultra large phase modulation capability. We develop also devices that incorporate Stressed Liquid Crystal (SLC) materials. Based on SLCs' decoupling of the thickness of the LC layer and the switching speed, new thick SLC phase retarders were fabricated. The SLC material is thicker than 100 μm, comprising uniform, interconnected microdomains of a LC dispersed in a stressed polymer structure. The stress deformation imposes unidirectional orientation of the surrounding LC. The SLCs material is optically transparent and provides electrically controllable phase modulation of the incident light. The new phase retarder can provide ~50 micron phase retardation within 10 milliseconds, which is the largest phase shift available today within shortest time frame. In principle, there is no limit on the thickness of the SLC film, i.e. phase retardation (figure 6).

Acknowledgment

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