

# Control of Liquid Crystal Pretilt Angle using Polymerization of Reactive Mesogen

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**Keywords :** Pretilt angle, Reactive Mesogen

## Abstract

We propose a method to control the pretilt angle of liquid crystal (LC) by doping a proper amount of UV curable reactive mesogen (RM) monomers in homeotropic polyimide (PI). The intermediate pretilt angles are produced by anchoring competition between homeotropic PI and the polymerized RM which direction is along the LC molecules under electric field.

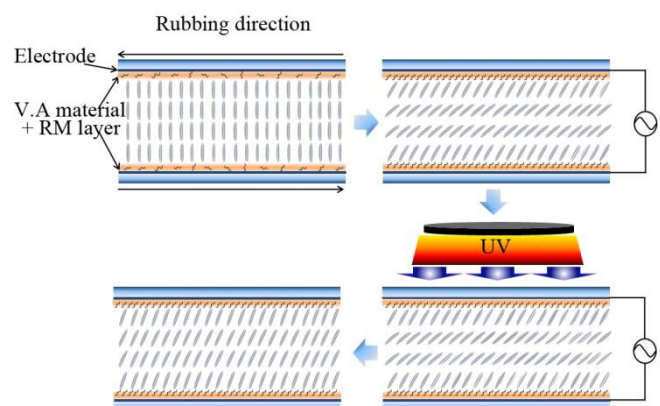
## 1. Introduction

In optical configuration of liquid crystal displays (LCDs), the pretilt angle is one of the most important parameters because it strongly influences the electro-optics properties of various LCD modes [1-2]. Most LCDs are based on either planar alignment or vertical alignment of the liquid crystal director by using alignment materials such as polyimide (PI), photopolymers, surfactants, silicon oxide, and so on. However, there is much demand for alignment layer that can produce the intermediate pretilt angles of LC molecules from planar to vertical. Many kinds of approaches to achieve the intermediate pretilt angle have been developed such as stacked alignment layers [3], mixture of homogeneous and homeotropic alignment material [4], oblique evaporation of silicon oxide [5], controlling the groove depth by atomic force microscopy [6], and double layer with different rubbing strength [7]. Such approaches have some problems intrinsically such as long thermal stability, reproducibility, adapting to large LCDs, high cost of manufacturing process and so on. In this paper, we suggest a method to generate the intermediate pretilt angle using the mixture of conventional vertical PI and UV curable reactive mesogen (RM) as alignment layer. The pretilt angle is controlled at the intermediate range by anchoring competition between

vertical alignment (VA) material and the polymerized RM in the alignment layer which has the polar direction along the LC molecules with the various applied voltage.

## 2. Experimental

The schematic diagrams of proposed pretilt angle generation process are shown in Fig. 1. The indium tin oxide (ITO) coated glasses were cleaned with mixture of de-ionized water and mucasol in the ultra-sonic for 1 hour and washed. The VA material (JSR), RM monomers (RM257, BASF) and photo initiator (Irgacure651, CIBA chemical) were mixed with the proper ratio in a magnetic stirrer for 6 hours. Then the mixtures were spin-coated at 1000 rpm for 10 sec and 3000 rpm for 20 sec on the cleaned ITO substrates. And then they were prebaked at 100°C for 10 min to remove the solvents, and hard-baked 180 °C for 1 hour on the hot plate to completely imidize the alignment material.



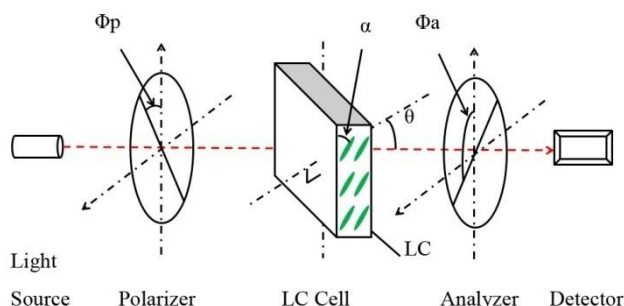
**Fig. 1. Schematic diagrams of proposed pretilt angle generating method**

Then alignment layers were rubbed with antiparallel direction each other. The made cell's gap was  $3.0\ \mu\text{m}$  and filled with LC (MLC-6610,  $\Delta\epsilon = -3.1$  and  $\Delta n = 0.0996$ , Merck) which has negative dielectric anisotropy. Then sample was exposed by UV light for 30 min in the presence of various applied voltage.

### 3. Results and discussion

At an initial state without electric field, the LC molecules were aligned vertically to the surface influenced by VA material and the RM monomers were distributed randomly in the alignment layer. When applied voltage larger than threshold voltage ( $V_{th}$ ), the LC molecules fell down to the substrate with the electric field induced pretilt angle and the RM monomers aligned along the LC molecules.

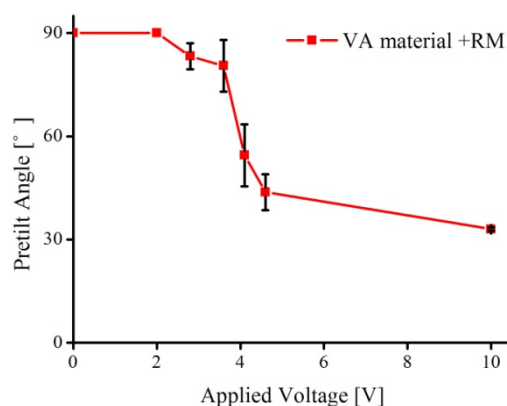
At this state, the cell was UV exposed and then the RM monomers were polymerized in the alignment layer. The polymerized RM which has specific polar angle realigns the LC molecules, so the pretilt angles are maintained even after removing the electric field.



