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Surface Polymer Stabilization by Reactive Mesogen in Optically Compensated Splay Mode

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We have studied the optically compensated splay (OCS) mode applied to polymer stabilization technique using polymerization of reactive mesogen (RM) to reduce or eliminate critical voltage, setting voltage, and phase transition time from bend to splay state. The pretilt angle of almost vertically aligned liquid crystal directors could be lowered through the polymerization of UV-curable RM and applied voltage, at surfaces of vertical alignment layers. To confirm initial stable splay state, we investigated electro-optic characteristics according to concentration of RM in this paper.

Keywords Optically compensated splay; polymer stabilization; pretilt angle; reactive mesogen

1. Introduction

Recently, liquid crystal displays have shown good performance such as high image quality, wide viewing angle and high brightness by adopting advanced liquid crystal (LC) modes such as multi-domain vertical alignment (MVA) [1–3], patterned vertical alignment (PVA) [4–6], in-plane switching (IPS) [7,8], fringe-field switching (FFS) [9–14] and optically compensated bend (OCB) [15–18]. In addition, to improve the performance of the cell such as response time and transmittance, polymer-stabilization (PS) technology [2, 19–22] in which specific alignment state of LC is fixed by polymerization of ultraviolet (UV)-curable reactive mesogen (RM) and thus reorientation of LC director according to applied voltage is stabilized. Especially, the OCB mode shows wide viewing angle and very fast response time; however, it needs a critical voltage which generates transition of LC orientation from splay to bend state. In order to remove such bias voltage, PS technology was applied [17,18]. Also new vertically aligned LC mode called as optically compensated splay (OCS) [23–25]

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shows wide viewing angle due to self-compensation effect by mirror symmetry configuration along the mid director and also has fast response time characteristic because of thin effective cell gap and flow acceleration effect similar to OCB mode. However, the device requires a generation voltage like in the OCB mode. Previously, we reported that the critical voltage V_c which is a specific value to change from initial bend to splay state and setting voltage V_s that is a minimum value of voltage for maintaining splay state decreases with decreasing tilt angle, and especially when the tilt angle is 45°, the LC has OCS structure from the beginning [25].

In this paper, we report a polymer-stabilized OCS mode with initial stable splay alignment. To obtain initial splay state in the absence of an electric field, the correlation between conditions of polymer stabilization process, especially concentration of RM, and pretilt angle formed by polymerization of RM was studied. If the surface pretilt angle close to 45° is formed, the critical voltage, setting voltage, and phase transition time are reduced and eliminated.

2. Experimental Methods

Figure 1 shows the process of the surface pretilt angle formed by polymerization of RM in the cell. Vertical alignment layer is spin-coated on the ITO-coated glass substrates, and adapted to rubbing process. The substrates are assembled parallel to each rubbing direction, and the mixture with LC and RM is injected in the cell. Initially, the LC is oriented vertically to substrate with bend state as shown in Figure 1(a), and then by applying a certain voltage and after enough relaxation time, the LC is reoriented with splay state of which mid-director orients parallel to the substrates as shown in Figure 1(b). For keeping the pretilt angle in this splay state, UV is irradiated to the cell, and then RM is polymerized at the surface as shown Figure 1(c). As a result, the pretilt angle formed by polymerization of RM is maintained without any applied voltage and thus initial splay state is achieved as shown in Figure 1(d).

For this experiment, LC with negative dielectric anisotropic ($\Delta\varepsilon$) value of -4 and birefringence (Δn) value of 0.077 were mixed with UV-curable RM at the different rate of concentration from 0 to 0.4 wt% changing by every 0.1 wt% and then the mixture is injected to the OCS cell with 4.8 μm gap. The sample cell was irradiated

