Advanced surface treatment technology for improving the performance of the liquid crystal display

Soo In Jo, Young-Ki Kim, Sang Woong Choi, You-Jin Lee, Jae-Hoon Kim, et al.

Soo In Jo, Young-Ki Kim, Sang Woong Choi, You-Jin Lee, Jae-Hoon Kim, Chang-Jae Yu, "Advanced surface treatment technology for improving the performance of the liquid crystal display," Proc. SPIE 7956, Advances in Display Technologies; and E-papers and Flexible Displays, 79560L (2 February 2011); doi: 10.1117/12.879810

SPIE.

Event: SPIE OPTO, 2011, San Francisco, California, United States

Advanced surface treatment technology for improving the performance of the liquid crystal display

Soo In Jo[1], Young-Ki Kim[2], Sang Woong Choi[1], You-Jin Lee[1], Jae-Hoon Kim[1,2], Chang-Jae Yu[1,2,*]

[1]Dept. of Electronic Engineering, Hanyang University, Seoul, 133-791, Korea
[1]Dept. of Information Display Engineering, Hanyang University, Seoul, 133-791, Korea

e-mail: cjyu@hanyang.ac.kr

ABSTRACT

We proposed a surface treatment technology for improving the performance of the liquid crystal displays (LCDs). The alignment surfaces are modified with the reactive mesogen (RM) which are mixed with alignment layers and directionally polymerized along the LC directors during UV curing process. Since the polymerized RMs within the alignment layers could control and memorize the specific pretilt and azimuthal angles of liquid crystal molecules at the specific panel region, we could improve the display performance such as response time and wide viewing angle with multi-domains and design the new LC modes.

Keywords : Surface treatment, reactive mesogen, fast response time, wide viewing angle

1. INTRODUCTION

Liquid crystal display (LCD) plays an important role in display device fields due to their high resolution, good image quality, low power consumption, and low fabrication cost. However, LCD device intrinsically has some problems such as slow response time and narrow viewing angle. To overcome those problems, many kind of researches have been reported by designing the electrode structures to generate the fringe field inside the sample such as in-plane switching (IPS), fringe field switching (FFS) and patterned vertical alignment (PVA) mode [1-3]. However, even the viewing angle characteristics could be improved with multi-domain LC modes, the response time characteristics were still remained as a problem. Therefore, complex system with LC molecules was adopted using nano-particles and reactive mesogens (RM) [4-5]. With complex system, the response time could be controlled, but the image sticking problems reveals comparing pure LC system due to residual charges within LC layer.

In our previous studies, we proposed the surface treatment method with pure LC and RMs which are mixed with alignment layer to improve the response time characteristics such as surface-controlled PVA (SC-PVA) mode [6]. For modification of alignment surface, we used the UV curable RMs which are mixed within alignment layers. The RM monomers within an alignment layer are dissolved in the LCs due to liquid crystalline property of RM and aligned along the LC molecules to reduce the excluded volume. Through UV exposure, the aligned RM monomers are directionally polymerized along the LC alignment and the polymerized RMs can produce and memorize the specific polar and azimuthal angle of LC molecules at specific panel regions. The degrees and directions of the polar and azimuthal angles are also controlled by UV exposure condition and applied voltage during UV curing process. The determined falling

Advances in Display Technologies; and E-papers and Flexible Displays, edited by Karlheinz Blankenbach, Liang-Chy Chien, Sin-Doo Lee, Ming Hsien Wu, Proc. of SPIE Vol. 7956, 79560L

direction in VA mode by directionally polymerized RMs could remove the reorientation process when applied voltage.

In this paper, we propose various VA modes through surface modification with RMs which are mixed in alignment layers. The directionally polymerized RMs determined the direct falling direction over whole panel area. As a result, we could realize the fast response and wide viewing angle characteristics for various LC modes.

