

P-104: Shearing Effects of Stressed Liquid Crystals with Various Liquid Crystal Domain Sizes

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Abstract

Stressed liquid crystals (SLCs) are fast light modulating materials based on polymer/liquid crystal composites. We used polarizing microscopy and fluorescence confocal microscopy to investigate liquid crystal domain sizes and shearing mechanism for SLCs with different domain sizes. We observed the stretch of polymer matrices and the reshaping of liquid crystal domains in SLCs during shearing. In addition, we demonstrated the shearing effects on reducing light scattering and the electro-optical performances of these samples.

1. Introduction

Polymer/liquid-crystal composites are promising light modulating materials for displays, shutters, switchable windows, etc. Introducing stress to polymer/liquid-crystal composites [1, 2, 3] has led to appearance of special features such as shearing-induced orientation, light polarizing ability, and fast response. Stressed liquid crystal (SLC) [4] materials are comprised of interconnected micron-domains of a liquid crystal dispersed in a stressed polymer structure. They have been applied in fields such as optical phase array [5] non-mechanical beam steering application [6], adaptive optical tip-tilt correction and fast displays. There are three major advantages of introducing shearing stress to the SLC system: 1) liquid crystal alignment along the shearing direction which helps to reduce light scattering and increase phase shift; 2) linearity between phase shift and applied voltage; 3) greatly reduced response times. It is well known that morphology and dimension of the liquid crystal domains inside polymer/liquid-crystal composites significantly affect the electro-optical performance including switching fields, response times, and light scattering properties [7, 8]. Therefore, it is crucial to explore the effects of size and shape of liquid crystal domains in SLC systems. In this paper, we investigate the shearing effects on transmittance and electro-optical properties of SLC films to optimize SLCs' performance through varying liquid crystal domain size.

2. Experiments

The SLC material we used is a mixture of 4-pentyl-4'-cyanobiphenyl (5CB), reactive mesogen diacrylate monomer RM82 and Norland Optical Adhesive NOA65 at a weight ratio of 94:2:4 while the initiator is 0.1 weight percent of the whole mixture. For the samples of fluorescence confocal microscopy measurement, we selected a fluorescence dye that accumulates in the polymer matrix during polymerization which allows one to enhance the contrast. The concentration of dye is small, 10^{-4} by weight. All the SLC samples were made by sandwiching the mixture between two indium-tin-oxide (ITO) coated glass substrates with the use of 12 μm fiber spacers controlling the cell gaps. There is no alignment layer on the ITO surface. All the samples were first polymerized at 60°C for 20 minutes under UV

exposure and then were cooled to room temperature. Another 20 minutes' post-cure with UV intensity of 22mW/cm² was applied at 20°C to guarantee complete polymerization. There are many factors influencing the liquid crystal domain size such as composition [9], curing temperature [10], curing UV intensity [9, 10, 11], coalescence effect [12], etc. With curing temperature and composition fixed, we varied curing UV intensity to obtain SLC samples with different liquid crystal domain sizes. Low UV intensity cure leads to slower polymerization, producing bigger liquid crystal domains. Slow-cooling favors coalescence of liquid crystal domains, which also gives rise to large droplets. In Table 1, we show the fabrication conditions for the four SLC samples.

Table 1: Fabrication conditions of the four SLC samples

Sample #	1	2	3	4
UV intensity (mW/cm ²)	6.0	6.0	6.0	6.0
Cooling rate (°C/min)	0.4	4	4	4
LC domain size: (diameter in μm)	30-40	10-20	5-8	~2

Liquid crystal domain size is estimated from the polarizing microscopic pictures shown in Fig. 1. All the samples show polyhedral droplet structure but for sample #4. With the size of about 2 μm , it is very likely that liquid crystal domains in sample #4 exist in interconnected domain structure instead of in regular droplet shape.