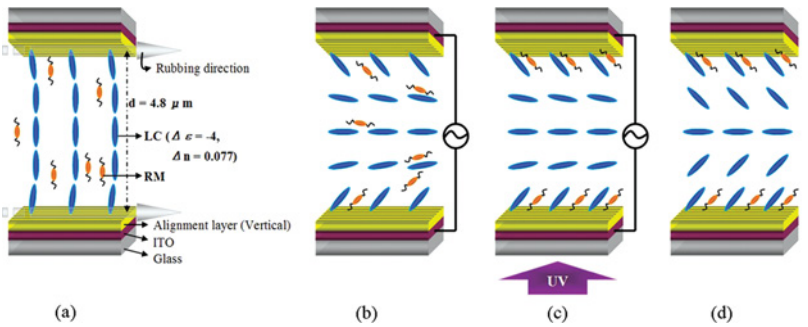
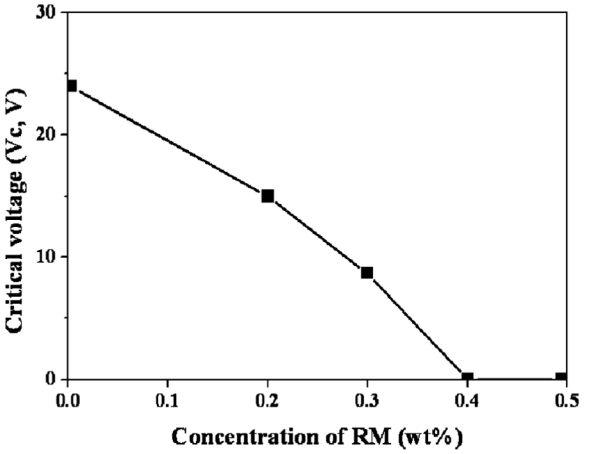


Figure 1. Schematic diagram of surface polymer stabilization in the OCS cell: (a) initial state, (b) applying voltage, (c) UV irradiation, and (d) maintaining pretilt angle without any applied voltage. (Figure appears in color online.)

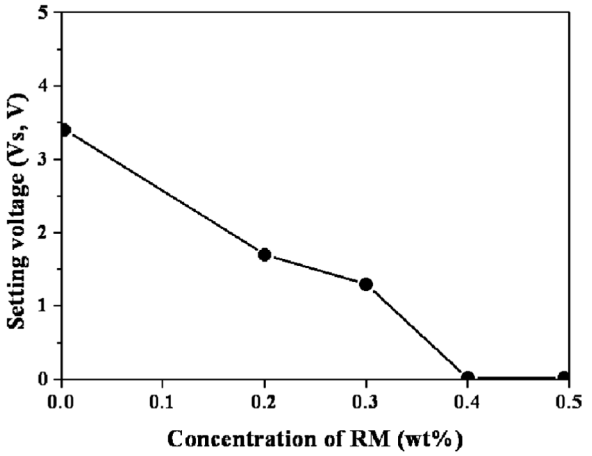
by UV light with a specific wavelength of 365 nm at a fixed intensity of 30 mW/cm^2, at room temperature for 10 minutes by applying 5 V as a square wave of 60 Hz. After the photo-curing, we confirmed the state of LC alignment according to variation of RM concentration in LC.

3. Results and Discussion

The test cells were cured by UV light to maintain splay state by applying certain voltage, however, all polymeric thin films did not completely support splay state of LC. Thus concentration of RM, applied voltage, and UV irradiation to the cell are main factors and a careful combination of these factors is required. As in the experiment, the voltage irradiating UV to the cell was fixed at 5 V where the LC have shown OCS state, so concentration of RM is only considered.



(a)



(b)

Figure 2. RM concentration-dependent (a) critical voltage and (b) setting voltage.

Figure 2(a) shows V_c according to variation of concentration of RM in the cell. As concentration of RM increases, V_c is decreasing and becomes zero at 0.4 wt%. This tendency of the results is also same for V_s according to change of concentration of RM as shown in Figure 2(b). To evaluate V_s, a voltage is gradually decreased after applying V_c, 24 V in the case of 0 wt%. As shown in the Figure 2(b), the concentration of RM increases, V_s is decreasing and becomes zero over 0.4 wt%. From these results, we conclude that in order to completely support the pretilt angle of OCS state, the minimum RM concentration of 0.4 wt% is required, so sufficient thickness of polymeric film through polymerization of enough concentration of RM might well support splay state of LC.

Further the pretilt variation has an effect on capacitance of LC cell. The capacitance values can be obtained by measured test cell as function of applied voltage. According to the definition of the capacitance for parallel capacitor:

$$C = \frac{\varepsilon \times A}{d} \tag{1}$$

where *A, d*, and ε are the area, distance between electrodes, and absolute dielectric constant of LC, respectively. Since *A* and *d* were fixed, a capacitance value only depends on ε, so alignment configuration of LC is important because of LC dielectric anisotropy, since when the LC configuration is closer to vertical, effective dielectric value is decreased to a greater extent. Negative LC has higher dielectric constant with perpendicular direction to electric field than with parallel direction to electric field. Figure 3 shows the resulted value of capacitance as a function of applied voltage for each concentration of RM. In the normal OCS cell, phase transition from splay to vertical alignment, when voltage condition was set down from 5 V to 0 V, is observed. Therefore, large change in capacitance is expected as applied voltage is decreased from 5 V to 0 V. With polymer stabilized cell, the change in capacitance should be reduced because of formation of surface tilt angle less than 90°. As expected, the normal cell without PS technology shows largest change in capacitance