2. FAST VERTICAL ALIGNMENT MODE

Figure 1 shows the schematic diagram of fabrication process for fast VA mode [7]. The mixtures of the vertical alignment material AL1H659 (JSR) and RM 257 (Merck) with proper weight ratio were spin coated on both indium tin oxide (ITO) glass substrates having no particular electrode pattern for generating oblique electric field, as shown in Fig. 1(a). The cell gap was maintained about 3.0 μm with glass spacer and the cell was filled with negative LC (MLC-6608, $\Delta\varepsilon = -3.1$ and $\Delta n = 0.0996$, Merck). At an initial state, the LC molecules were aligned vertically on the substrate and RM monomers were distributed uniformly within the alignment layer at the monomer state, as shown in Fig. 1(a). When applied voltage larger than threshold voltage (V_{th}), the LC molecules fell down randomly, and the RM monomers aligned along the LC molecules [Fig. 1(b)]. The RM monomers are easily dissolved in the LCs and movable due to the liquid crystalline property of RM. After a few times later until the LC directors, defects, and disclination lines are stabilized, the cell was exposed to the UV light of 4 mW/cm^2 for 30 min with applied 4 V, and then the RM monomers were polymerized in the alignment layer [Fig. 1(c)]. Finally, the unrubbed alignment layers kept in the memory of the LC director at this structure even after removing the electric field [Fig. 1(d)].

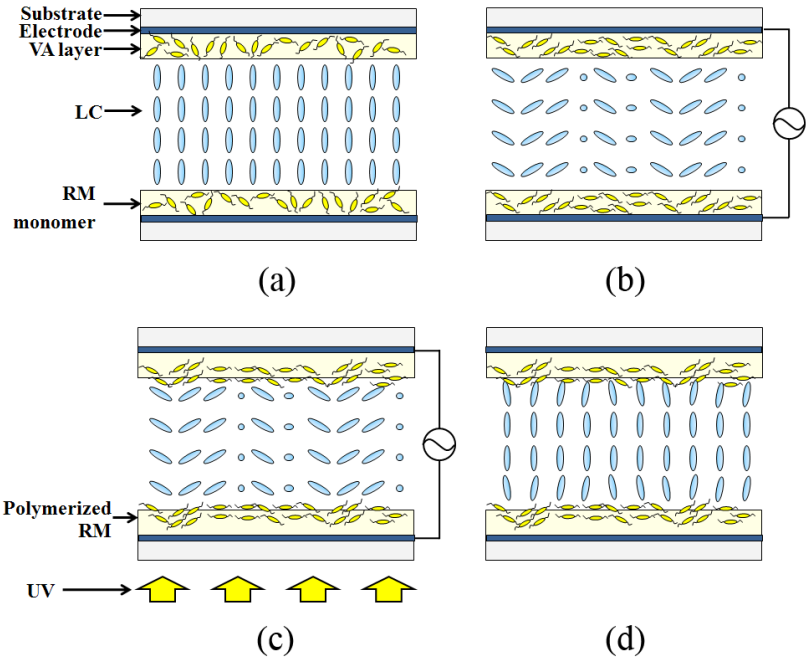

Figure 1. The schematic diagram and fabrication process of the proposed fast-VA mode

Figure 2 shows the microscopic textures under crossed polarizers for conventional VA mode and proposed fast VA mode without rubbing process in both cases. The LC molecules aligned vertically on the alignment layer surface without electric field at their initial state. In the presence of the electric field, the LC molecules fall down to the surface with random azimuthal direction due to unrubbed alignment surface, which generate the 4-brush ($s = \pm 1$) defects. After that, the LC molecules are reoriented to minimize the free energy with changing the position of core of disclination lines and