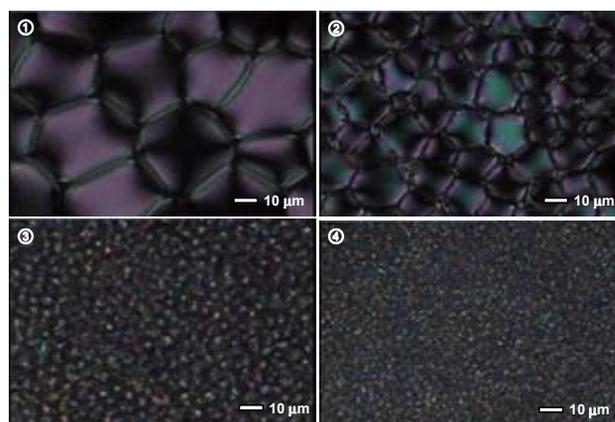


Figure 1: Polarizing microscopic pictures of the SLC samples 1 to 4. The white bar represents 10 μm in length.

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Shearing was applied by fixing one substrate of the cell to a support while the other substrate was moved. The distance of shearing was controlled with a micro-screw (accuracy of about 5 μm).

3. Results and discussions

For a high liquid crystal loading polymer/liquid crystal composite system, each liquid crystal domain is surrounded by other randomly-oriented liquid crystal domains, which introduces major light scattering. The light scattering resulting from refractive index mismatch between liquid crystal and polymer matrix is less significant since polymer's dimension is much smaller than the liquid crystal domain dimension [7, 13]. When liquid crystal domains are aligned along the same direction, the light scattering of the film will be reduced dramatically. This phenomenon is observed in the SLC systems in which liquid crystal domains are aligned along the shearing direction when shearing stress is applied. Fig. 2 shows fluorescence confocal microscopic [14, 15] textures of the vertical optical scans of samples #2 and #3. The image data are collected by scanning the tightly focused laser beam in the vertical cross-section of the sample and thus, providing the side view of the polymer morphology between the two bounding plates; the plates are seen as dark top and bottom regions in Fig.2. Fig.2a and 2b are taken before shearing samples #2 and #3, while Fig. 2c and 2d are taken after shearing. The shearing direction is from left to right. The white color represents the polymer matrix and the gray color inside the white is the liquid crystal domain. One can see that, during shearing, polymer matrices in both SLC samples are stretched along the direction of shearing and liquid crystal domains adopt an elongated shape. In addition, from both the observation under crossed polarizer microscope and our transmittance spectra measurements, we find that liquid crystal domains get aligned along the shearing direction during shearing. Furthermore, transmissions increase dramatically after shearing.

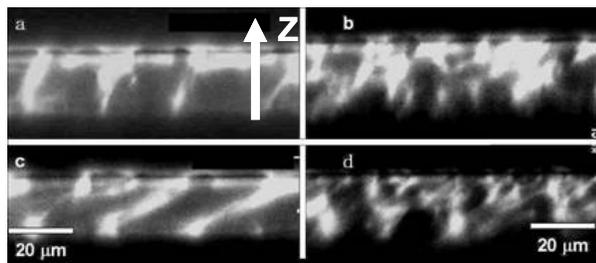


Figure 2: Fluorescence confocal microscopic Z-scan pictures of samples #2 and #3 before and after shearing. a) sample #2 before shearing; b) sample #3 before shearing; c) sample #2 after shearing; d) sample #3 after shearing.

We investigated the transmittance of these four SLC samples at two states: before-shearing and after-shearing. The reference used to correct the reflection loss is a 12- μm -thick fully-cured NOA65 film sandwiched between two ITO glasses. We found that, for sample #1, there is little difference between before and after shearing as a result of insufficient shearing alignment, arising from relatively small shearing distance (30 μm) applied on large domains (40 μm). However, shearing alignment has an impact on the other three samples as seen in Fig. 3. Samples with smaller domains are better aligned upon shearing. In particular, with the

smallest liquid crystal domains, sample #4 exhibits the best shearing ability (over 100 μm shearing distance) as well as the most significant increase in transmission after shearing.

