

Vertically Aligned Nematics at Polymer interfaces and Its device implications

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Abstract

In-situ photopolymerization of alkyl acrylate monomers in the presence of a nematic fluid provides a cellular matrix of liquid crystalline droplets in which the chemical structure of the encapsulating polymer exerts control over the alignment (anchoring) of the liquid crystalline molecules. Control is obtained by variation of the alkyl side chains and through copolymerization of two dissimilar monofunctional acrylates. Two monofunctional acrylates with opposing tendencies on copolymerization provide control over the tunability of anchoring over a wide temperature range. Using various acrylates we show that a uniform vertical alignment can be achieved over a large area. Utilizing this technique and a nematic with negative dielectric anisotropy, we have fabricated highly flexible liquid crystal based devices, with high contrast and fast response time, without using any alignment layer.

1. Objectives and Background

The operation of liquid crystal display (LCD) devices relies on manipulation of optical birefringence of a uniformly oriented thin liquid crystal (LC) layer with application of external fields. This predetermined orientation of LC layer is achieved by using properly treated (mainly rubbed) polymer film on glass substrates¹. In recent years, the interest in developing flexible

LCDs for various applications such as smart cards, cell phones, personal digital assistants (PDAs), e-books, head mounted devices etc. have grown exponentially because of their light weightness, flexibility, and possibility of roll-to-roll processing. Various electro-optical modes such as polymer dispersed liquid crystal (PDLC), twisted nematic (TN), super-twisted nematic (STN), cholesteric, etc. have been employed to fabricate prototype flexible LCDs²⁻⁴. All of these modes except PDLC require rubbed polyimide films to achieve a uniform alignment of LCs. The mechanical rubbing has disadvantages such as generation of static charges and dust particles and mechanical damage to the underlying thin film transistors (TFTs) resulting in low throughput. Although various other non-contact technologies⁵⁻¹⁰ have been developed to circumvent this problem, none of these technologies have been implemented in mass production of LCDs to replace mechanical rubbing. Moreover, the LCDs fabricated using these techniques do not possess high flexibility.

Using LCs with negative dielectric anisotropy we have fabricated LCDs with high flexibility, high contrast, low operating voltage, and most importantly, without use of any alignment materials. The principle of such a device is shown in Figure 1.

2. Experiment

In its simplest form, preparation of the *such devices* requires two glass substrates coated with transparent indium tin oxide (ITO) electrodes. These substrates are separated by glass fibers of diameter d , typically 3-5 micrometer. The nematic fluid with negative $\Delta\epsilon$, MLC 6608 ($\Delta\epsilon = -4.2$, $\Delta n = 0.083$, clearing temperature = 90°C), was obtained from E. Merck Industries. The *n*-alkyl acrylates and triacrylate were obtained from Scientific Polymer Products Inc. and used without further purification. The nematic, monofunctional acrylate monomers and 1,1,1-trimethylol propane triacrylate were mixed in an 76:22:2 w/w ratio. The triacrylate is added to provide rigidity to the matrix structure. The mixture was placed in a 16- μm gap of an ITO coated glass cell and illuminated with ultraviolet irradiation at 23°C . A slow polymerization process is initiated by irradiation at 360 nm with low intensity (180-300 $\mu\text{W}/\text{cm}^2$), followed by curing at higher intensity (5 mW/cm^2). The reactive mixture with higher LC composition (nematics, monofunctional acrylate and triacrylate ratio, 92:7:1 w/w) was also used to prepare the film that contains less amount of polymer walls in the film. The photopolymerization was carried at 68°C in the latter case.

