Realization of Vertical Alignment with Low Pretilt Angle by Polymer-Stabilize Technique

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A polymer-stabilized technique with a bias voltage (BPS) combined with a photo-alignment method has been applied for a vertical LC alignment to achieving stable and uniform pretilt angle as low as 80deg. An initially-pretilted vertically-aligned LC medium produced by a photo-alignment method, which is doped with a small amount of UV-curable monomer, is followed by a BPS method for further increase of the pretilt angle. The achieved pretilt angle as low as 80deg, by the combined method is very stable and uniform. This result clearly demonstrates the usefulness of the present BPS method to achieve very low pretilt angle for vertical LC alignment.

Keywords: photo alignment, polymer-stabilized, VA-LC

1. Introduction

A vertically-aligned liquid crystal display (VA-LCD) mode was applied to many liquid crystal displays such as monitors for TV and mobile phone. This is due to its nature of high contrast and wide viewing zone. But this VA display mode has some drawback such that a rubbing method for producing a pretilt angle, which is essential to make a defect-free image in LCDs, is not applicable due to the inevitable creation of scratch defects during the process. [1] For this reason, another LC alignment control method using fringing electric fields, produced by a protrusion and/or a slit structure in a pixel, is widely used to induce a self-organized multi-domain structure. This self-organized structure is very useful to improve the viewing angle performance, but is not applicable to the formation of a uniform single domain structure. In order to produce a defect-free single domain structure in a pixel, a photo-alignment method was use as a LC alignment method for a VA display mode, and its usefulness over a conventional rubbing method was demonstrated. [2,3]

Recently there was a report that a high-performance passive matrix display, called vertically-aligned super-twisted nematic (VA-STN) LCD, could be realized if very low pretilt angle of much as 80deg. could be produced.[4] But even using a photo-alignment method, such a very low pretilt angle with good uniformity and stability was difficult to achieve.[5]

In this paper, to realize a defect-free VA-LCD with low pretilt angle, we investigate the application of a polymer-stabilized (PS) method [6,7] with a bias voltage (a biased polymer-stabilized method; BPS method), and demonstrate the pretilt angle generated by a BPS method has excellent temperature stability and uniformity.

2. Experimental

A vertical alignment layer, which has dense and long surface alkyl-branches (SE-1211 and RN-1338 from Nissan Chem.), was spin-coated on an ITO-coated glass substrate and then it was baked at 200°C for 1 hour. For initiating a bias pretilt angle on a vertical alignment layer, we used

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a photo-alignment method. In the process, a high-pressure mercury lamp was used as a UV light source, which was filtered using a 254nm band-pass filter and was linearly polarized by using a multi-layered dielectric polarizer. A vertical LC alignment layer on an ITO-coated glass surface was exposed to the p-polarized UV light at the incident angle of 45deg. from the substrate normal. A typical UV irradiation energy was 1J/cm². A sandwich-type LC cell with UV-processed two glass substrates was assembled so as to form an anti-parallel LC alignment with a cell gap of about 5.5μm. A LC material used was specially-blended one (Δn=0.19) having a negative dielectric anisotropy (Δε=-2.1). Two kinds of photo-curable monomers of monoaacrylate (A) and diacrylate (B) types were used for forming a polymer network in a LC medium. The concentration of each monomer in a LC medium was varied from 1wt% to 4wt% and we also co-doped a photoinitiator (IRG-907, Ciba-geigy, Inc.) into the LC medium for promoting photo-polymerization, which concentration was 2wt% that of a photo-curable monomer. After the LC mixture was injected into an empty cell in a nematic phase, a BPS method using a UV light of 365nm with the intensity of 32mW/cm² was done for producing low pretilt angle in the cell.

3. Results and Discussions

3.1 Bias Voltage Dependence of Pretilt Angle

In order to determine an appropriate bias voltage used in a BPS method, the dependence of pretilt angle on the bias voltage during a photo-polymerization process was examined and the result is shown in Fig.1, where the monomer B was used and the concentration was 1wt%. In the case that the bias voltage was below the threshold (2.5V), the induced pretilt angle is almost constant and keeps the initial value. A further increase in the bias voltage (>2.5V) induces a gradual decrease in pretilt angle depending on the bias voltage and finally the induced pretilt angle tends to saturate at about 10deg. This dependence semiquantitatively matches the bias voltage dependence of the LC director in the cell. From these results, it is clear that the bias voltages more than 3V is appropriate for producing a low pretilt angle by a BPS method.