**Fig. 2. Schematic diagrams of polarizer rotation method.**

To measure the pretilt angle, crystal rotation method [8] was widely used due to its high accuracy and convenience measurement process. However, in crystal rotation method, it is difficult to measure the intermediate pretilt angle range because the optically symmetric point is ambiguous and the determination of symmetric point is difficult in the intermediate pretilt angle. Therefore, we use the polarizer rotation method [9] to measure the intermediate pretilt angles. Figure 2 shows the schematic diagrams of polarizer rotation method. In contrast to the crystal rotation method, two polarizers were rotated and LC sample was fixed with proper angles compared to light propagating direction. Rotating the polarizers can provide more accurate pretilt angle in laboratory

experiment than rotating the LC cell. And controlling the tilt angle of LC cell at the initial state, it can be obtained the precise pretilt angle range within error range of  $0.1^\circ$ .

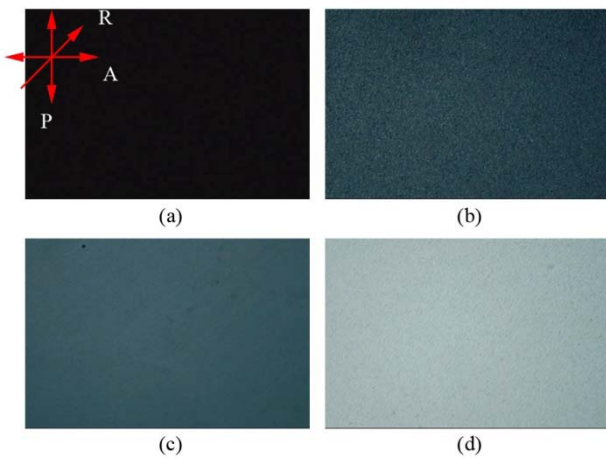


**Fig. 3. The pretilt angles as a function of the applied voltage during UV curing process.**

Figure 3 shows the measured pretilt angles using above method as a function of applied voltage during UV curing process. The pretilt angles were controlled at the intermediate range ( $30^\circ \sim 90^\circ$ ). When the applied voltage is less than  $V_{th}$  ( $\approx 2.5\text{V}$ ), the pretilt angle is almost same to the initial state because LC molecules do not fall down. However, applied voltage is larger than  $V_{th}$ , the pretilt angle start to decrease and the applied voltage getting larger, the pretilt angle gradually decreased to the intermediate range. That is because RM monomers inside the alignment layer aligned along the electric field driven tilting direction of LC molecule due to LC characteristics of RMs and then the aligned RM monomers are directionally polymerized through UV exposure process. So, polymerized RM can induce the pretilt angle of LC molecules and memorize the LC falling direction with applied voltage.

However, the pretilt angles are not perfectly matched with the tilting angles of LC molecules induced by applied voltage. We think that the anchoring competition between the vertical alignment material and the polymerized RM material produce the intermediate pretilt angle. Therefore, pretilt angle cannot be decreased to the zero but proper angle by the influence of the competed anchoring strength between the vertical alignment material and polymerized RMs. If the anchoring strength of the RM is much more dominate than vertical alignment material, lower pretilt angle can be achieved with this mechanism. And it can also be achieved by increasing

the RM monomer concentration in an alignment material.



**Fig. 4. Polarized microscopic images of fabricated LC samples. The arrows indicate that polarizer (P), analyzer (A), and rubbing (R) direction. The cells are cured through UV exposure with (a) 0V, (b) 4.1V, (c) 4.6V, (d) 10V and their pretilt angles are (a) 90°, (b) 56°, (c) 49°, (d) 32.5°, respectively.**

Figure 4 shows the microscopic images of the fabricated LC cells with changing the applied voltage during UV curing process under crossed polarizers. With increasing the applied voltage, the transmittances of cells are also increased. The general optical transmittance in uniaxial LC medium under crossed polarizers is given as

$$T = \frac{1}{2} \sin^2\left(\frac{\theta}{2}\right) \sin^2\left(\frac{\Gamma}{2}\right) \quad (1)$$

where  $\Gamma$  is the effective phase retardation notes as

$$\Gamma = \frac{2nd(n_e - n_o)}{\lambda} \quad (2)$$

and  $\theta$  is the angle between entrance LC director and the polarizers,  $\Delta n (= n_e - n_o)$  is the effective birefringence of LC considering pretilt effect,  $d$  is the thickness of LC cell, and  $\lambda$  is the wavelength of the incident light. In our experiment,  $\theta$  was fixed to 45° to maximize the transmittance. In eq. (1), if the effective phase retardation value is not excess the  $\pi$ , the transmittance is increased with increasing the  $\Gamma$  (i.e. decreasing the value of pretilt angle). This result is well matched in Fig. 4. Figure 4(a) indicates that light cannot pass through crossed polarizer because the pretilt angle was 90° and light only experience the ordinary refractive index of the LC molecule due to

effective phase retardation was zero. However, increasing the curing voltage, the lower pretilt angles are induced, as mentioned above. As the pretilt angle reduced to intermediate range, the effective birefringence is increased. For this reason, phase retardation occurred and polarization state of the light changed inside the LC cells and light can pass through the crossed polarizers, as a result, we get higher transmittance characteristics at the initial state without electric field (see Fig. 4(b)~(d)).

#### 4. Conclusions

We propose a new method to control the intermediate pretilt angles using UV curable RM. The RM was mixed in alignment layer and aligned along the LC director which has the electric field induced tilt direction. And the RM monomers are polymerized through UV exposure with applied voltage. The polymerized RMs produced the pretilt angles by anchoring competition with VA material. The proposed technique has very simple process with conventional alignment and RM materials. We expect that it can be applied to various LC applications and design the new LC modes.

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