The electro-optical properties were measured using the set-up shown in Figure 2. Two iris apertures were used to collect the beam only along the forward direction. The polarizer (P) and analyzer (A) are set perpendicular to each other. To measure the switching voltage (V_{90} , the voltage required for the film to reach 90% of the maximum transmittance), a 1KHz, square-wave AC voltage was applied to the film. The voltage amplitude varied from 0 to 10 Volts by step-increase. The duration between two consecutive step-increase is 1000 ms to allow the equilibrium state of LC deformation to be achieved at every step. Rise and decay times are defined as the time interval between 10% to 90%, or 90% to 10%, respectively, of the total change between

the “on” and “off” transmittance. Both response times are measured with application of a 0.5 HZ or 1 Hz, square-wave DC voltage (the fixed amplitude of 10 volt is used). By using the thermal chamber, the above E-O properties can also be measured as function of temperature.

3. Results and Discussion

For polymer dispersed liquid crystal (PDLC) films prepared by photopolymerization-induced phase separation of MLC 6608/acrylates system, a cellular morphology can be obtained using a slow photopolymerization process. The anchoring and anchoring transition temperature (T_i) of MLC 6608 in various polyacrylate matrices are evaluated and shown in Table 1. MLC 6608 at the surfaces of homopolymers of linear side chain acrylate, from *n*-hexyl through *n*-decyl acrylate, all show good homeotropic anchoring below H-to-P transition temperatures which is near T_{NI} , while the branched side chain acrylates e.g., poly (2-ethylhexyl acrylate) provide only tilted or planar anchoring. If the copolymer of one linear side chain and one branched side chain acrylate is used instead of a homopolymer, the tendency of homeotropic alignment decreases as increasing the fraction of branched side chain acrylate which is similar to TL205/ poly(alkyl acrylates) system.¹¹⁻¹³

We study the electro-optical properties of these composite films made by using both homopolymerization or copolymerization.

Figure 3 shows a typical curve of Fredericckz transition, from which both switching voltage (V_{90}) and contrast ratio can be measured. V_{90} is the voltage required to achieve 90% of the maximum intensity and the contrast ratio is defined as the ratio between the maximum intensity when the electric field is on and the intensity of “off” state. V_{90} and the contrast ratio are measured from figure 3. To obtain a higher contrast, one can make either the “off” state darker or “on” state brighter. The major reason causing high background intensity of the “off” state in the system we studied is light scattering

due to disturbed LC alignment from a perfect homeotropic anchoring by polymer walls and polymer filaments that is distributed through the film. To improve this, we made films with a higher LC composition in preparation of the LC-polymer composite film to increase the size of LC domains and reduce the amount of polymer walls and filaments, thus making the off state darker. Thus, we were able to make devices that had a contrast greater than 300. Thus we have demonstrated that by using a simple photopolymerization scheme one can make structures that provide homeotropic anchoring over large areas, and with the suitable choice of a nematic fluid, devices with good electro-optical characteristics can be fabricated.

Such devices have a number of advantages over the conventional LC modes. First, a uniform alignment of LC can be achieved without using any alignment material. This avoids series of problems related to the alignment materials and cumbersome rubbing technique. Second, since the devices made using this method are based on the vertical alignment of LCs, the OFF state is completely dark and the brightness of the ON state can be controlled by selecting LCs with higher anisotropy in the refractive index. Therefore, it is possible to fabricate LCDs with high contrast. Third, the microscopic polymer columns provide strong bonding between two substrates making the display virtually insensitive to any mechanical deformations and pressure. This makes them ideal for the flexible display applications.

4. Acknowledgements

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5. References

- [1] J. Cognard, Mol. Cryst. Liq. Cryst. Suppl. 1 (1982).
- [2] F. Matsumoto, T. Nagata, T. Miyabori, H. Tanaka, and S. Tsushima, Society of Information Display Technical Report, pp

963(1993).

