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Suppressing pretilt angle for enhancing black quality in diagonal viewing angle of homogenously aligned liquid crystal display

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ABSTRACT
The diagonal viewing angle light leakage in a black state of in-plane switching (IPS) liquid crystal display (LCD) associated with pretilt angle has been investigated. The mechanical rubbing process with a cloth causes relatively high pretilt angle in the homogenously aligned liquid crystals (LCs) so that the tilted LC director results in increase of a light leakage in a black state at diagonal viewing angles. In this study, we theoretically estimated using classical optic theory how the light leakage in a black state at diagonal viewing angle is associated with the pretilt angle and also proposed an effective method to reduce the pretilt angle from 1.5° to 0° in rubbed IPS LCD by utilising polymer stabilisation. With this approach, we could successfully acquire a better black quality in all viewing angles as compared with normal IPS LCD.

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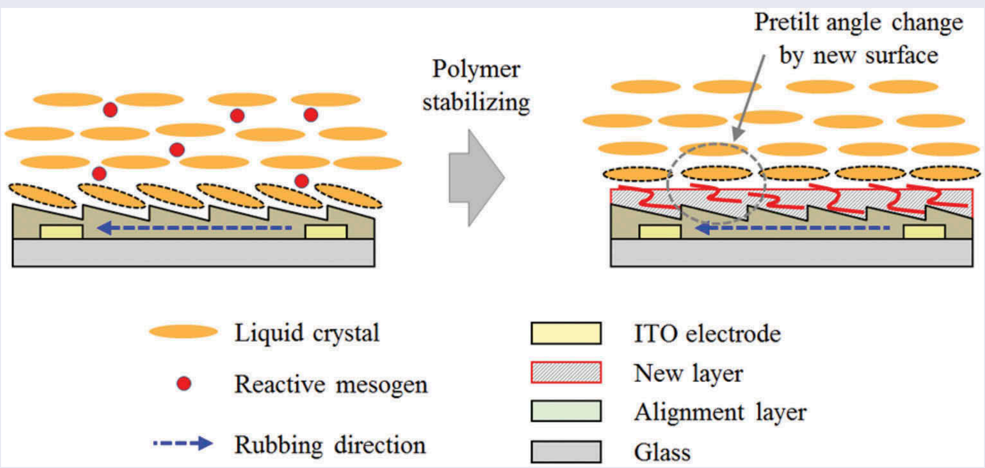
In-plane field switching; dark state; pretilt angle; polymer stabilisation



1. Introduction

In these days, liquid crystal displays (LCDs) are dominating flat panel display market owing to its great improvements in image quality and product cost although the standing level of LCDs is challenged by organic light-emitting diodes [1]. Many liquid crystal (LC) modes such as polymer-stabilised (PS) multi-domain vertical alignment [2–4], in-plane switching (IPS) [5–7] and fringe-field switching (FFS) [8–11] contribute to the development of high image quality in LCDs.

Especially, homogeneously aligned LC modes (IPS and FFS) become very popular in most of LCDs with high resolution and high image quality because both exhibit wide viewing angle, fast switching speed, high colour accuracy and high transmittance with least touch mura. It is generally known that both modes have an excellent viewing angle characteristic compared with other LCD modes; it has some disadvantage in a dark state such that a unique light leakage property in the black level exists, especially in diagonal viewing angles. The main cause of that comes from problem of crossed polarisers [12]. If top and bottom polarisers of LCD cell are stacked with their absoption axes at azimuthal angle of φ = 0° and φ = 90°, and one observes them from the plane at azimuthal angle of φ = 45°, the effective angle between the absorption axes of the two

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polarisers becomes larger than 90°, causing a light leakage by the two crossed absorption axes mismatching of polarisers that the crossed absorption axes are larger than 90° at oblique angles. In addition, this light leakage intensity in diagonal viewing angles is also strongly related to pretilt angle of LC [13]. In IPS LC mode, LC molecules are homogeneously aligned by either rubbing or photo-alignment process. Usually, photo-aligned IPS LCD can provide excellent viewing angle characteristics because of its unique zero pretilt angle property [14]. However, even though photo-alignment process has various advantages that enable us to overcome the drawbacks of the rubbing process, it has not yet been fully applied in mass production because of several problems. Besides, the mechanical rubbing process is a still good method because this process is still effective for mass production and gives rise to very strong and reliable LC alignment with competitive cost. However, the rubbing process for homogenous LC alignment yields relatively a high pretilt angle because of its unique mechanism [15] so that the IPS LCD made with mechanical rubbing process results in a high light leakage at diagonal viewing angles as compared with the photo-aligned IPS LCD. Therefore, it is very useful to find a competitive method to realise pretilt angle of almost zero with rubbing process.

In a previous work [16], a method of obtaining zero pretilt angle was proposed, in which ultraviolet (UV) curable reactive mesogen (RM) is mixed with a homogenous alignment material and then a rubbing process is performed. After the rubbing, a few degree of pretilt angle was generated. Once LC cell was made, a vertical electric field was applied to the cell to suppress the pretilt angle because an LC with negative dielectric anisotropy was used, and then finally UV was irradiated to fix the suppressed tilt angle by polymerisation of RM inside the alignment layer. This is a very good method to realise almost zero pretilt angle; however, this method has some weak points for real IPS LCD applications such as additional electrode on upper glass for generating vertical electric field and changes in electro-optics due to the field distortion by this electrode. In this work, we tried to find new effective approaches to suppress pretilt angle in which an RM is mixed in the LC and UV is applied after the LC cell is made. With this approach, we improve the black-level light leakage intensity on diagonal viewing angles with newly proposed IPS LC mode having the pretilt angle of zero. In addition, the dependency of pretilt angle on the light leakage property of a black level at diagonal viewing angles and also the dark state of an optically compensated IPS LC mode has been investigated.

