

## 45.1 Fabrication of Fast Switchable Patterned Vertical Alignment Mode using Modified Surface with Reactive Mesogen

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### Abstract

We proposed a new fast switchable patterned vertical alignment (PVA) mode using UV curable reactive mesogen (RM) which was mixed with vertical alignment layer. In this mixed alignment layer, the pretilt angle was controlled according to an applied voltage during UV exposure for curing the RM. As a result, the response time was dramatically improved at the whole grey levels by controlling the pretilt angle in conventional PVA mode.

### 1. Introduction

The thin-film transistor liquid crystal displays (TFT-LCDs) have been much attention due to the advantages of high resolution, light weight, slim thickness, and low power consumption. For realizing the high performance display, many research groups and companies have been developing new LC modes such as in-plane switching (IPS) [1], fringe-field switching (FFS) [2,3], multi-domain vertical alignment (MVA) [4], and patterned vertical alignment (PVA) [5,6]. Among them, PVA mode is one of the most useful modes for large size LCD applications due to rubbing free fabrication process, high contrast ratio at normal direction, and wide viewing angle characteristics through multi-domain structures controlled by a fringe field effect from patterned electrodes. However, the PVA mode reveals low transmittance and slow response time, particularly for rising time due to the formation of disclination between the LC

molecules in the presence of an electric field. In order to remove disclination and resultantly improve the response time, a polymer stabilized PVA (PS-PVA) mode was suggested in which the mixture of the LCs with reactive mesogen (RM) was used to generate pretilt angle within the patterned electrodes [7,8]. In the PS-PVA mode, the pretilt angle is determined by polymerization of RM monomers in the presence of an electric field. Due to the pretilt angle, threshold voltage was decreased and response time is drastically improved in the PS-PVA mode. However, since the remaining uncured RM monomers in LCs would be acted as impurities in the LCs, it is possible to generate severe image degradation such as image sticking.

In this report, we presented a new PVA mode with controlled alignment layers in which the RM monomers were mixed not with the LCs but with the alignment layers, namely surface controlled PVA (SC-PVA) mode. Like as the PS-PVA mode, the pretilt angle was defined by polymerization of the RM monomers in the alignment layer through the UV exposure in the presence of an electric field. In other word, when the electric field is applied, a falling direction of the LC directors is defined and the pretilt angle is introduced by polymerization of the RM monomers along the LC molecules. As a result, the SC-PVA mode shows dramatic improvement of response time in whole grey levels without any defects or disclinations. Moreover, since the RM monomers are confined in alignment layers, the uncured monomer does not generate any severe degradation of image quality unlike the PS-PVA mode.

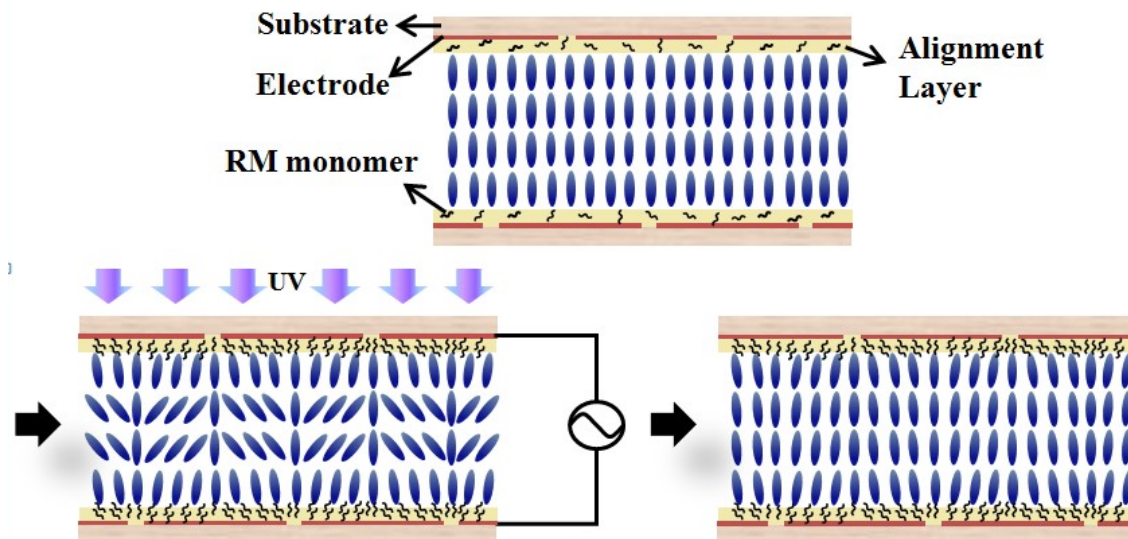


Figure 1. The schematic diagram and fabrication process of the SC-PVA mode.