- [3] J. L. West, M. Rouberol, J. J. Francl, J. W. Doane, and M. Pfeiffer, Asia Display Conference Paper pp55 (1995).
- [4] R. Buerkle, R. Klette, E. Lueder, R. Bunz, and T. Kallfass, Society of Information Display Technical Digest, pp 109(1997).
- [5] H. Aoyama, *et al.*, Mol. Cryst. Liq. Cryst. **72**, 127(1981).
- [6] Y. Ikeno, *et al.* Jpn. J. Appl. Phys. **27**, L475(1998).
- [7] J. L. Janning, Appl. Phys. Lett. **21**, 173(1972).
- [8] M. O' Niell, and S. M. Kelly, J. Phys. D; Appl. Phys. **33**, R679(2000).
- [9] J. -H. Kim, B. R. Acharya, S. Kumar, and K. R. Ha, Appl. Phys. Lett. **73**, 3372(1998)
- [10] P. Chaudhari *et al.* Nature, **411**, 56(2001).
- [11] K. R. Amundson and M. Srinivasarao, Phys. Rev. E., 1998, 58, R1211.
- [12] J. Zhou, D. M. Collard, J. O. Park and M. Srinivasarao, *J. Am. Chem. Soc.*, 2002, 124, 9980.
- [13] J. Zhou, D. M. Collard, J. O. Park and M. Srinivasarao, *J. Phys. Chem., B.*, 2005, 109, 8838.

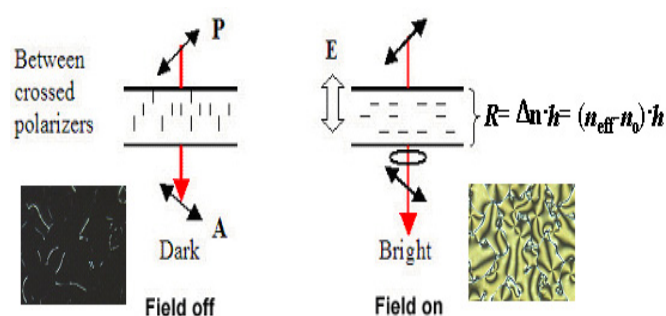


Figure 1. Switching principle of a LC display based on homeotropic aligned nematic fluid with a negative $\Delta\epsilon$. R is optical retardation given by birefringence times sample thickness

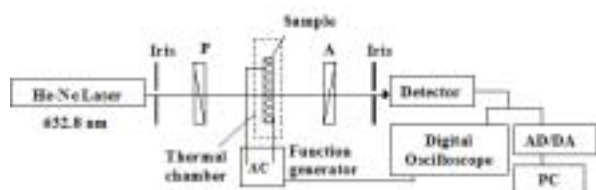


Figure 2. Schematic of the apparatus used for measurements of the electro-optical characteristics of the LC based display devices

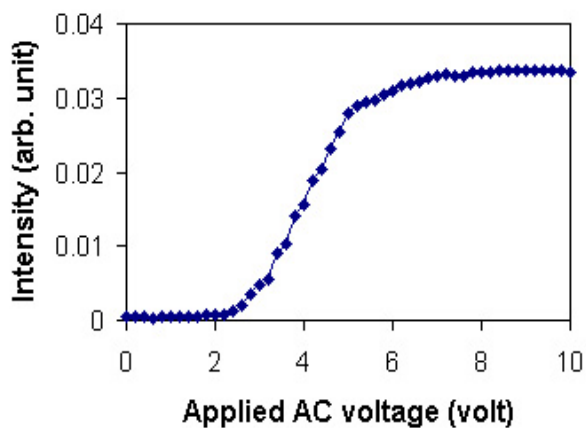


Figure 3. A typical transmission curve of the devices made using a – ve dielectric anisotropy material

Acrylates	Homeotropic-to-planar transition temperature $T_i / T_{Ni} (^{\circ}\text{C})$
n-hexyl acrylate (C6A)	80 / 89
n-heptyl acrylate (C7A)	81 / 89
n-octyl acrylate (C8A)	80 / 87
n-decyl acrylate (C10A)	83 / 89
2-ethylhexyl acrylate (2-EHA)	Tilted
Isobornyl acrylate	Planar

Table 1: Effect of side chain length and branching on anchoring behavior of MLC 6608 at polyacrylate surfaces