Novel Surface-Stabilized Vertical Alignment Mode for Fast-Response Liquid Crystal Display

Jun Hyup Lee, Keunchan Oh, Hee Sub Kim, and Shin-Tson Wu, *Fellow, IEEE*

***Abstract*—Novel vertical alignment (VA) mode is presented for fast response and wide viewing angle in the LCD panel. The key concept of the new mode is that the pre-tilt for fast response and multi-domain is generated in the surface of alignment layer composed of vertical alignment part and photo-reactive moiety. The UV treatment of the new alignment layer under applied voltage provides fast control of liquid crystal texture and wide viewing angle in liquid crystal display. Because of the uniform distribution of the reactive monomer (RM) and inherent prevention of the RM migration in the LC cell, the enhanced picture quality and reliability in the LCD TV panel are achieved.**

***Index Terms*—Liquid crystal display (LCD), pre-tilt, surface stabilization, vertical alignment (VA).**

I. INTRODUCTION

RECENTLY, many efforts have been dedicated to improve the display performance in the vertical alignment liquid crystal (VA-LC) mode for the large-area display [1]–[5]. In general, the VA-LC mode provides high contrast ratio in the LCD device because of excellent dark state generated by perfectly aligned LC molecules in the vertical direction, hence most of LCD panel makers have adopted the VA-LC mode for large-scale commercial displays. In particular, the LC mode for the 3D or moving picture application needs fast response and wide viewing angle characteristics. Over the past few years, new VA-LC modes such as photo-aligned UV vertical alignment (UV^{2}A) [6] and polymer-stabilized vertical alignment (PS-VA) [7]–[9] modes have been introduced and commercialized to improve the response time of the LCD device. These modes utilize the surface pre-tilt made by UV reaction of photo-reactive molecules included in the functional alignment layer and LC mixture, respectively.

Especially, PS-VA mode has been newly developed for the fast response, high transmittance, and simple manufacturing process. However, it has several problems resulting from the reactive monomer (RM) in the LC cell. The adoption of RM into the LC medium might cause the potential problems such as image sticking resulting from the residual RM in the LC cell, the low picture quality from the nonuniform distribution of RM, the high cost of RM material, and long manufacturing lead time for the removal of the remaining RM in the bulk LC region. Surface-controlled VA (SC-VA) mode has been recently proposed for generating the pre-tilt by using blend materials composed of RM and polyimide materials [10]–[12]. In spite of the high performance in the SC-VA mode, the latent risk remains to be solved which is related to the residual RM in the alignment layer. For example, the diffusion of residual RM to the bulk LC layer might cause severe image sticking in the course of time.

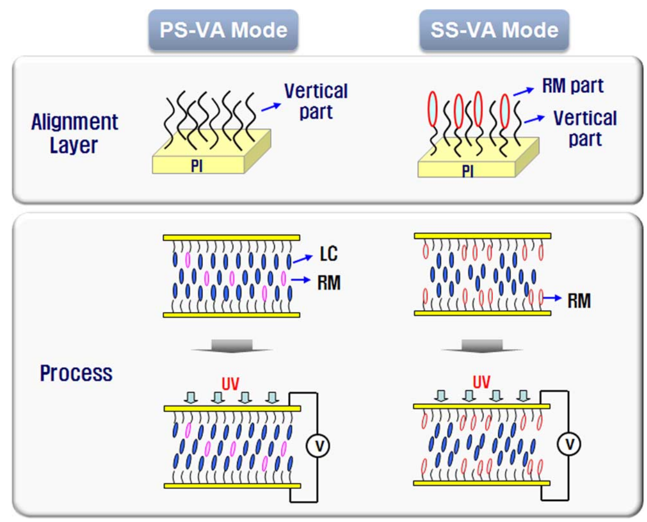

Fig. 1. Schematic diagram of basic concept and manufacturing process of SS-VA mode.