point defects, as shown in Fig. 2(a). When switching the electric field, the LC directors changed every time, so we always get the different textures(compare with Figs. 2(a), 2(b) and 2(c)). In our proposed fast VA cell, the LC directors are also aligned randomly in the presence of electric filed and then reoriented. But, after UV exposure with applied voltage, RM polymers in the alignment layer memorize the LC directors because the polymers elongated with the LC directors during UV exposure with electric field. Therefore, the LC directors when applied the voltage fall down to the surface with the fixed azimuthal direction along the RM polymers without any reorientation processes for minimizing the free energy. As a result, we can always obtain the same microscopic textures at the same position, as shown in Figs. 2(e), 2(f) and 2(g). In conventional VA mode without rubbing process, a response time, particularly rising time, is very slow because the LC molecules aligned with reorientation process in the presence of electric field for minimizing the free energy. However, in our fast VA mode, since the azimuthal tilting down directions of the LC molecules is not defined, it takes more than 10 sec to reach the stable state through the reorientation process. On the contrary, our fast VA mode has very fast response characteristics because the memorized azimuthal tilting-down direction by the RM polymer guide to the stable alignment state of the LC molecules without reorientation process. So, it takes less than 3 msec with applied 10 V.

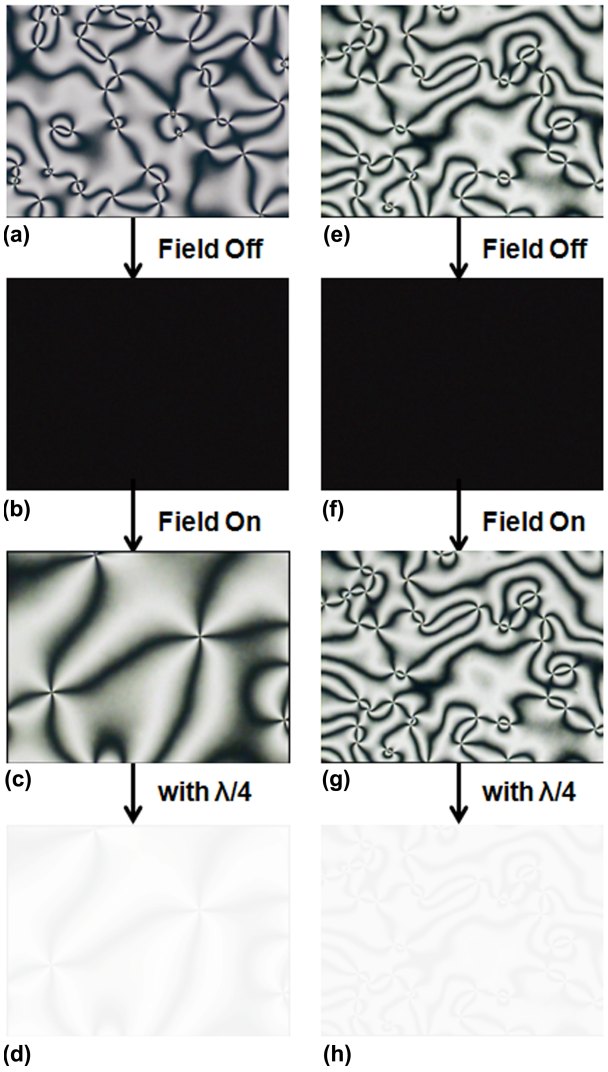

Figure 2. Microscopic textures under crossed polarizers for (a)-(d) the conventional VA mode and (e)-(h) fast VA mode with the electric filed switching.

Though many 4-brush defects decrease the transmittance, we can overcome this problem using two λ/4 retardation films that each films located between polarizer and glass substrate of top and bottom, respectively, by 45° with respect to the optic axis of polarizer as conventional LCD does. Because the linearly polarized light through after polarizer is changed to circularly polarized light due to λ/4 retardation film, the area in which the direction of LC molecules and polarizers are parallel or perpendicular each other is not dark state but bright state, as a result, we could increase the transmittance (see Fig. 2(d) and 2(h)).

3. PATTERNLESS VERTICAL ALIGNMENT MODE

Nevertheless, our fixed defect structure in fast VA mode is difficult to use in LCD application devices due to the randomly generated defect. Defect structures have to be placed uniformly at each pixel to obtain the uniform textures and viewing angles. To control those defects, we propose the simple electrode pattern method at pixel region [8]. Figure 3(a) shows the electrode configuration of the proposed VA mode. In contrast to the conventional PVA mode, we remove the electrode pattern in common electrode region to simplify the fabrication process and reduce the manufacturing cost. Pixel structure is designed similar to the delta structures and connection line between the square pixels can generate the precise oblique field without slit in common electrode. The LC molecules start to fall down to the substrate at the edge of the electrode when the electric field is applied to the sample and propagate to the center of the square shaped electrode in each pixel to minimize the free energy. Therefore, three spiral defects are generated at each pixel uniformly.

