Liquid crystal-directed polymer nanostructure for vertically-aligned nematic cells

Voolodymy Borshch, Jeoung-Yeon Hwang and Liang-Chy Chien
Liquid Crystal Institute and Chemical Physics Interdisciplinary Program
Kent State University, Kent, Ohio 44242, USA
vborshch@kent.edu, Job425@lci.kent.edu, lcchien@lci.kent.edu

ABSTRACT

We demonstrate a fast switching surface polymer-assisted vertically aligned (SPA-VA) liquid crystal (LC) cell. The deposition of the polymer nano spikes as a part of the alignment layer is achieved by polymerizing a small amount of a reactive monomer in vertically aligned liquid crystal in the absent of an applied voltage. The phase-separated polymer localized at the both substrate surfaces and formed nano-sized spikes. These polymer nano-spikes act as internal surface alignment layers and enhance the speed of field-induced reorientation of liquid crystal molecules.

Keywords: Fast Switching, Liquid Crystal, Surface Polymer, Vertical Alignment,

1. INTRODUCTION

Liquid crystal displays (LCDs) with motion picture response time (MPRT) to display fast action media have been sought after for quite some time for applications from mobile displays to LCD-TVs. Recent advances in technical issues including poor viewing angle and color definition have been addressed to an acceptable level for liquid crystal displays (LCDs) in mobile devices, monitors and television (TV) sets; however, the picture blur of LCDs using a nematic liquid crystal is an issue. To achieve fast response speed in a LCD, one method is to improve the performance of liquid crystal materials and the other is to improve the device configuration of liquid crystal displays. Several ideas based on modification of device configuration have been developed with the aim of improving the response time including the increase in frame rate. In past decades, several advanced liquid crystal display (LCD) modes and methods have been developed to solve the response speed, viewing angle and motion picture quality, for example, in-plane switching (IPS) [1], fringe field switching (FFS) [2], multi-domain vertical alignment (MVA) [3] and patterned vertical alignment (PVA) [4]. Furthermore, through advanced addressing methods such as scanning backlight [5], higher-frequency driving [6] and black stripe insertion [7] LCDs with improvement in response speed are reported.

In a vertically-aligned (VA) system, the LC molecules are aligned perpendicular to the substrates in the absent of field, thus producing a black image. In this state the polarized light passes through the cell without interruption from the LC molecules and is blocked by the front polarizer. Because there is no twisted structure the LC molecules are simply switched between vertical and horizontal alignments with a fast response speed. When a voltage is applied across the cell, the nematic LC molecules shift to a horizontal position, producing a white image. The optical transmittance of the vertically aligned nematic LC layer

between crossed polarizers can be given as $T = \sin^2(2\phi(V))\sin^2(\pi d\Delta n(V)/\lambda)$, where $\phi(V)$ is voltage dependent azimuthal component of the angle between the LC optic axis and the transmission axes of the crossed polarizers and $\pi d\Delta n(V)$ is voltage dependent retardation of the LC layer (where d is the thickness of LC layer, Δn is the birefringence value of LC layer) and l is the wavelength of incident light. With an applied voltage, the vertically aligned LC molecules are switched in a direction parallel to substrates making conditions of $\phi(V)=\pi/4$ and $\pi d\Delta n(V)/\lambda = \pi/2$ to maximize the light transmittance, that is, $T=1$.

The new multi domain S-MVA and S-PVA modes produce displays with an ultra-high optical contrast between the bright and dark states and wide angle view because the blockage of light transmission is complete at the field-off state and the viewer sees this black from all viewing angles. The switching times of turn-on (rise, τ_{on}) and turn-off (decay, τ_{off}) can be described by the following equations: $\tau_{on} = (\gamma_1 d^2/\pi K_{eff})(1/[(V/V_{th})^2 - 1)]$ and $\tau_{off} = (\gamma_1 d^2/\pi K_{eff})$, where γ_1 is the rotational viscosity of LC molecule, K_{eff} is the effective elastic constant (for VA, the K_{eff} is equal to K_{33}) and V and V_{th} are the applied voltage and threshold voltage, respectively. Due to the weak surface anchoring slow decay time it is insufficient for the above mentioned VA LCDs to display motion quality images.

