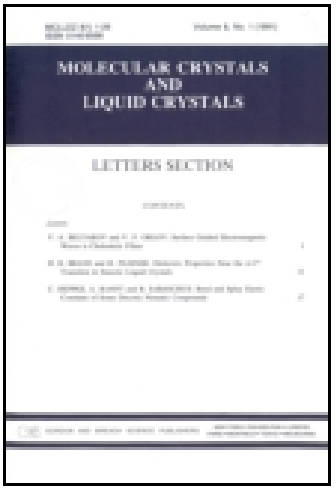

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Fast-Switching Vertical Alignment Liquid Crystal Displays Driven by Surface Polymer Stabilization

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A new method of improving the response time of vertical alignment (VA) liquid crystal devices using surface polymer stabilization is introduced. A minute amount of a reactive monomer and photo-initiator is mixed with a nematic liquid crystal host and the mixture is polymerized under UV light to form sub-micron sized polymer protrusions on the two substrates of the cell with an applied bias voltage. Several kinds of reactive monomers with different molecular structures are tested, and a faster response time and a lower light leakage at dark state are achieved. This finding will be useful for display applications.

Keywords Vertical alignment; polymer stabilization; response time

1. Introduction

Liquid crystals are widely used in display devices due to their low operation voltage and low power consumption. However, there is a demand for high contrast ratio and high response time in applications such as high frequency addressing high-definition television (HDTV). Among various advanced LC modes including in-plane switching (IPS) [1], vertical alignment (VA) mode [2] has advantages of extreme good dark state quality and high contrast ratio. The challenge for VA mode displays is the long response time due to the weak surface anchoring energy. Various methods have been proposed to improve the response time of VA mode displays including development of new LC mixtures with lower viscosity.

Recently, a method of incorporation of a small amount of polymer network into the LC cell to enhance the surface anchoring and modify the orientation of LC directors is reported [2–5]. The tiny amount of monomers can form a very thin confined polymer layer on the surfaces of two substrates by UV induced phase separation, which stabilizes the LC molecules and increases the anchoring energy. This method can achieve a faster response time and keep a good dark state at the same time.

The objective of this paper is to study the effects of different reactive monomer structures on the response times and dark states of polymer stabilized VA mode display. Furthermore, we further explain the physics related to the improvement of response time and polymer network on the surface anchoring of liquid crystal molecules.

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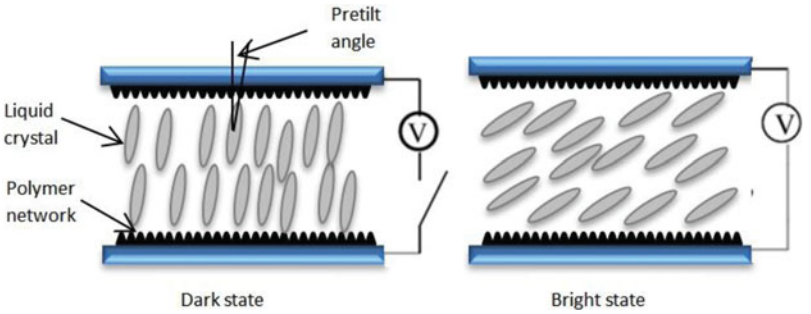

Figure 1. Schematic diagram of surface polymer stabilized VA LCD switched between (a) off-state and (b) on-state with an applied voltage.

2. Experiment

In this work, the VA cells are made by assembling two indium tin oxide(ITO) glass substrates with deposited vertical alignment layers (SE1211, Nissan Co.) which are baked at 180°C for one hour and lightly buffed by a velvet cloth. The spacers are sprayed on the alignment layer, and the two substrates are assembled in an anti-parallel manner with respect to the rubbing directions. The cell gaps are controlled at about 3um with glass bead spacers. The polymerizable mixture consists 99.52% of a nematic liquid crystal with a negative dielectric anisotropy ($\Delta n = 0.098$ $\Delta\varepsilon = -3.4$), 0.4% of reactive monomers and 0.08% of Irgacure 819 photoinitiator (Ciba Additive). Five different reactive monomers with various molecular structure and length were tested in the experiment. The empty cells are filled with LC and reactive monomer mixtures, and irradiated by a collimated UV light source at 365 nm wavelength with high intensity (25–35 mW/cm^2) while an AC voltage (15V) was applied across the cell to generate a certain pretilt angle. After curing, the electro-optical properties of these cells are studied by measuring the transmittance of the cell as a function of applied voltage with a set up consisting of a pair of polarizes crossed at 90 degrees, He-Ne laser and photodiode detector. The data are collected with a lab-developed data acquisition software.