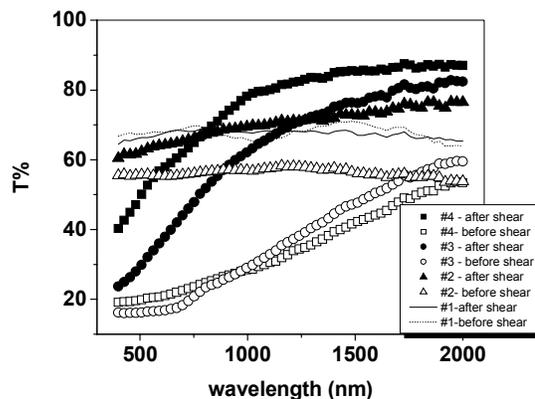


Figure 3: Transmittance of SLC samples with different domain sizes before and after shearing.

During electro-optical measurement, we put the SLC samples in between two crossed polarizers. The shearing direction is aligned at 45° angle to each polarizer. The laser wavelength is 633 nm. For all the samples, we measured switching fields at different shearing distances. The results are shown in Fig. 4a. Sample #1 broke after being sheared over 40 μm . Therefore, the shape of liquid crystal domain didn't change enough during shearing. As a result, the required switching field remains unchanged. In contrast, the switching field is increasing in shearing distance for the rest of the samples. At the same shearing distance, the switching field is larger for the SLCs with smaller domains. When the shearing distance increases, the switching field grows at a higher rate for the SLCs with smaller domains.

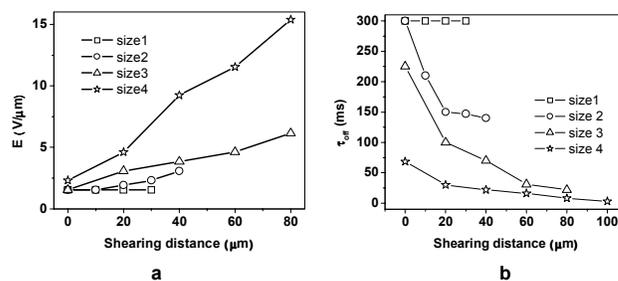


Figure 4: Electro-optical measurement of the four SLC samples at different shearing distances. a) shearing distance dependence of switching field; b) shearing distance dependence of relaxation time.

The rise time (τ_{on}) depends on the magnitude of electric field. It is in the sub-millisecond (ms) time range for SLC samples. On the other hand, the relaxation time (τ_{off}) of SLC systems is more significantly affected by shearing. To measure the τ_{off} , we first applied a switching electric field to align liquid crystals along the field direction. Then we removed the field to allow the liquid crystals to relax back to their initial unpowered state. The time that liquid crystals take to relax back is the τ_{off} . The τ_{off} 's for all

the samples at different shearing distances are shown in Fig. 4b. Relaxation time decreases when shearing distance increases except sample #1. Comparing the results across these four samples, sample #4, with 2 μm liquid crystal domain, has the shortest τ_{off} (1.26 μs phase shift in 2 ms at 100 μm 's shearing distance).

We further varied SLC compositions to obtain even smaller liquid crystal domains (i.e., less than half a micron). SLCs with submicron liquid crystal domains achieved 1.55 μs phase shift in 100 μs . The dependence of electro-optical properties on liquid crystal droplet size and shape is consistent with B-G Wu [1] et al.'s simulations, which were based on the balance of elastic distortion torque and electric field torque.

4. Conclusions

Overall, we have found that domain sizes of stressed liquid crystal samples significantly affect their shearing ability and relaxation time. Specifically, smaller (as opposed to larger) liquid crystal domains are better aligned by shearing stress. In addition, the relaxation time is shorter for SLCs of smaller domains. As such, SLC optimization can be achieved based on these characteristics.

5. Acknowledgements

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6. References

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