Simultaneously, various efforts have been carried out to improve the response time of a nematic type LCD based on the development of advanced liquid crystal (LC) materials [8,9]. Further improvements have been reported for LC materials using mixtures with lower viscosity in order to reduce the switching times smaller than one frame time (16 msec) [10]; yet, this is still not sufficient to realize motion pictures in a LCD TV, due to the striking difference between cathode-ray-tube (CRT) TV (the so-called impulse driving) and LCD TV (the so-called hold type driving). The hold-type driving scheme of the LCD TV still causes blurring of images even in the theoretical case where the pixels switching voltage is zero.

Combining a small amount of polymer network in a liquid crystal to provide the ability of stabilization or modification of the reorientation of LC director in response to applied electric field has been reported [11]. Recently, our lab developed a fast switching electro-optical device using an advanced polymer stabilization method where the LC directors are oriented with a surface localized polymer. The device consists of a small amount of surface localized polymer at both substrates [12]. A similar approach, i.e., a polymer sustained alignment (PSA) was reported in 2004 to improve the light leakage of a MVA mode [13,14] to obtain high contrast ratio LCDs. A bulk polymer network stabilized VA mode LCD showed fast response time but low transmission due to the light scattering effect [15].

In order to obtain surface localized polymers with desired pretilt angle without the need to apply an electric field during the formation of polymer, here we present a new method in forming nano polymer spikes at the substrate surfaces for VA LCDs.

2. EXPERIMENTAL

Sample Preparation

Using a nematic LC with a negative dielectric anisotropy and a fixed low concentration of a reactive monomer (RM), we demonstrate how striking polymer nano spikes can be obtained due to alignment of LC molecules by surface alignment layers. The polymerized polymer nano spikes copy the orientation of the host and act as internal surfaces to modify and control the field-induced re-orientation of the host LC molecules.

We demonstrate how improvements in decay time can be achieved in polymer-assisted vertically aligned liquid crystals.

In order to control the cell thickness, 3.6μm spacers were used. The spacers were sprayed on the treated glass and then assembled in a class 100 cleanroom. The cells were filled with the liquid crystal/polymer mixtures and then irradiated for both sides of cells with UV light sources at room temperature. Sample *1* was irradiated with UV light source 1 and samples *2* and 3 were UV light source 2. The electro-optical properties of these cells were studied by measuring the transmittance of the cell with a He-Ne laser light. The AC voltage of 1 kHz frequency of a square wave was applied and increased at the desired rate using electro-optical measurement software developed in-house. The intensity of transmitted laser light as a function of applied voltage was automatically recorded into a computer.

3. RESULTS

Figure 1 shows the transmittance curves versus applied voltage for two samples as compared to the pure ZLI-4788-000. The transmittance curve of the mixture of liquid crystal with 3% monomer was also measured and proved to be very similar to pure liquid crystal. From this plot we can clearly see that the threshold voltage has changed and the shapes of the curves differ.
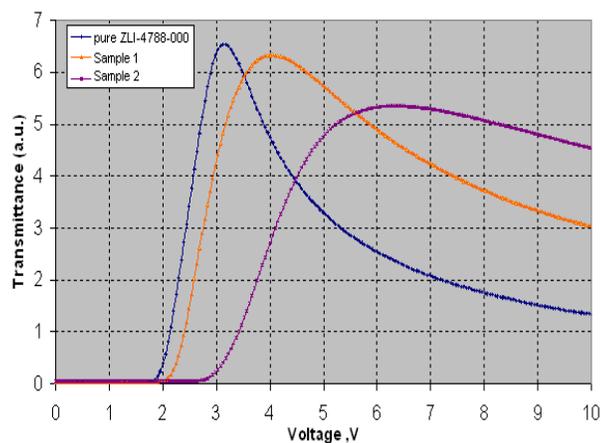

Fig. 1. Transmittance versus applied voltage curves for four samples and pure liquid crystal.