3. Results and Discussion

In reference to Fig. 1, due to the small concentration of reactive monomers and phase separation effect in the polymerization process, the polymer network is mainly formed on the surfaces of two cell substrates, which changes the surface anchoring energy. Moreover, because of the applied voltage during curing, the polymer structure on the surface can generate a tiny pretilt angle which is smaller than 90°. The electro-optical properties are strongly related to the surface anchoring energy and pretilt angle.

For a VA cell with infinite strong surface anchoring, the rise time (τ_r) and decay time (τ_d) can be analytically expressed as:

$$\tau_d = \tau_o = \frac{\gamma_1 d^2}{K_{33}\pi^2} \tag{1}$$

$$\tau_r = \frac{\gamma_1}{|\varepsilon_0|\,\Delta\varepsilon|E^2 - \frac{\pi^2}{d^2}K_{33}|} = \frac{\tau_0}{\left|\left(\frac{V}{V_{th}}\right)^2 - 1\right|} \tag{2}$$

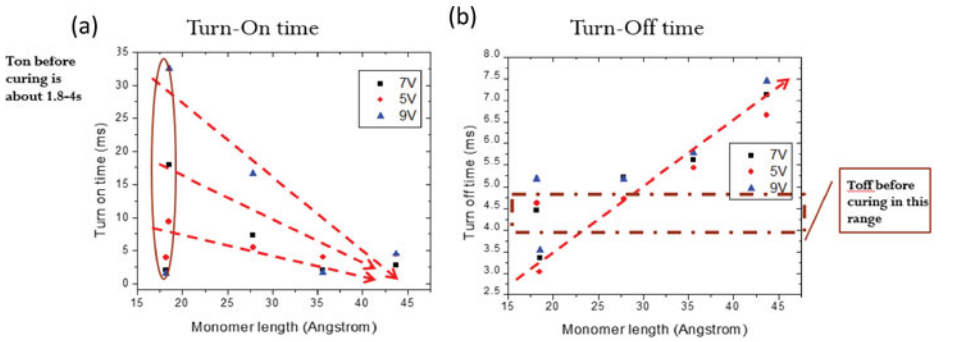

Figure 2. Response time for various monomers with different molecule length; (a) turn-on and (b) turn-off times. Straight dashed lines are for visual guide.

However, when the anchoring energy W is finite, we need to take the extrapolation length $b = K/W$ into consideration, where W is the polar anchoring energy strength coefficient. For a VA cell, the azimuthal anchoring is not involved. $K = K_{33}$, is the bend elastic constant [6].

We replace the physical cell gap d with the effective cell gap d'

$$\tau_0' = \frac{\gamma_1 d'^2}{K_{33}\pi^2} = \frac{\gamma_1}{K_{33}\pi^2}(d+2b)^2 = \frac{\gamma_1}{K_{33}\pi^2}\left(d^2 + \frac{4dK}{W} + \frac{4K^2}{W^2}\right) \tag{3}$$

The actual decay time increases as the surface anchoring energy decreases [7]. If taking pretilt angle effect into consideration, the derived response time will be:

$$\tau_d^* = \tau_0^* = \frac{\gamma_1 d'^2}{4K_{33}\left(\frac{\pi}{2} - \frac{\theta_p}{\theta_m}\right)^2} = \frac{\gamma_1}{4K_{33}\left(\frac{\pi}{2} - \frac{\theta_p}{\theta_m}\right)^2}\left(d^2 + \frac{4dK}{W} + \frac{4K^2}{W^2}\right) \tag{4}$$

$$\tau_r^* = \frac{\tau_0^*}{\left|\left(\frac{V}{\left(1-\frac{2\theta_p}{\pi\theta_m}\right)V_{th}}\right)^2 - 1\right|} \tag{5}$$

where is the pretilt angle and is the maximum tilt angle which is much larger than the pretilt angle. In real experimental measurement of voltage-transmittance curve, the threshold- like behavior will be gradually smeared as the pretilt angle deviates from normal direction.

Figure 2 shows the response times for VA cells using five reactive monomers with different molecule lengths. As the molecule length of RM increases, the pretilt angle generated by the formed surface polymer network is larger and the polymer formed by longer molecule has a better alignment effect on LC molecules, so the turn-on time decreases. On the other hand, turn-off time increases with increase in molecular length of monomer, which is due to the increase in pretilt angle and the decrease in surface anchoring energy.