2. Understanding relationships between a pretilt angle and light leakage in diagonal viewing angles of a black state in IPS LCD

As mentioned above, IPS mode has a unique light leakage property of black level at diagonal viewing angles. Several types of optical configuration of IPS LC mode have been proposed to solve this natural problem of IPS LC mode [17–19]. A few of them are being manufactured as commercial IPS LCDs for various applications. In the IPS mode, the transmittance of light passing through LC (uniaxial medium) is represented as follows:

$$T/T_o = \frac{1}{2}\sin^2 2\alpha_{\mathrm{eff}}(\varphi,\theta)\cdot\sin^2\left(\frac{\pi d\Delta n_{\mathrm{eff}}(\varphi,\theta)}{\lambda}\right) \quad (1)$$

where $\alpha_{\mathrm{eff}}(\varphi,\theta)$ is the angle between the direction of the incident polarised light and the optical axis of the uniaxial LC media, $\Delta n_{\mathrm{eff}}(\varphi,\theta)$ is effective birefringence of the LC medium dependent on the azimuthal (φ) and polar (θ) angles of an incident light with respect to the substrate normal direction and λ is the wavelength of the light. One can easily understand that as the pretilt angle (θ_p) is changed, the effective birefringence of the LC at diagonal viewing angle is changed. Consequently, the light leakage intensity of a black level at certain viewing angles is also changed. In general, as the θ_p increases, the light leakage intensity of black level also increases because of increase in Δn_{eff} at certain diagonal viewing angles.

To analyse the quantitative effect of the θ_p on viewing angle characteristics in IPS mode, we calculated the black-level luminance distributions of both optically compensated and non-compensated IPS cell using a commercially available LCD optic simulator (Techwiz LCD 1D, Sanayi CO., Incheon, South Korea). In non-compensated LC cell, the LC layer with triacetylcellulose (TAC) film at both sides exists between crossed polarisers (PVA[Poly Vinyl Alchol] layers). In the optically compensated IPS cell structure, we used two optical compensation layers with positive C plate ($n_x = n_y < n_z$) and positive A plate ($n_x > n_y = n_z$) on top layer of LC cell, as indicated in Figure 1. Here, two-domain IPS cell was considered. An LC with physical properties (birefringence Δn = 0.1030 at 550 nm, dielectric anisotropy $\Delta\varepsilon$ = 7.6 at 1 kHz, 20°C) was used, and the cell gap was 3.4 µm. The birefringence of each optical layer was given as follows: The positive C plate has birefringence n_x = 1.5139, n_y = 1.5113 and n_z = 1.6226; the positive A plate has birefringence n_x = 1.5315 and n_y = n_z = 1.5292; the TAC film has birefringence n_x = 1.4778, n_y = 1.4777 and n_z = 1.4769. The thicknesses of positive C plate, positive A plate and TAC are 1.2, 58 and 40 µm, respectively. The black

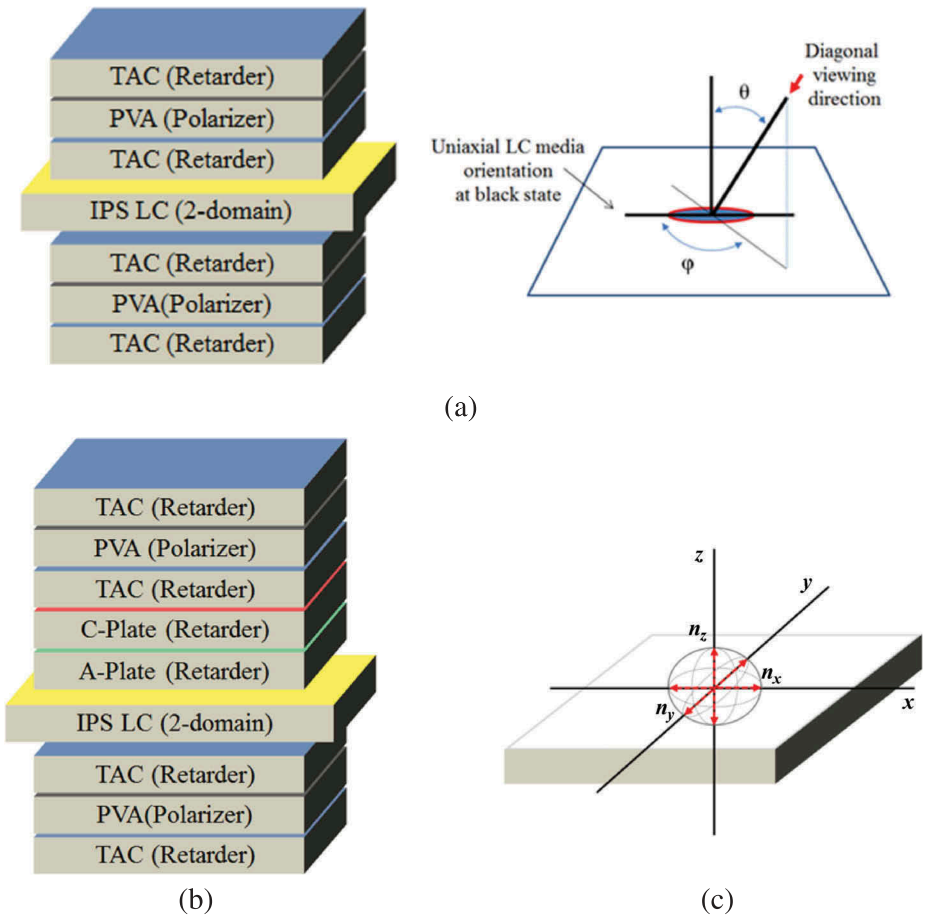

Figure 1. (Colour online) (a) Optical structure of normal IPS LCD and definition of viewing angle (azimuthal angle φ and polar angle θ), (b) optical structures of optically compensated IPS LCD and (c) definition of its optical axis.

luminance distributions were simulated at a wavelength of 550 nm.