Rise and fall times were measured between 10% and 90% of the maximum transmittance of the cell. The transmittance curves versus applied voltages for the pure LC (ZLI-4788-000) and two samples are shown in Figure 1. Figure 2a shows the transmittance versus switching time of pure LC with applied voltage of 0 to 3.1V and 3.15 to 0V for the rise and fall times measured, respectively. The difference in rise and fall times of pure and mixture of liquid crystal with 3% polymer is negligible. Figure 2b shows the rise and fall time curves of sample *2* measured by applied voltage of 0 to 6.35 V and 6.35 to 0 V, respectively. The response times for two samples were measured in similar way except difference in the turn on voltages and the results are summarized in Table 1.
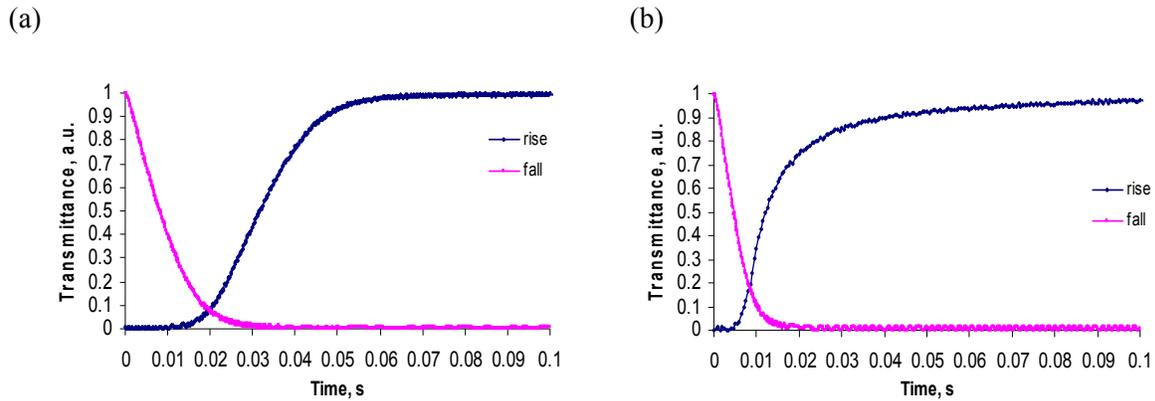
Fig. 2. (a) Rising and falling times for pure ZLI-4788-000 were measured by applied voltage of 0 to 3.15 V and 3.15 to 0 V, respectively. (b) Rising and falling times for Sample *2* measured by applied voltage of 0 to 6.35 V and 6.35 to 0 V, respectively.

According to Table 1, compared with the response time of the pure VA liquid crystal, sample *1* shows a 40% improvement in response time; however, the improvements mainly arise from the reduction in rise time. Strikingly, Sample *2* shows 21% improvement in response time; however, the major contribution arises from the shortening in fall time (~44%). This experiment was reproduced as described above as Sample *2'*, which shows even better improvements in rise time. The measured rise time of Sample *3* at 0 to 6.4V gives 32 ms, yet, the fall time for Samples *2* and 3 are pretty much similar.

Table 1. The response times, rising and fall times, for the three samples.

Sample	τ_{rise} (ms)	τ_{fall} (ms)	Total (ms)	Peak voltage (V)
ZLI -4788-000	36	16	52	3.2
1	16	15	31	4
2	32	9	41	6.4
3	27	9	36	6.6