In this work, we present novel surface-stabilized vertical alignment (SS-VA) mode designed for fast response and wide viewing angle in the LC display. The new VA mode is based on the novel alignment layer having both chemically bonded photo-reactive unit and vertically aligning part, as shown in Fig. 1. The expected effectiveness for the present work is the high picture quality from the uniform distribution of RM in the alignment layer, and the improvement in the panel reliability caused by inherent prevention of the RM migration with the firm cross-linking of chemically bonded photo-reactive groups in the alignment layer. By applying the new SS-VA mode to the commercial display, a large-sized 46″ Full HD (FHD) TV panel, which has fast response, good wide viewing property, and enhanced long-term reliability, has been realized.

II. MANUFACTURING PROCESS

Manufacturing process of the proposed SS-VA mode is schematically shown in Fig. 1. The new alignment layer in the SS-VA mode is composed of photo-reactive acrylic unit forming the surface pre-tilt and conventional hydrocarbon moiety for homeotropic alignment. In comparison with the

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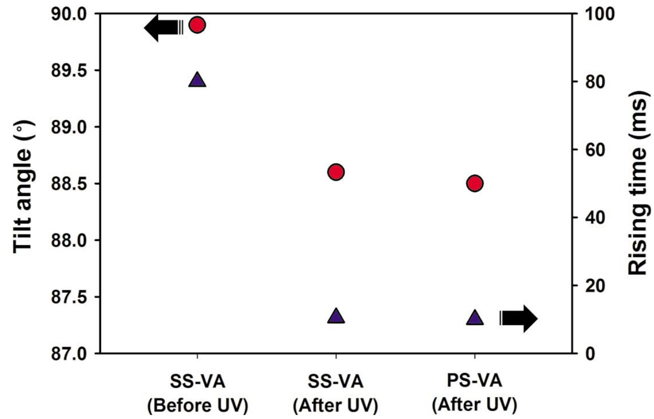

Fig. 2. Tilt angle and rising time of new mode compared with conventional PS-VA mode.

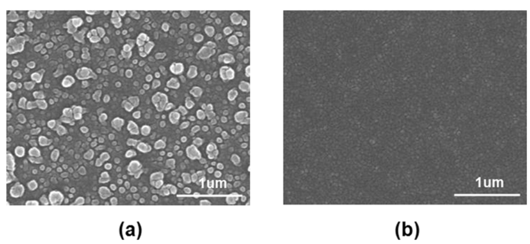

Fig. 3. SEM micrographs of the top surface of alignment layers in: (a) PS-VA and (b) SS-VA modes.

conventional PS-VA or SC-VA mode, the alignment layer functions as both a pre-tilting and a vertically-aligning of LC molecules in the SS-VA mode. The cell configuration for the present investigation is constructed according to the previous report [13]. The electrode structure and fabrication process of new mode is similar to that of PS-VA mode. After the fishbone electrode surfaces are coated with the new alignment material, the sealed LC cell is irradiated with scattered UV light under applied voltage. This reaction process gives rise to the pre-tilt formation by cross-linking of the photo-reactive moieties within the alignment layer.

III. Results and Discussion

The pre-tilt angle and response time of the SS-VA mode are compared with the conventional PS-VA in Fig. 2. After UV treatment in the SS-VA mode, an abrupt decrease in both the tilt angle and rising time is observed, which means that the surface pre-tilt formed by photo-reaction of RM facilitates more rapid LC motion under on/off switching conditions. This result convincingly demonstrates that the new VA mode is comparable to PS-VA mode.

Fig. 3 shows the top surface images of alignment layers in both PS-VA and SS-VA mode. Random distribution of RM within the LC medium in PS-VA mode usually generates a rough surface morphology and broad size distribution of polymer bump as shown in Fig. 3(a), and requires additional UV treatment to remove residual RM. On the other hand, uniform distribution of chemically bonded RM in SS-VA mode gives rise to smooth surface, as shown in Fig. 3(b) and reduces additional UV exposure.