## 2. The configuration of the SC-PVA mode

In the conventional PVA mode, as aforementioned, the response time is intrinsically slow due to no preference of LC director rotation in the center of the patterned electrodes. Such ambiguity of the director rotation is originated from no rubbing process. In general, when an electric field is applied, the LC molecules with a negative dielectric anisotropy are randomly rotated perpendicular to the electric field without any azimuthal preference in the PVA mode. Then, the LC directors are reoriented to a certain azimuthal direction to minimize elastic free energy. Due to this reorientation process, the rising time of the PVA mode should be slow. Through introducing the preference of the director rotation controlled by the pretilt, it would be expected that the response time is dramatically reduced.

Figure 1 shows the schematic diagram and fabrication process of the SC-PVA mode proposed here. The mixture of the vertical alignment materials and the RM monomers was coated on patterned ITO substrates which have chevron-shaped electrodes. The thickness of the sample cell was maintained by using glass spacers and the LC of MLC-6610 (E. Merck) was filled. In the absence of an applied voltage, the LC molecules were aligned vertically and the RM monomers randomly distributed in the vertical alignment layer of AL60101 (JSR). When the voltage was applied slightly above a threshold voltage ( $V_{th}$ ), the LC molecules are tilted downward due to the negative dielectric anisotropy in four different diagonal directions as same as that of a conventional PVA mode. Then, the LC directors were aligned to a certain azimuthal direction to minimize elastic free energy. Simultaneously, the RM monomers in the alignment layer were also aligned along the LC molecules since the interaction between the LC molecules and RM monomers with the nematic LC phase. In this situation, the cell was exposed to the UV light for 30 min and then the RM monomers were polymerized. Even though the applied voltage was removed, the LC molecules were anchored with a certain pretilt angle due to the polymerization of the RM monomers. Finally, the pretilt angle was achieved along the expected azimuthal direction to form no disclination and the response time would be reduced dramatically because the reorientation time was not required.

First, we investigated to control the pretilt angle depending on a curing voltage of the RM monomers. The alignment layer mixed with the RM monomers was coated on top and bottom ITO

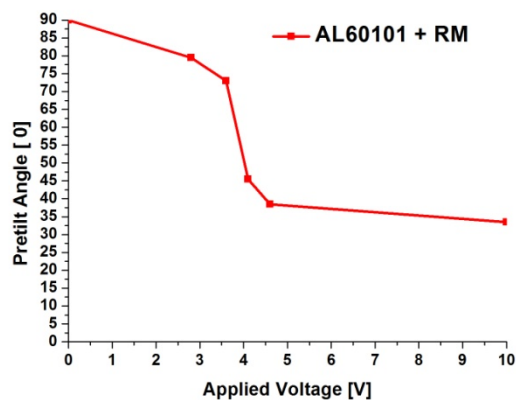


Figure 2. The pretilt angle of the mixture of the vertical alignment materials and the RM monomers as a function of the curing voltage.

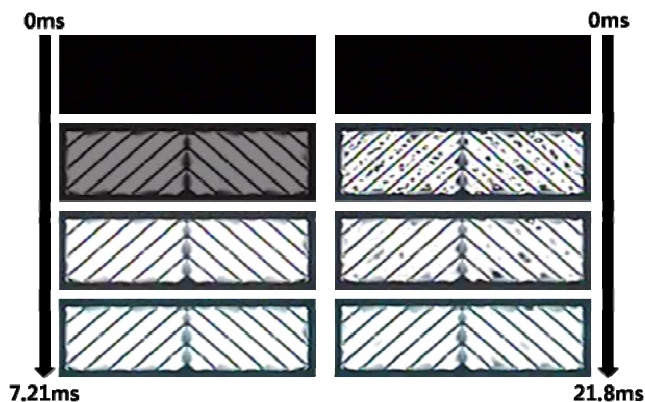


Figure 3. The time-resolved microscopic textures at 5 V for (a) the SC-PVA mode with the RM cured at 4 V and (b) the conventional PVA mode without the RM in the alignment layer.

substrates. The top and bottom substrates were rubbed with antiparallel direction and then assembled with 3  $\mu\text{m}$  glass spacers. The LC, MLC-6610 ( $\Delta\epsilon = -3.1$ , and  $\Delta n = 0.0996$ ), is injected to the sandwiched cell. With applying the electric field, the sample was exposed by UV light for 30 minute to polymerize RM monomers in the alignment layer. Fig. 2 shows the pretilt angle of samples fabricated in different applying voltage during UV curing process. As shown in Fig. 2, the pretilt angle is controlled by the curing voltage during UV exposure. Especially, the pretilt angle was remarkably reduced near 4 V corresponding to a threshold voltage (strictly speaking, slightly above the threshold voltage)