Figure 2 shows simulation results of viewing angle-dependent iso-luminance curves at black level for non-compensated and compensated IPS cell. For non-compensated cell structure (see Figure 2(a,b)), the light leakage intensity of the cell with θ_p = 0° is two to three times less than that of LC cell with θ_p = 1.5° in diagonal viewing angles (θ = 70°, φ = 45° and 135°). Even in optically compensated cell structure, the light leakage intensity of LC cell with θ_p = 0° is two to five times less than that of LC cell with θ_p = 1.5° at diagonal viewing angles (θ = 70°, φ = 225° and 315°), as shown in Figure 2(c,d). Furthermore, the viewing angle dependence of the light leakage in LC cell with θ_p = 0° is more symmetric than that of LC cell with θ_p = 1.5°. These results indicate that black-level light leakage intensities at all diagonal angles and asymmetry of black-level light leakage intensities at diagonal viewing angle are drastically increased as θ_p increases. Therefore, in the IPS mode, realisation of low pretilt angle is a very important technology for improving diagonal viewing angle picture qualities.

In general, IPS LCDs with conventional rubbing process have a θ_p of about 1–2°. It is well known that LC director profiles (anchoring level and pretilt angle) at rubbed surface area of homogenously aligned LC mode are mainly related to both the chemical structure and the physical morphology of rubbed surface [20–24]. And until now, it has been difficult to control the pretilt angle to almost zero level with the present rubbing process because of the limitations of material structure and process conditions. On the other hand, polymer-stabilised vertical alignment (PS-VA) LC mode with a pretilt control method utilising RM was commercialised and got the spotlight in commercial LCD technology because of its unique and good electro-optic properties [3,4]. In the PS-VA mode, the LC alignment can be controlled with the help of a polymer layer formed on the surface of the substrate.

In this study, we doped RM into LC mixture [25,26] and irradiated UV once the mixture formed a homogeneous alignment. Then we focused on understanding

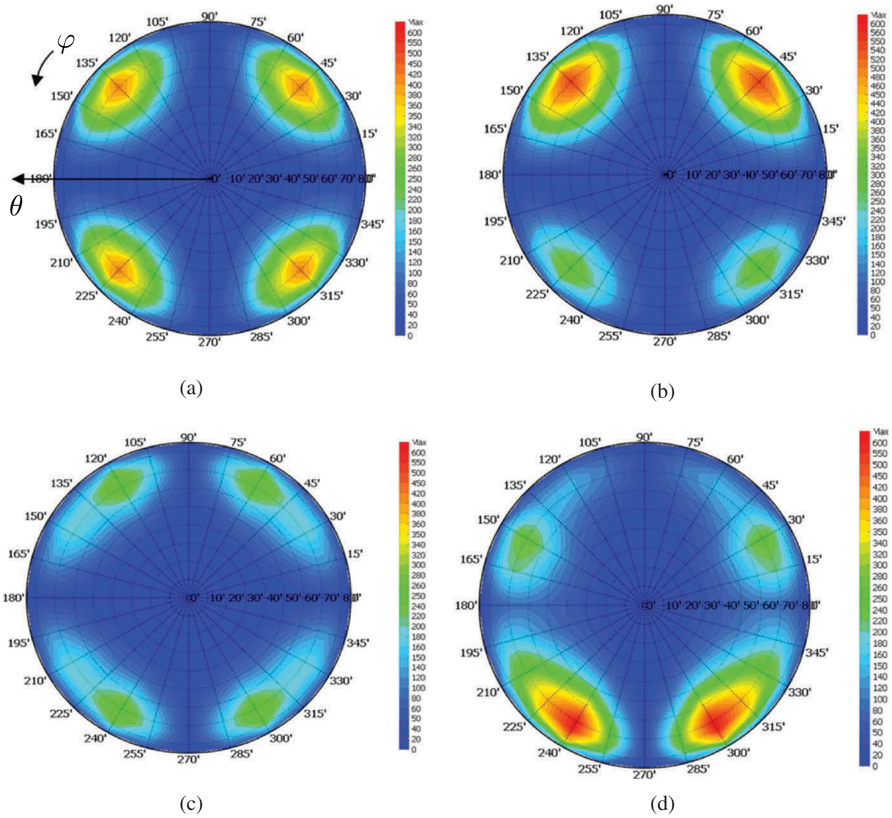

Figure 2. Calculated iso-luminance curves in a black state: (a) normal IPS mode with $\theta_p = 0°$, (b) normal IPS mode with $\theta_p = 1.5°$, (c) optically compensated IPS mode with $\theta_p = 0°$ and (d) optically compensated IPS mode with $\theta_p = 1.5°$.

of the phenomenon how the RM material with UV radiation process could affect the surface morphology of both top and bottom substrate surfaces of LC cell and θ_p. In addition, we also studied the surface morphology and θ_p depending on the structures of RMs, and finally we tried to develop a new method to make almost zero pretilt angle in IPS cell with PS process.

3. Experimental conditions

In order to make a low pretilt angle IPS LC cell with PS process, the cell with a simple electrode structure is prepared, as shown in Figure 3(a). The test cell size is 4.5×3.0 cm^2 with its active area 2.0×2.0 cm^2. And, one sub-pixel size is 300 μm × 100 μm. Come-like electrodes in the active area have wedge shape for two domains with 20° with respect to the vertical axis. All common electrodes are connected to common (V_{com}) signal pads, and all data electrodes are connected to data signal pads. Both electrodes made of indium tin oxide (ITO) exist on bottom glass substrates and an additional ITO layer is prepared on the upper layer of the top glass to prevent static electricity damage. To maintain the cell gap of the LC cell, column spacers are used on the whole area of the test cell. A commercially available IPS alignment material (JALS-3031, Japan Synthetic Rubber, Japan) is used for homogeneous alignment of the LC, and the rubbing process followed by anti-parallel rubbing with adoptable rubbing process on each top and bottom glasses.