TABLE I
Specifications of 46″ FHD LCD TV Manufactured by SS-VA Mode

Item	Specification
Brightness	450 cd/m^2
Response time (rising)	8 ms
Contrast ratio	5000 : 1
Viewing angle	180°
*Advantages	1) Cost effective 2) Short UV process time 3) Suitable for low cell gap

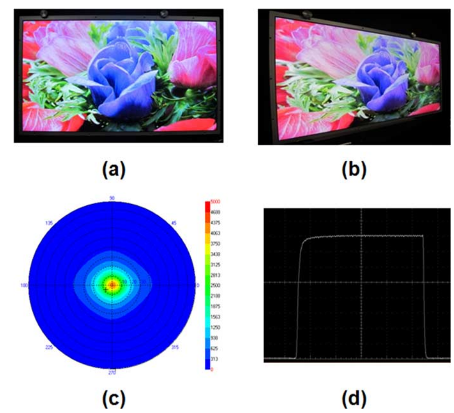

Fig. 4. Photographs and performance of the 46″ FHD LCD TV fabricated by SS-VA mode: (a) front view; (b) side view; (c) iso-contrast plot; and (d) measured response time curve of 46″ FHD TV.

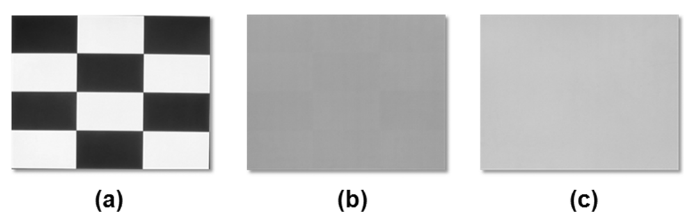

Fig. 5. Photographs of the 46″ FHD LCD TV tested at 50 °C for three weeks: (a) image sticking pattern; (b) an image at 100gray/256gray; and (c) an image at 150 gray/256 gray.

Thus, a new mode is suitable for the display requiring fast response, good wide viewing, and low manufacturing costs. In addition, inherently uniform distribution of RM throughout the entire active area enables the surface pre-tilt formation without stain in the picture even under the extremely low cell gap conditions. Table I summarizes the performance of SS-VA mode applied to commercial size panel and highlights its advantages over those of the conventional PS-VA mode. A large-sized 46″ FHD panel fabricated by SS-VA mode has fast response time, high contrast ratio of 5000:1, and good wide viewing angle property. The displayed images reveal that both excellent off-axis image quality and superior contrast ratio can be achieved in the SS-VA mode, as shown in Fig. 4(a) and (b). The iso-contrast map observed in Fig. 4(c) also shows a wide viewing angle with its CR $>$ 300 : 1 at every direction. From Fig. 4(d), the measured rising time and decay time defined as 10%–90% of the transmittance change are about 8 ms and 3.5 ms respectively, which is suitable for the 3D or moving picture application.

Fig. 5 shows the image sticking photographs of 46” FHD panel evaluated with test pattern as shown in Fig. 5(a) at 50

°C for three weeks. When the panel has a good image sticking performance, the sticking image is hardly visible to the naked eye above 150 gray in 256 gray. As shown in Fig. 5(b) and (c), the test pattern is visible to a certain extent at 100 gray but perfectly invisible at 150 gray, which means the improvement in panel reliability caused by SS-VA mode. The residual RM within the bulk LC layer in PS-VA mode might cause the additional RM migration, resulting in serious image sticking problem. On the contrary, the permanent chemical bonding between RM moiety and other components within the alignment layer in SS-VA mode could prevent RM migration, leading to the improved panel reliability.

IV. Conclusion

Novel VA mode has been developed for fast response and wide viewing angle in the LC display. The new mode in the present work provides the stain-free picture quality resulting from the inherently uniform distribution of reactive monomers and enhanced long-term reliability due to the firm cross-linking of photo-reactive groups within the alignment layer. In addition, SS-VA mode is expected to have an impact on 3D devices due to the high picture quality under the extremely low cell gap conditions.

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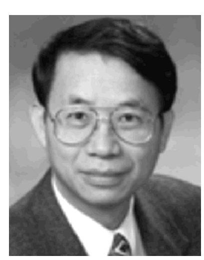

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