## 3. Response characteristics of SC-PVA mode

The time-resolved textures of the SC-PVA and the conventional PVA samples were observed by using a polarized microscope and a frame-grabbing system and shown in Fig. 3 in the presence of an applied voltage of 5 V. The SC-PVA sample was prepared with the RM monomers cured at 4 V through UV exposure. As shown in Fig. 3(a), the SC-PVA sample shows uniform texture without any defects and disclinations even transiently switching process. In the case of the SC-PVA sample, the LC directors have a pretilt angle with a certain azimuthal direction by the polymerized RM monomers. Thus, when the electric field is applied, the LC directors are rotated to the predetermined azimuthal direction without reorientation process producing slow response time. On the contrary, in the conventional PVA sample, the defects were observed during the switching as shown in Fig. 3(b). Because the falling direction of the LC directors is not determined in the centers of the patterned electrodes, the LC directors fall in random azimuthal direction when the electric field is applied. Therefore, the LC directors are reoriented to a certain azimuthal direction and the defects are formed during the reorientation of the LC directors. Finally, after a certain saturated time, the defects disappear gradually.

Figure 4 shows the response time as a function of the applied voltages for both conventional and proposed SC-PVA samples. The rising time of the SC-PVA sample was faster than that of the conventional PVA sample in the whole range of the applied voltage as shown in Fig. 4(a). On the other hand, the falling time was slightly increased [see in Fig. 4(b)] because the

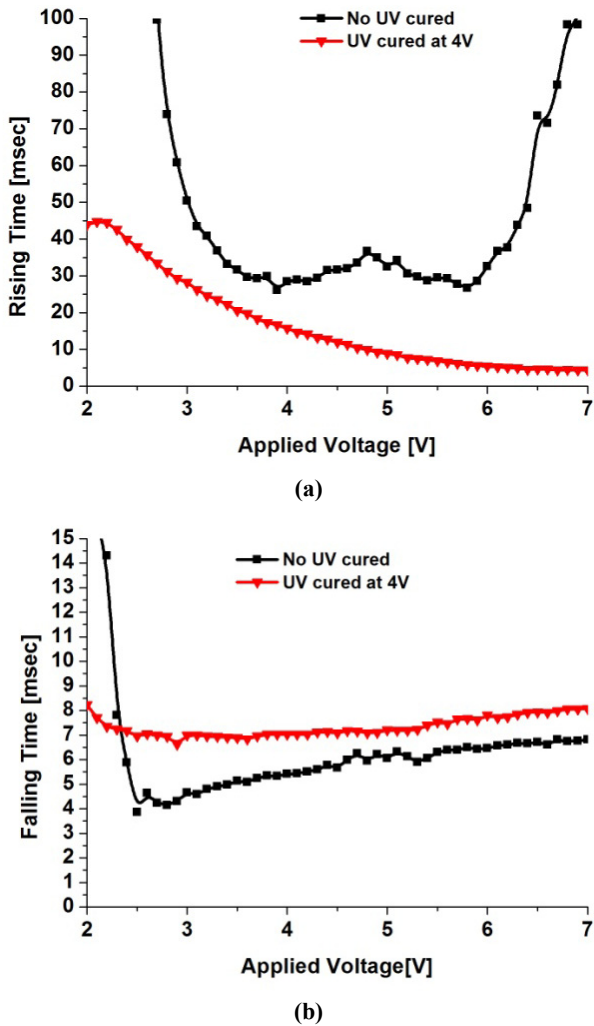


Figure 4. (a) Rising time and (b) falling time as a function of the applied voltage for the conventional PVA sample and the SC-PVA sample cured at 4 V.

pretilt angle controlled by the polymerized RMs reduces the elastic deformation energy corresponding to the resorting force of the LC director. However, it should be noted that the total response time together with the rising and the falling times was

dramatically decreased in the SC-PVA sample in the whole grey levels.

#### 4. Conclusion

We proposed a PC-PVA mode with fast response time using UV curable RM monomers which was mixed with vertical alignment layer. The SC-PVA sample was fabricated by UV exposure under an applied voltage. The RM monomers possessing the nematic LC phase were rearranged along the LC directors stabilized by the applied voltage and polymerized by UV exposure. In this situation, the polymerized RMs produce the pretilt angle to a certain azimuthal direction in the absence of the applied voltage. The pretilt angle, depending on the applied voltage during UV exposure, governs the rotation direction of the LC directors under the applied voltage without any reorientation process observed in the conventional PVA sample. As a result, the response time was improved dramatically without any defects. Furthermore, in our proposed method of the mixture of the alignment material and the RM, the possibility of an aforementioned drawback such as image sticking is slimmer than that of the mixture of the LC and the RM although the unpolymerized RM monomers are still remained because the RM monomers are strongly confined in alignment layer. It is expected that the surface controlling method proposed here plays an important role in the fast response LCD applications.

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