For a host LC, a superfluorinated LC mixture with physical properties (MAT-09–190 Merck, birefringence $\Delta n = 0.1030$ at 589 nm, dielectric anisotropy $\Delta\varepsilon = 7.6$ at 1 kHz, 20°C) is used and the cell gap is 3.4 μm. Two kinds of commercially available RM materials RM-A and RM-B (Merck Advanced Technology, Korea) were used. Each RM is doped into host LC with 0.5 wt.% and RM-B doped host LC with 0.5 wt.%. RM-A and RM-B materials are UV-reactive materials which have almost similar chemical structure with acrylic functional groups, however, chemical structure of UV-reactive functional group differs each other.

The PS process is performed with UV light radiation after cell assembly process. For the PS process, we used a UV radiation equipment LC8 (Hamamatsu Co., Iwata, Japan Power 45 mW/cm^2) with non-polarised light source with proper time conditions. Its main peak wavelength is 365 nm. After the UV irradiation process to the test cells with different radiation conditions (0J, 6J, 9J and 18J) for two different kinds of RM materials (RM-A and RM-B), the pretilt angle of each surface of the top and bottom layers was measured by an optical analysis

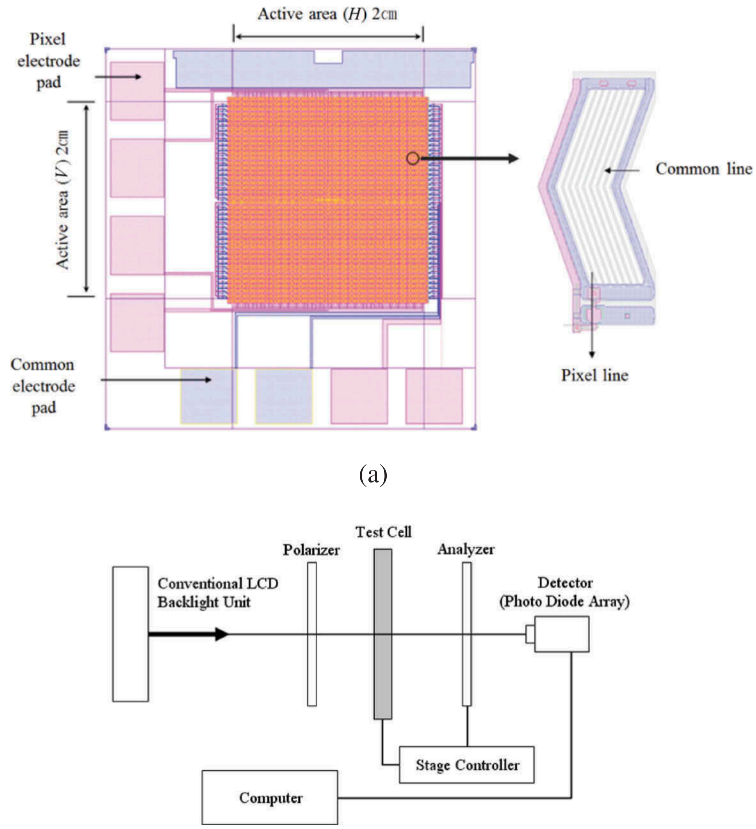

Figure 3. (Colour online) (a) Schematic electrode structure of the IPS test cell and (b) a brief schematic system for measuring transmittance in black state of IPS cells used for measuring black level and other electro-optic properties.

system (Axoscan, Axometrics, Huntsville, AL, USA). As shown in Figure 4(a–c), to compare the reactivity between RM-A and RM-B materials, the residual RM monomer concentrations (%) were quantitatively analysed by gas chromatography–flame ionisation detector (GC-FID) analysis at various UV dosage conditions. At first, we cut the bottom glass of de-capped test cells for GC-FID sample preparation after different UV irradiation process (0J, 6J, 9J and 18J). The sample size is 1.0 ° 1.0 cm^2. And then, the surface of sample glass was washed by 1000 μl of methylene chloride (MC) for sampling LC–RM mixture. This diluted LC–RM mixture solution was diluted again with 1500 μl of MC, and then 1 μl of diluted solution sample was injected for GC-FID analysis. Because a quantity of each LC component in LC–RM mixture sample does not change after UV process, we normalised residual RM's quantity on the basis of normalised peak intensity of RM material compared with peak intensity of one LC component. And, we calculated residual RM content at each UV condition by calculating a relative quantity ratio of normalised peak intensity of RM compared with normalised peak intensity of no UV radiation condition. As shown in Figure 4(d), the RM-B's reactivity for UV radiation is 6.3 times higher than the RM-A's reactivity at UV 6J condition. Furthermore, no RM-B peak is detected at UV 18J condition, however, 44.2% of non-reacted RM-A still remained at the sample at UV 18J condition.

For measurements of electro-optics properties (response time, voltage vs. transmittance curve), the electro-optics measurement system (PX-03) was used. For measurements of luminance in a black state, a brief schematic system is shown in Figure 3(b). A general LCD backlight system with a proper spectrum was irradiated to the LC cell while the best dark state was achieved by rotating the LC cell and the analyser once the polariser axis and LC's optic axis were fixed to be coincident each other at first. The outgaining light intensity in the normal direction of the test cell was measured using a luminance detector.