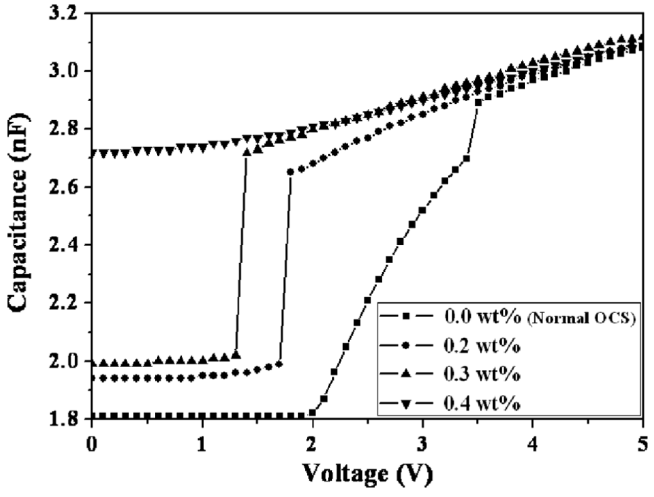


Figure 3. Voltage-dependent capacitance curve according to concentration of RM.

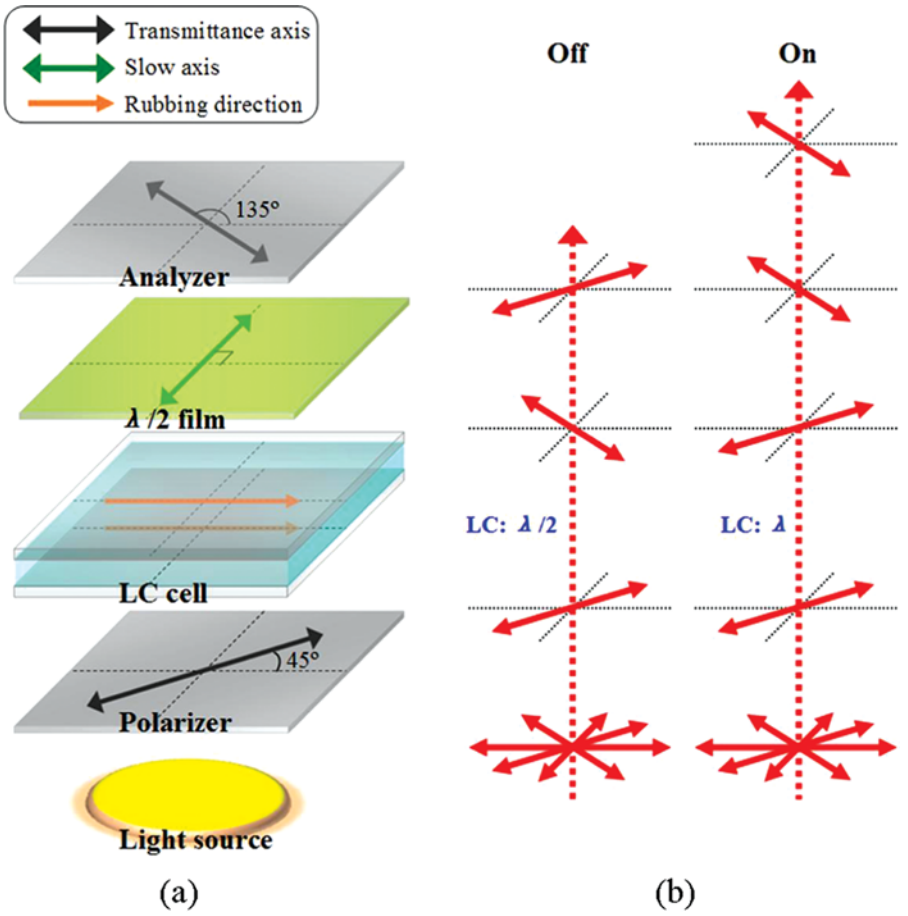


Figure 4. (a) Structure of OCS mode for normally black state and (b) variation of light polarization state through the OCS cell. (Figure appears in color online.)