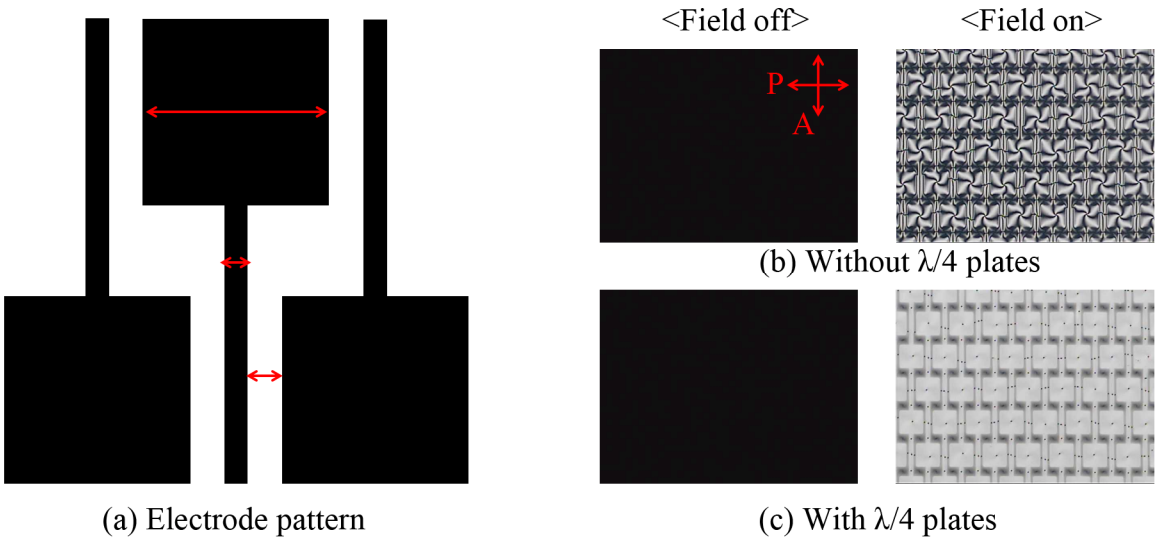

Figure 3. Electrode configuration of (a) proposed VA mode and microscopic textures of the sample under the crossed polarizers without λ/4 plates and (c) with λ/4 plates.

However, it can be easily noticed by Fig. 3(b) that transmittance is very poor due to the spiral defect structure. If the spiral defect structures are removed by the optical modification, then the transmittance will be increased. Therefore, we adopt the two λ/4 plates to enhance the transmittance characteristics as same as fast VA mode as mentioned in section 2. Each λ/4 plate was introduced between polarizer and LC cell by 45° and -45° with respect to the polarizers. As a result, the spiral defects are optically removed due and transmittances are increased as shown in Fig. 3(c).

Even though the high transmittance and simple fabrication processes, this method was difficult to apply to the real

display because of the slow response time to stabilize the LC directors when electric field induced to the sample. However we can optimize the response time characteristics using our surface treatment method as mentioned above section. Figure 4(a) shows the time-resolved microscopic textures of the patternless VA cell without surface modification using RMs. As shown in textures, due to the propagation of LC directors from pixel electrode edge to center, it takes more than 30 msec to reach the stable state. On the contrary, patternless VA cell with RMs on the alignment surface has very fast response characteristics because the memorized azimuthal tilting-down direction over whole pixel area, as shown in Fig. 4(b).