4. Results and discussion

At first, we attempted to clarify the correlation between PS conditions and pretilt angle change at IPS LC cell. Table 1 shows pretilt angle changes for RM-A and RM-B materials according to each UV radiation condition. In the case of process conditions with RM-A, polymer-

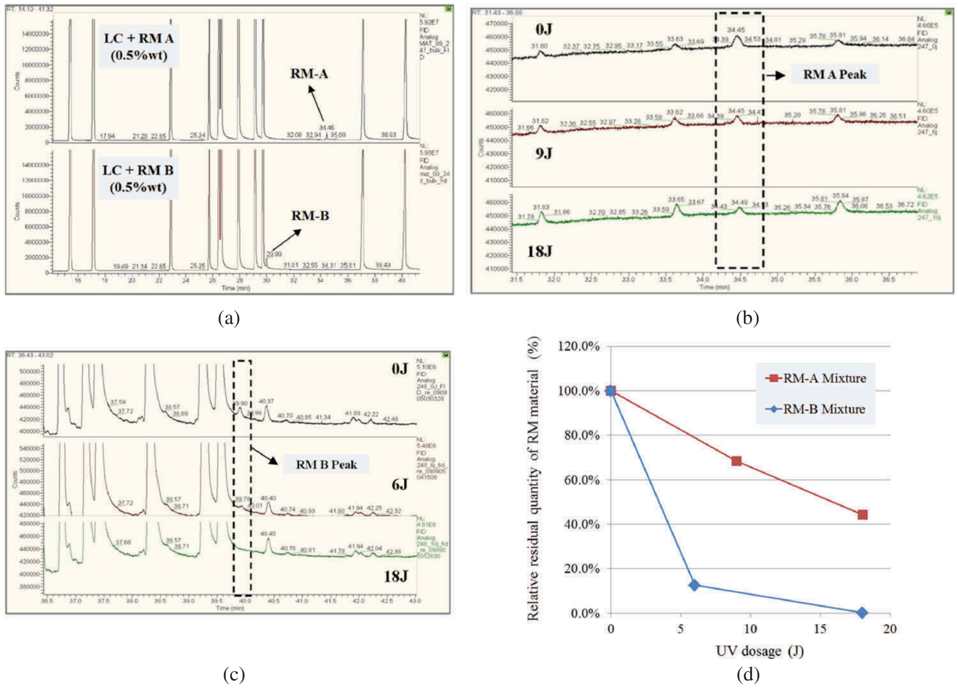

Figure 4. (Colour online) GC-FID analysis results for residual RM material concentration after UV radiation process: (a) relative peak positions of RM-A and RM-B in LC mixture, (b) relative peak intensity of residual RM-A material at 0J, 9J and 18J UV radiation conditions, (c) relative peak intensity of residual RM-B material at 0J, 6J and 18J UV radiation conditions and (d) UV dosage-dependent relative residual RM material concentration plots for estimating RM reactivity.

Table 1. The result table of pretilt angle change in the PS-IPS process with RM-A and RM-B materials.

		Pretilt angle after UV radiation with RM-A (top surface/down surface)			Pretilt angle after UV radiation with RM-B (top surface/down surface)		
	Pretilt angle of ref. (°/°)	UV 6J	UV 9J	UV 18J	UV 6J	UV 9J	UV 18J
Sample 1	1.47/1.47	1.54/1.65	1.64/1.61	1.67/1.87	0.01/0.04	0.03/0.01	0.01/0.04
Sample 2	1.61/1.63	1.43/1.65	1.52/1.65	1.77/1.45	0.06/0.08	0.00/0.02	0.06/0.08
Sample 3	1.51/1.17	1.67/1.76	1.61/1.80	1.34/1.64	0.03/0.07	0.04/0.04	0.03/0.07
Sample 4	1.47/1.15	1.34/1.78	1.31/1.45	1.76/1.91	0.01/0.06	0.05/0.05	0.01/0.06
Average	1.52/1.36	1.49/1.71	1.52/1.63	1.64/1.71	0.03/0.06	0.03/0.03	0.03/0.06

stabilised IPS (PS-IPS) LC cells showed no changes in pretilt angle for all UV radiation conditions. On the contrary, in the PS formation process with RM-B, all PS-IPS LC cells showed almost zero pretilt angle irrespective of UV radiation conditions (6, 9 and 18J). With this result, we could confirm that a certain RM material with PS process could change the surface pretilt angle of homogenous alignment layer.

In a previous work [16], the mechanism of pretilt angle change at the PS process was proposed that the unidirectional striped morphology may enhance the azimuthal anchoring energy because directionally polymerised RMs on the surface can induce strong interactions with LC. The shift in voltage-dependent transmittance (V-T) curves was suggested to explain their proposed mechanism. Therefore, we also analysed the electro-optic properties of PS-IPS LC mode to check if a surface anchoring energy change happened. Comparison of response time (rising time/falling time), black luminance and V-T curves were measured. Response time of PS-IPS LC cell from black to white was compared with that of normal IPS LC cell. Surprisingly, as clearly shown in Figure 5 and Table 2, the result indicates that there is no change in response times compared to normal IPS LC cell. Also, we found that there were no changes in V-T curves such as threshold voltage, maximum driving voltage and maximum transmittance. The maximum driving voltage for full white level is 5.8 V and the response times (T_{on}/T_{off}) are 36.1–36.5 ms in the PS-IPS LC cell, while it was 5.8 V and 36.1 ms, respectively, in normal IPS LC cell. In the black-level luminance, two cases had almost the same level, that is, 1.17 nit and 1.19–1.23 nit for each normal and PS-IPS LC cells, respectively. With

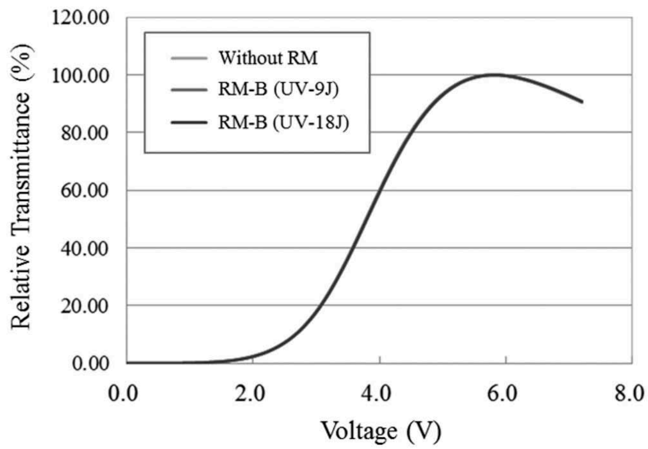

Figure 5. Voltage-dependent transmittance curves of conventional rubbed IPS cell and PS-IPS cells.