Morphologies of the samples were studied using SEM to show that different electro-optical properties of the cells are caused by different polymer structures formed at the surface of the samples. Tilting the sample at 45° allows us to estimate the size of polymer spikes. There are two contrasting results as polymer nano-sized spikes or the rods or grow on inner surfaces of the cell as shown in Fig. 3. Sample *1*, shows small spikes formed on both surfaces of the cell. They are randomly located and very rarely merged into networks. The estimate size is about 140-200nm in diameter and 130-200nm height. Samples *2* and *3* were irradiated with UV light source 2. Both samples 2 and 3 show more fluffy fibrillar networks on both surfaces compared

with that of smaple 1 which is shown in Fig. 3.b. In addition, asymmetric distribution of polymer; one surface has more intense networks than the other, has been observed. At 3% polymer concentration of the studied samples, the fibrillose polymer causes light scattering and reduces the light transmission compared with the sample with neat liquid crystal. Thus, reduction in polymer concentration will lead to a display with high light transmission.

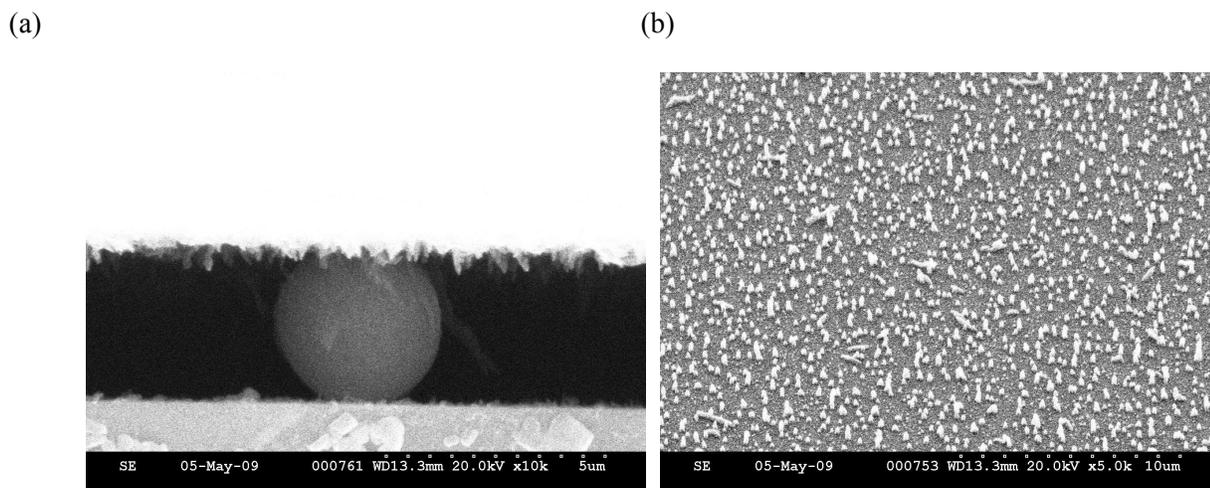(a)   (b)

Fig. 3. SEM images of surface-localized polymer nanospikes (a) side view and (b) top view.

The experimental investigation presented here demonstrates the feasibility of controlling polymer morphology and electro-optics of liquid crystal. A very good model describing the formation of polymer networks is given in [16]. Nano-sized polymer spikes act as the internal surface layer providing strong anchoring strengths. The improvement in response time can be explained as the increase in anchoring strength of liquid crystal due to the surface- localized polymer nanospikes.

4. CONCLUSIONS

We have demonstrated a surface-polymer-assisted for fast switching VA cells technique. We have also demonstrated a simple process and a controllable formation of polymer spikes at the inner surface of cell substrates. Significant improvement in response time has been achieved through the nanospikes which enhance the liquid crystal molecules anchoring at the surface. Increase in both the light scattering and driving voltages was observed at high polymer concentration of current studies. The SPA-VA can become an enabling display technology by further optimization the type and composition of polymer, concentration of polymer and method of device preparation. For example, to obtain a multi-domain structure one can use substrate with zig-zag electrode pattern in combination with an applied voltage during the formation of polymer nano-spikes and low polymer concentration.

REFERENCES

[1] M. Oh-e et. al., *Principles and Characteristics of Electro-Optical Behavior with In-Plane Switching Mode*, Proceedings of Int. Disp. Res. Conf. IDRC '95 Digest (Asia Display '95), pp.577-579 (1995).