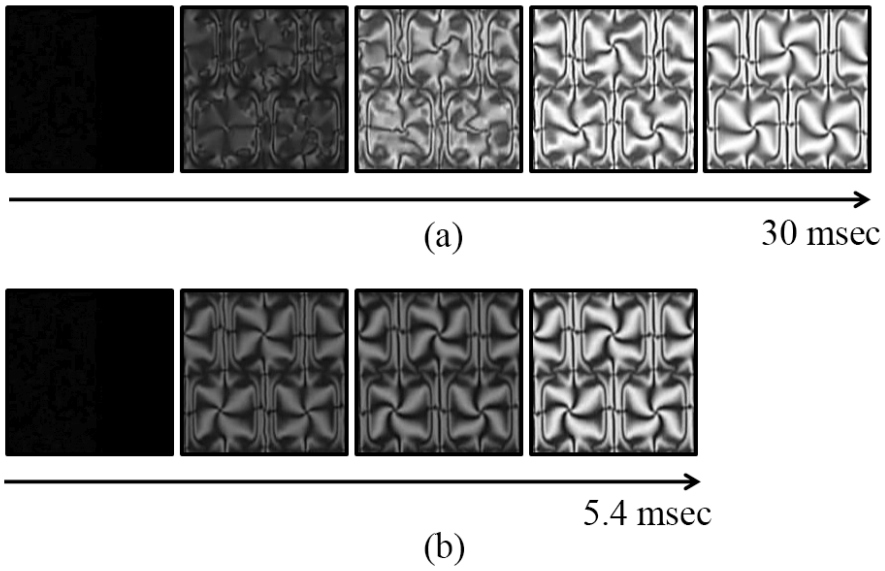

Figure 4. The time-resolved microscopic textures under crossed polarizers with 10 V for the patternless VA cell (a) without and (b) with surface modification using RMs.

4. FAST EIGHT-DOMAIN PVA MODE

Recently, to improve the viewing angle characteristics on off-axis direction for the PVA mode, eight-domain PVA mode was developed using two transistors in one pixel, namely super-PVA mode [9]. However, complicated driving scheme, low aperture ratio due to additional TFTs, and cost increase are inevitably involved in the upper-PVA mode. In this section we propose the advanced eight-domain SC-PVA mode with introducing two different pretilt angles in a single pixel driven by a single transistor [10].

Figure 5 shows a schematic diagram of fabrication process for the advanced eight-domain SC-PVA mode with the different pretilt angles in a single pixel. The RM monomer (Merck) and photoinitiator (Ciba Chemical IRGACURE 651) was mixed in vertical alignment material (JSR AL60101). The mixed alignment layer was coated on the ITO substrate with chevron type electrode pattern for generating oblique electric field. The cell thickness of the assembled substrates was maintained by the use of 3 μm glass spacers. The LC (Merck MLC-6608, Merck) were injected into the assembled cell by capillary action in the isotropic phase. At an initial state, the LC molecules were aligned vertically to the substrate and the RM monomers were distributed randomly in the alignment layer as shown in Fig. 5(a). When a voltage (V1, 5V) was applied larger than a certain threshold voltage, the LC molecules fell down perpendicular to the electric field, similarly to a conventional PVA mode, and the RM monomers were aligned along the LC molecules. At this situation, the area B of LC cell was irradiated as the first step UV exposure through a photo mask and thus the RM monomers were polymerized in the alignment layer at exposed area B [Fig. 5(b)]. The polymerized RMs produce the pretilt angle whose azimuthal direction are determined by the direction of the fringe field by UV exposure in the presence of the applied

voltage. To produce a different pretilt angle, the second step UV light was exposed to the whole cell area [Fig. 5(c)] applying a different voltage (V2, 0V). In the area B, the RMs were already polymerized and there was no change. In the area A, however, the remained RM monomers produce the different pretilt angle from the area B during UV curing process due to a different applied voltage. It should be noted that the pretilt angles depend on the curing voltage, exposure time, RM concentration, and so on. The pretilt angles are fixed at whole region after curing the RM monomers completely and removing the curing voltage as shown in Fig. 5(d). Finally, the two kind of pretilt angles are produced in a pixel, which can make the eight-domain in the PVA mode to improve the viewing angle characteristics.