Table 2. Comparison of measured electro-optic properties between normal LC cell and PS-IPS LC cell with RM-B material.

	Ref.	Condition A	Condition B
Active mesogen	None	RM-B	RM-B
UV intensity (J)	None	9	18
V_{max} (V)	5.8	5.8	5.8
T_{on}/T_{off}/response time (ms)	13.2 /22.9 /36.1	14.7 /21.8 /36.5	13.5 /22.6 /36.1
Black-level luminance (nit)	1.17	1.23	1.19
Full white luminance (nit)	1013	1045	1032
Contrast ratio	865	850	867

these results, we understand that newly proposed PS method in which UV irradiation was performed to the LC and RM mixture after the cell assembly could make an IPS LC cell with almost zero pretilt angle and without any electro-optical changes caused by azimuthal anchoring energy, unlike those in the previously proposed method.

Also, we measured the iso-luminance curves of the light leakage in a black state for normal LC cell and PS-IPS LC cell with RM-B in order to confirm low pretilt angle effect on viewing angle qualities of a black state. Measurements were performed with a proper optic measurement system (EZ Contrastratio, ELDIM, Herouville Saint Clair, France). Both normal IPS cell and optically compensated PS-IPS cell with positive A and positive C plates were used for measurements. As shown in Figure 6, the decrease in light leakage can be observed along the diagonal directions with respect to the transmission axes of the crossed polariser. The light leakage at polar angles of −60° to −50° and azimuthal angles of ±45° in PS-IPS LC cell is two times lower than that of normal LC cell. And, the viewing angle dependence of the light leakage in PS-IPS LC cell is more symmetric than that of normal LC cell. This result is also well matched with the calculated black state luminance distribution shown in Figure 2.

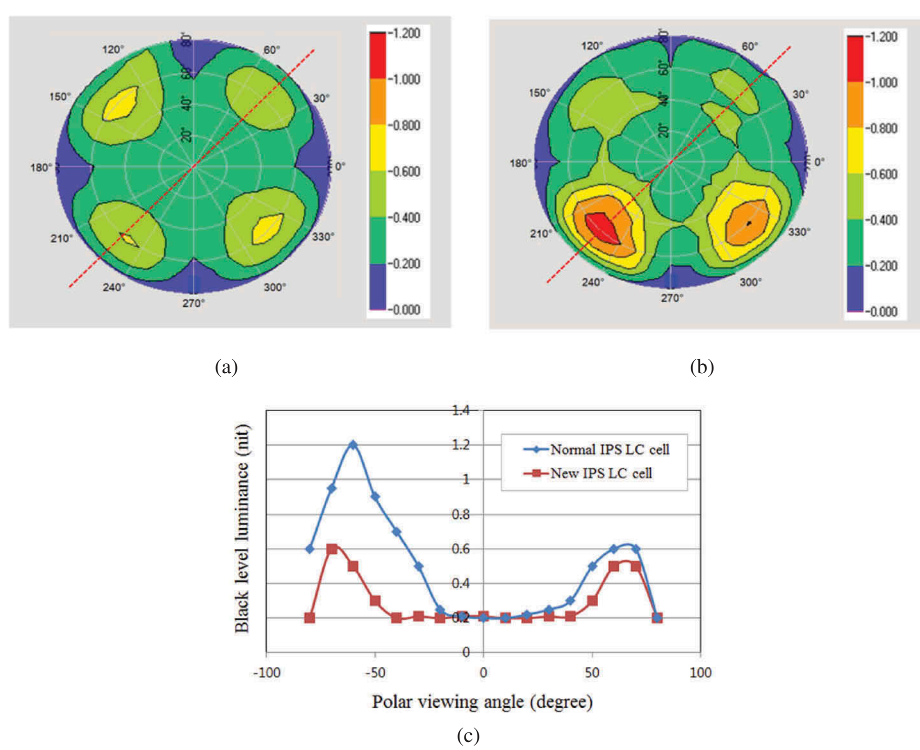

Figure 6. Iso-luminance contours of black-level luminance at all diagonal viewing of (a) optically compensated PS-IPS cell with pretilt angle of 0.03° and (b) optically compensated normal IPS LC cell with pretilt angle of 1.56°. (c) Its comparison of black-level luminance according to all polar viewing angles (−80° to 80°) at an azimuthal angle of 45°.

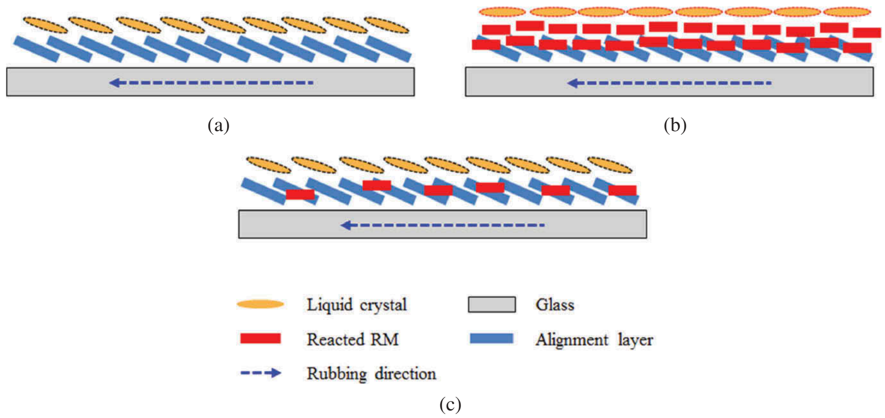

Figure 7. (Colour online) A brief figure of LC's pretilt formation (a) with normal rubbing process, (b) with PS process with RM-B material and (c) with PS process with RM-A material.