[2] S. H. Lee, S. L. Lee, and H. Y. Kim, *Electro-optic characteristics and switching principle of a nematic liquid crystal cell controlled by fringe-field switching*, Appl. Phys. Lett. 73, 2881 (1998).

[3] A. Takeda, et al., *A Super-High-Image-Quality Multi-Domain Vertical Alignment LCD by New Rubbing Less Technology*, Proceedings of Soc. Info. Disp. SID 98 Digest, pp. 1077-1080 (1998).

[4] K. H. Kim and J. H. Souk, K. H. Kim and J. H. Souk, *Patterned Vertical Alignment (PVA) Mode for High Performance LCD Monitors*, Proceeding of Euro-display 99, pp.115-119, 1999.

[5] S, Araki, K. Nakao, S. Kawaguchi, Y. Nishimoto, K. Nishiyama, K. Shiiba, A. Takimoto, R. Nonaka, M. Baba, and G. Ito, S. Araki, *High-Contrast Low-MPRT OCB-LCD with Dynamic-Backlight-Control Technology*, Information Display 20-23 (2008).

[6] S. S. Kim, N. D. Kim, B. H. Berkeley, B. H. You, H. Nam, J.-H. Park, and J. Lee, *Novel TFT-LCD Technology for Motion BlurReduction Using 120Hz Driving with McFi*, SID 07 Digest, **37**, 1003 (2007).

[7] I. Mori, Y. Sato, Y. Ooishi and K. Onoet, *Improvement of Motion Blur for IPS-Pro LCD-TVs Drivenby 180 Hz Impulsive Driving*, IDW 07 Digest, 14, 79 (2007).

[8] H. Takatsu, S. Kawakami, G. Sudo, T. Kusumoto, Y. Nagashima, M. Negishi, and T. Matsumoto, *Development of Advanced Liquid Crystal Materials*, Proceedings of Int. Disp. Res. Conf. IDRC 08 Digest, pp. 29-32 (2008).

[9] M. Bremer, M. Klasen-Memmer, D. Pauluth, K. Tarumi, *Novel liquid-crystal materials with negative dielectric anisotropy for TV application*, Journal of the SID 14, pp. 514-521 (2006).

[10] M. Wittek, S.-E. Lee, H.-K. Lee, M. Bremer, H. Hirschmann, V. Reiffenrath, B. Rieger, *Advanced LC Materials for Ultra-Fast Switching for Active-Matrix-Device (AMD) Applications*, Proceedings of Int. Disp. Res. Conf. IDRC 08 Digest, pp. 253-255 (2008).

[11] D.K. Yang, L.-C. Chien and J.W. Doane, *Cholesteric Liquid Crystal/Polymer Gel Dispersion for Haze-Free Light Shutters*, Appl. Phys. Lett., 60, 3102 (1992).

[12] L. Komitov, L.-C. Chien and S. H. Kim, *Electro-optical devices from polymer-stabilized liquid crystal molecules*, U. S. Patent No. 7,038,743, May 2, 2006.

[13] K. Hanaoka, Y. Nakanishi, Y. Inoue, S. Tanuma, K. Koike, *A New MVA-LCD by Polymer Sustained Alignment Technology*, SID '04 Digest, pp. 1200-1203, 2004.

[14] T.-S. Chen, et al., *Advanced MVA III technology for high-quality LCD TVs*, SID '09 Digest, pp. 776-779, 2009.

[15] K.-H. Kim, J.-I. Baek, J. C. Kim, and T.-H. Yoon, *Anisotropic Polymer-Networked Vertical-Aligned LC Cell with Fast Response*, Proceedings of IDW 08 Digest, 1555-1558.

[16] C.V. Rajaram, S.D. Hudson and L.C. Chien, "Morphology of Polymer Stabilized Liquid Crystals," *Chem. Mat.*, **7**, 2300 (1995).