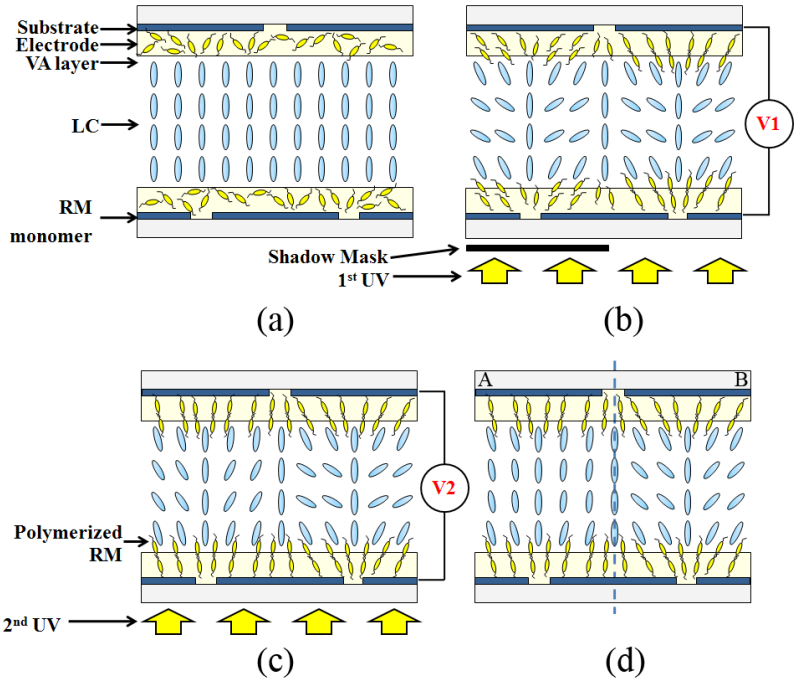

Figure 5. The schematic diagram of our advanced eight-domain SC-PVA mode and the fabrication processes.

Figure 6 shows the microscopic textures under crossed polarizers after two-step UV exposure with triangular shape photo mask. In the absence of the applied voltage, the LC molecules aligned vertically in both areas and thus they are indistinguishable to each other due to the slight difference of pretilt angles [Fig. 6(a)]. Figures 6(b), 6(c), and 6(d) are shown the textures for 3.2, 4.5, and 10 V, respectively. As increasing the applied voltage, the LC molecules are fallen down to the substrate. However, the falling degrees at each area A and B are different due to their different pretilt angles, so we got different transmittance with the same applied voltage (see the boxes with Fig. 6(c)). Since each area has the four domains like the conventional PVA cell, we obtained eight domains with different azimuthal and polar direction, which make possible to improve the viewing angle characteristics in off-axis directions. As a result, our proposed eight-domain SC-PVA mode is free from gray inversions almost all gray levels as shown in Fig. 6(e).