The surface anchoring energy results for five RMs are measured and shown in Fig. 3(a). The results indicate that surface anchoring energy is inversely proportional to the monomer length. Fig. 3(b) shows the dark state transmittance and contrast ratio as a function of molecular length of RMs. The contrast ratio shows a monotonic increase of studied RMs;

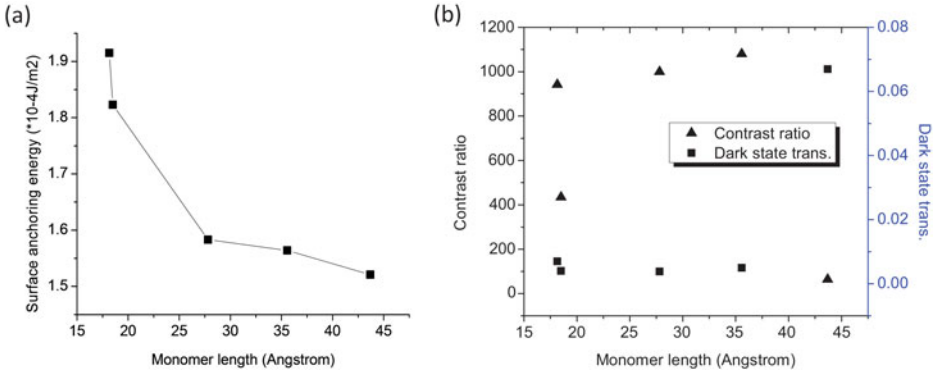

Figure 3. (a) Anchoring energy vs. monomer length; (b) Contrast ratio and dark state transmittance vs. monomer length. (Color figure available online).

compared to short and long RMs, medium length RMs give good contrast ratios. The polymer network formed from long RM tends to cause the refractive index mismatch problem with LCs due to the large pretilt angle at the surface and results in light leakage at dark state. This can be correlated to the SEM pictures of polymer morphology taken from these test cells as shown in Fig. 4.

From SEM pictures, we find that the polymer fibers formed from the longest RM restrained at the substrate surfaces have a longer length which is around 3um, and therefore tend to generate a larger pretilt angle. By contrast, the short RMs are polymerized to form small polymer protrusions with a size of about 200–300 nm and tethered at the substrate surfaces. The polymer protrusions provide an extra surface anchoring to LC molecules and result in a faster turn off time. Moreover, due to the small size of the polymer structure, the pretilt angle is almost not changed. Therefore, the turn on times of shorter RMs are slower comparing with those of longer RMs.

From above results, we find that a shorter RM forms fine polymer protrusions and gives a better turn-off time as well as better dark state. By contrast, a long RM gives better alignment and larger pretilt angle which reduces the turn-on time more than that of short RM. However, long RM increases the turn-off time due to the decrease in surface anchoring strength as seen in Fig. 3a.

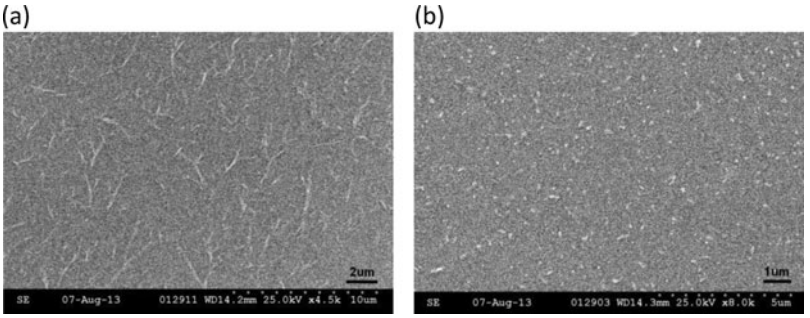

Figure 4. SEM pictures (a) polymer fibers formed from longest RM; (b) polymer structures formed from short RMs.

4. Conclusion

Surface localized polymer structure has been found to improve the response time of VA mode liquid crystal devices while keeping the display with a high optical contrast ratio. Polymer stabilized VA cells with short RMs forms short polymer protrusions at the substrate surfaces, gives fast turn off time due to strong surface anchoring, and has a good dark state. On the other hand, a VA cell with a long RM forms long polymer fibrils, a large pretilt angle and poor dark state. In addition, a polymer stabilized VA cell with long RM has a slow response time due to weak surface anchoring. The mechanism is further explained by theoretical analysis. Finally, with medium length of RM, LC response time of a VA cell has been significantly improved.

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