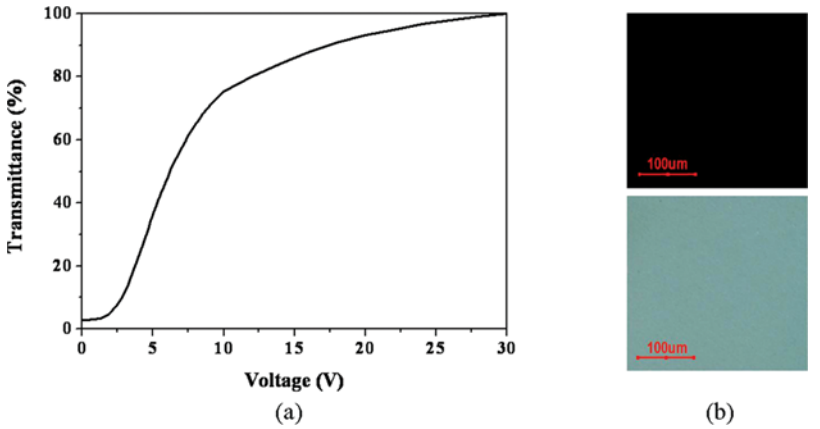


Figure 5. (a) Voltage-dependent transmittance curve and (b) microscopic images in on and off state. (Figure appears in color online.)

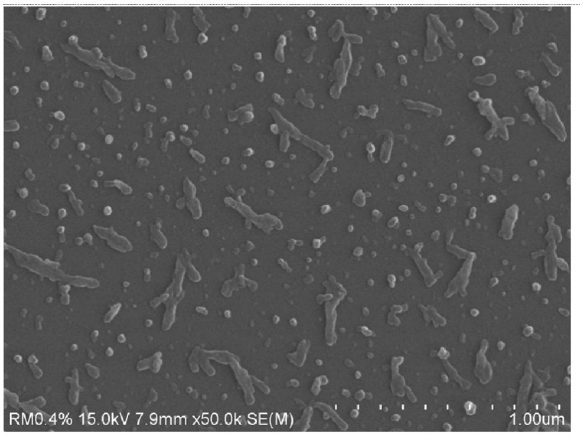


Figure 6. SEM image of surface in OCS cell with 0.4 wt% of RM concentration.

and the cells 0.2 and 0.3 wt.% RM show rapid drop of capacitance at 'specific voltage'. However, in the case of 0.4 wt% concentration of RM, initially the LC is aligned in a splay state so that continuous molecular reorientation does occur so that the capacitance change also shows continuity.

Figure 4 shows the cell structure for normally black (NB) state OCS mode and variation of polarization state according to penetration of light passing through each part of the cell. Without any applied voltage, the polarization direction of light to pass the polarizer is changed to crossed direction after passing through LC layer because the effective phase retardation ($d\Delta n_{eff}$) of LC layer is $\lambda/2$, and further the direction is changed again to crossed direction due to $\lambda/2$ film, and then light is completely blocked by analyzer. However, if $d\Delta n_{eff}$ is close to λ according to applying voltage, the light polarization direction passing through the polarizer does turn into crossed direction by just passing through the $\lambda/2$ film and thus light can pass through analyzer, as shown Figure 4(b).

Figure 5 shows the normalized voltage-dependent transmittance curve in splay state achieved by 0.4 wt% of concentration of RM and microscopic images in off and on state at 0 V and 30 V, respectively. As shown by the graph in Figure 5(a), light leakage exists at 0 V because $d\Delta n_{eff}$ of the cell at normal direction is larger than $\lambda/2$ and phase is not cancelled completely. However, the device does not require any extra setting or critical voltage for transition from bend to splay state.

Figure 6 shows the scanning electron microscope (SEM) image of the surface of OCS cell in the case of 0.4 wt% of RM concentration. The grain-shaped substances on surface are formed by polymerization of RM, as a result, the pretilt angle for OCS state is completely supported.

4. Conclusions

To achieve initial stable splay state in absence of an electric field, the method, maintaining pretilt angle by polymerization of UV-curable RM with applying a specific voltage is studied. We conclude that with sufficient weight percent of RM, critical voltage, setting voltage, and phase transition time are not required to achieve

OCS state because the pretilt angle is completely supported by polymerization of RM. Consequently, the new device with wide viewing angle and fast response time characteristics can be applicable to LCDs or LC phase or amplitude modulator.

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