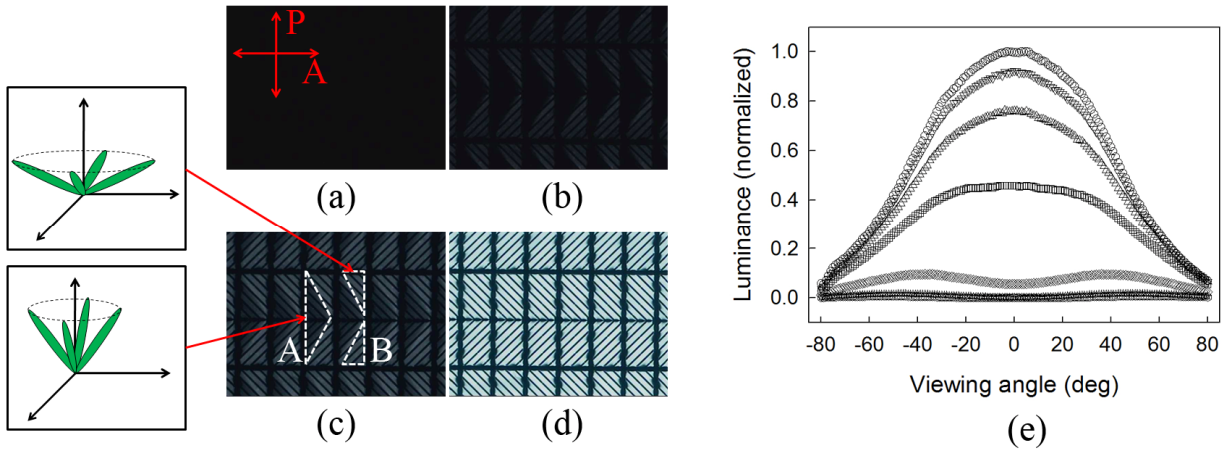

Figure 6. Microscopic textures under crossed polarizers with (a), (b), (c), (d) different gray level and inset configuration is the schematic diagrams of the LC director for each area. And measured brightness viewing characteristics of the eight domain PVA for 45º with respect to polarizers.

5. CONCLUSIONS

In this paper, we proposed a surface treatment technology for improving the performance of the LCDs using UV curable RM mixture with alignment layers. The RM monomers are polymerized along the LC molecular direction with applied electric field during UV curing process and produced pretilt and azimuthal angles are memorized on the alignment layer. Since our proposed the method of controlling alignment of LCs using RMs mixed with alignment layer is possible to be adopted into all kinds of LCDs, it is very useful to improve the display performance and design new LC modes. As results, we could realize the fast response time, high brightness, and wide viewing angle characteristics in LCD.

6. REFERENCES

[1] M. Oh-e, and K. Kondo, "Electro-optical characteristics and switching behavior of the in-plane switching mode," *Appl. Phys. Lett*. **67**(26), 3895 (1995).
[2] S. H. Lee, S. L. Lee, and H. Y. Kim, "Electro-optic characteristics and switching principle of a nematic liquid crystal cell controlled by fringe-field switching," *Appl. Phys. Lett*. **73**(20), 2881 (1998).
[3] K. H. Kim, K. Lee, S. B. Park, J. K. Song, S. N. Kim, and J. H. Souk, "Domain divided vertical alignment mode with optimized fringe field effect," *Proceeding of The 18th International Display Research Conference Asia Display*, 383 (1998).
[4] M. D. Lynch and D. L. Patrick, "Organizing carbon nanotubes with liquid crystals," *Nano Lett.* **2**(11) 1197 (2002).
[5] S. G. Kim, S. M. Kim, Y. S. Kim, H. K. Lee, S. H. Lee, G.-D. Lee, J.-J. Lyu, and K. H. Kim, "Stabilization of the liquid crystal director in the patterned vertical alignment mode through formation of pretilt angle by reactive mesogen," *App. Phys. Lett*. **90**, 261910 (2007).
[6] Y.-J. Lee, Y.-K. Kim, S. I. Jo, J. S. Gwag, C.-J. Yu, and J.-H. Kim, "Surface-controlled patterned vertical alignment mode with reactive mesogen," *Opt. Exp*. **17**(12), 10298 (2009).
[7] Y.-J. Lee, Y.-K. Kim, S. I. Jo, K.-S. Bae, B.-D. Choi, J.-H. Kim, and C.-J. Yu, "Fast vertical alignment mode with continuous multi-domains for a liquid crystal display," *Opt. Exp*. **17**(26), 23417 (2009).

[8] S. I. Jo, Y.-J. Lee, S.-W. Choi, A. R. Yoon, C.-J. Yu, and J.-H. Kim, "Patternless vertical alignment mode with infinite domains for mobile displays," *SID Int. Symp. Dig. Tech*. *Pap.* **126**, 1738 (2010).
[9] S. S. Kim, "Super PVA sets new state-of-the-art for LCD-TV," *SID Int. Symp. Dig. Tech*. *Pap*. **35**(1) 760 (2004).
[10] Y.-J. Lee, S. I. Jo, J.-H. Kim, and C.-J. Yu, "Fast eight-domain patterned vertical alignment mode with reactive mesogen for a single-transistor-driving," *Jpn. J. Appl. Phys*. **49** 030209 (2010).