Finally, we try to explain the possible mechanism for pretilt angle change in the newly proposed method. Previously, we mentioned that only rubbing process (contact alignment) made high pretilt angle in homogenous LC alignment method. Otherwise, non-contact process (UV alignment) makes almost zero pretilt angle. In general, RM makes new layer at surface of alignment layer during PS process with LC–RM mixture [27]. As well known, polymerised RMs on alignment surface produce the surface ordering to same direction of homogeneously aligned alignment surface with same or higher optical anisotropy value compared with original alignment surface [28]. Also, various approaches have been used to control LC pretilt angle using vertical and planar alignment material mixture system [29,30], and it is well known that thickness of the blend film and of pure alignment film affected their surface energy and pretilt angle at two alignment materials system [31]. With this previous work, we explained the possible mechanism of our works. Basically, RM materials in LC mixture move to the surface of alignment layer and makes polymer network formed by RM at alignment layer surface during UV curing process. This UV-induced new layer is aligned at rubbed Poly Imide(PI) surface by non-contact method. So, there is possibility that new layer makes lower pretilt angle. And if its thickness is high enough, new layer can fully cover rubbed alignment layer surface. As a result of this phenomenon, new process can make zero pretilt angle. However, if its thickness is not enough, new layer cannot change pretilt angle. As schematically shown in Figure 7, RM-A cannot cover fully rubbed alignment layer surface because of its low UV reactivity, whereas RM-B fully covers the surface of alignment layer, suppressing pretilt angle.

To confirm a proposed mechanism of zero pretilt angle formation and a reason for the different results of pretilt angle change between RM-A and RM-B, we investigated the surface morphology of the normal LC cell and PS-IPS LC cells with RM-A and RM-B using scanning electron microscope (SEM). The scales of all images were set to be identical for proper comparison of the morphology differences. We also analysed the atomic force microscopy of each LC cell to check exact surface roughness change. The root mean square roughness values for PS-IPS cells with RM-A and RM-B condition are 14.7 nm and 17.8 nm, while it was 0.37 nm in normal condition. In addition, SEM images on surface morphology of LC cell appear clearly different, as shown in Figure 8. As compared with the surface of normal LC cell, the PS-IPS LC cell with RM-A and RM-B exhibited noticeable surface shape changes on alignment layer surface. However, as compared with the surface of the PS-IPS LC cell with RM-B, the surface shape changes of PS-IPS LC cell with RM-A happened partially on the alignment surface. On the contrary, in case of RM-B condition, the surface shape changes fully happened over whole surface area. In addition, we also investigated the cross-sectional SEM image for normal cell and PS cell with RM-A and RM-B. As shown in Figure 9, noticeable thickness change was observed only at surfaces of LC cell in RM-B condition. On the contrary, no thickness change was observed at LC cell in normal and RM-A conditions. This result indicates that additional new layer is formed between LC and alignment layer, and this new layer can change physical morphology of PI surface. In summary, these results indicate that RM creates a new layer on the whole surface of alignment layer by sufficient reaction with UV light, and this physical morphology change by a new layer can induce balanced surface interaction in polar anchoring direction with LC. This balanced surface interaction in polar direction can make zero pretilt angle without changing azimuthal anchoring energy, that is, only pretilt angle change occurred without changes in electro-optic properties. However, PS-IPS LC cell with RM-A condition could not make a new layer on the surface of alignment layer because of its low reactivity with

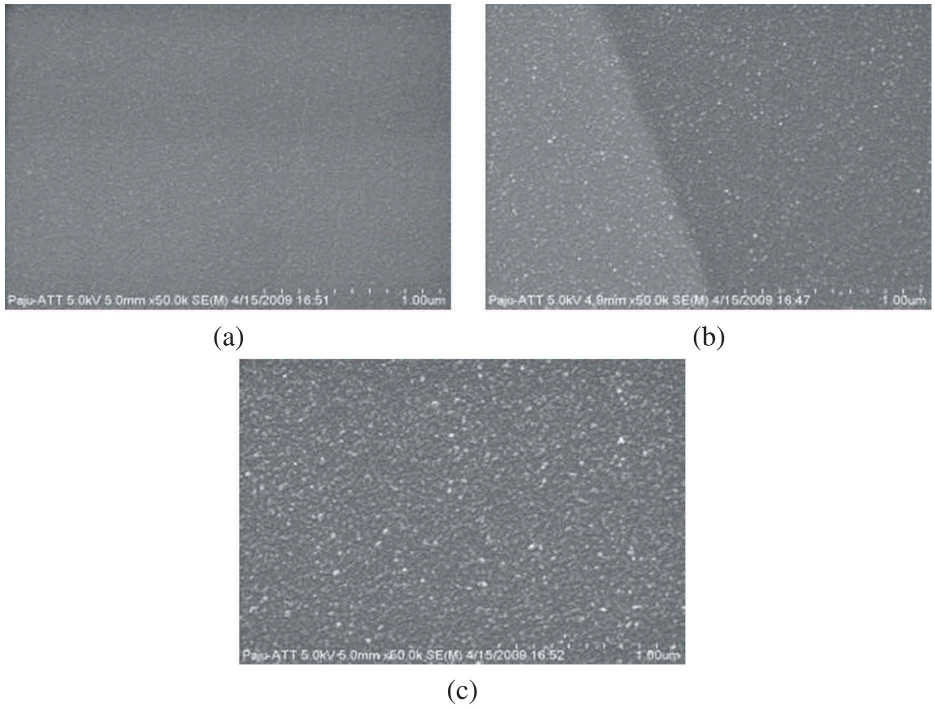

Figure 8. (Colour online) SEM images of alignment layer surface on bottom glass after cell assembly for each process conditions: (a) normal IPS cell surface without PS process, (b) PS-IPS cell with RM-A mixture at 18J of UV irradiation condition and (c) PS-IPS cell with RM-B mixture at 9J of UV irradiation condition.

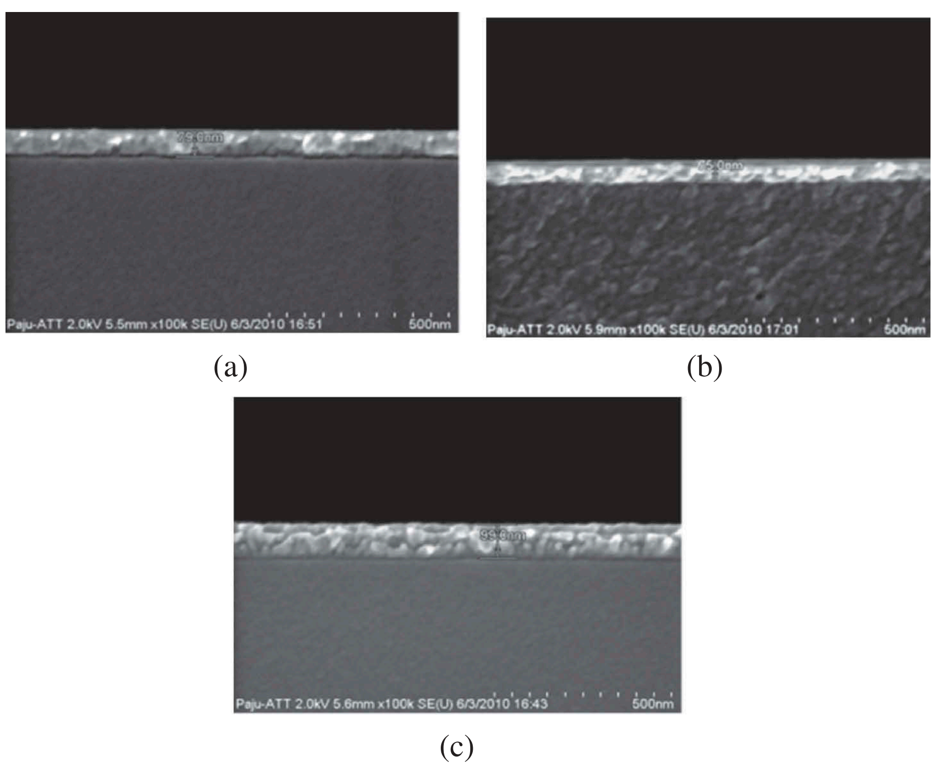

Figure 9. SEM images of cross-sectional view of alignment layer on bottom glass after cell assembly for each process conditions: (a) normal IPS cell surface without PS process (thickness of alignment layer: 790 □), (b) PS-IPS cell with RM-A mixture at 18J of UV radiation condition (thickness of alignment layer: 750 Å) and (c) PS-IPS cell with RM-B mixture at 9J of UV radiation condition (thickness of alignment layer: 990 Å).

UV light. As a result, it is insufficient for changing physical property on surface. This concludes that only sufficient surface change with new layer formation can result in physical change on the alignment layer surface. At last, we could propose possible mechanism that new layer could change the polar anchoring energy [32] without change in azimuthal anchoring energy so that zero pretilt angle is generated, but no changes in electro-optical properties such as response time and V-T curve, which is associated with azimuthal anchoring energy, are observed, as shown in Figure 10. Before UV irradiation, RM molecules are uniformly distributed in LC layer, and thus LC on PI surface makes pretilt angle to polar direction due to physical non-uniform morphology caused by rubbing direction. After UV irradiation, RM molecules move to PI surface and then forms a new layer on PI surface, which makes physical morphology of the PI surface uniform to polar direction, giving rise to zero pretilt angle.

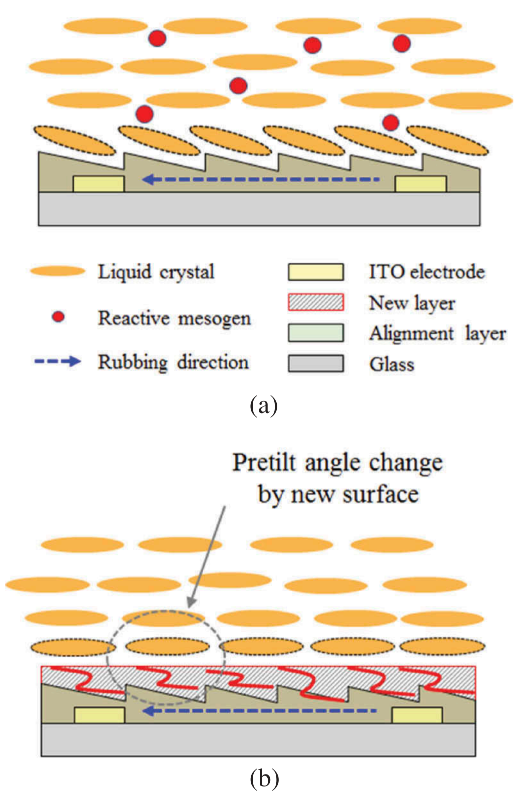

Figure 10. (Colour online) A brief mechanism of low pretilt formation with PS-IPS LC mode. (a) Before UV irradiation, RM molecules are uniformly distributed in LC layer and thus LC on PI surface makes pretilt angle to polar direction due to physical non-uniform morphology caused by rubbing direction. (b) After PS process by UV irradiation, RM molecules move to PI surface and then forms a new layer on PI surface, which makes physical morphology of the PI surface uniform to polar direction, giving rise to zero pretilt angle.

5. Conclusion

Conventional IPS LC mode with the present rubbing process has a relatively high pretilt angle property. We found a new method to make IPS LC mode with almost zero pretilt angle, in which UV is irradiated into host LC and RM mixture and thus RM is polymerised on the surface of alignment layer. The additional polymer layer formed by RM on the surfaces gives rise to almost zero pretilt angle without changing any electro-optic properties compared to the conventional rubbed IPS cell. The possible mechanism explaining such behaviour is that the additional polymer layer changes only polar anchoring energy but not the anchoring energy. With this approach, we could successfully acquire better viewing angle picture quality at black level as compared with normal IPS LCD.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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