3.2 UV Irradiation Energy Dependence of Pretilt Angle by BPS Method

Figures 2 and 3 show the UV irradiation energy dependence of pretilt angle produced by a BPS method with a bias voltage of 6V, where the concentrations of monomer A and monomer B were varied from 1wt% to 4wt%.

In the case that the concentration of monomer A is 1wt% (Fig.2), the pretilt angle shows very weak dependence on the UV irradiation energy and induce pretilt angle is ~88 deg. A further increase in the concentration of monomer A to 2wt% and 4wt% results in decreasing the pretilt angle with UV irradiation energy and the decreasing rate of the pretilt angle was enhanced with the monomer concentration. The maximum achievable pretilt angle using monomer A was about 70deg. as seen in Fig.2.

On the other hand, in the case that the concentration of monomer B is 1wt%, a lower pretilt angle of about 80deg. is obtained as seen in Fig.3. The similar results are also observed in the cases of the monomer concentrations of 2wt% and 4wt%. In the monomer concentration of 4wt%, a drastic decrease in a pretilt angle of about 30deg. is achieved as seen in Fig.3, which is due to the formation of the large amount of polymer networks in a bulk LC layer as discussed later. It is to be noted that monomer B is more effective to lower the pretilt angle than monomer A. This may arise from a difference number of a functional group (acrylate group) between monomer A and B, and diacrylate monomer B could form a firm polymer-network.

The pretilt angle formed by a BPS method also depends strongly on the concentration of a photoinitiator doped into a LC medium, and the result is shown in Fig.4, where LC doped with
monomer B of 1wt% and the UV irradiation energy of 12J/cm² was used. And the concentration of the photoinitiator was estimated from the relative concentration of monomer B. The pretilt angle shows a strong dependence on the concentration of photoinitiator, and the induced pretilt angle decreases as the concentration of photoinitiator increases.

![Figure 2](image)

Figure 2. UV irradiation energy dependence of pretilt angle at an applied voltage of 6V. The concentration of monomer A was varied from 1wt% to 4wt%.

![Figure 3](image)

Figure 3. UV irradiation energy dependence of pretilt angle at an applied voltage of 6V. The concentration of monomer B was varied from 1wt% to 4wt%.

From this result, we can conclude that the faster polymerization, which is promoted by the photoinitiator, induces lower pretilt angle, which may be caused by the difference structure of the polymer network formed in a LC medium. The similar result was also obtained by measuring the UV irradiation intensity dependence of pretilt angle; higher UV intensity irradiation during a BPS process resulted in lower pretilt angle.

From these results, the polymerization rate of monomer is also an important parameter to control the pretilt angle in a BPS method.

![Figure 4](image)

Figure 4. The dependence of pretilt angle on the concentration of the photoinitiator.

3.3 Applied Voltage Dependence of Tilt Angle Produced by BPS Method

Figures 5 and 6 show the applied voltage dependence of pretilt angle for samples with monomer A and B produced by a BPS method, where the UV irradiation energy of 12J/cm² was used during the process.

From the figures, it is clear that the pretilt angle decreases with increasing the applied voltage for all the samples. In the case that the concentration of monomer A is 1wt% (Fig.5), a decreasing rate of the pretilt is very small so that the pretilt angle obtained is about 88deg. even at the applied voltage of 10V. A further increase in monomer concentration to 2wt% and 4wt% produces the lower pretilt angle, that is, 81deg. for 2wt% and 43deg. for 4wt% at an applied voltage of 10V.

On the other hand, use of monomer B is more effective to lower a pretilt angle, which is consistent with the results shown in Fig.2 and 3.

From these results, we can optimize the monomer concentration used in a BPS method, that is, 2wt% for monomer A and 1wt% for monomer B to obtain a low pretilt angle around 80deg.
Figure 5. Applied voltage dependence of pretilt angle. The concentration of monomer A was varied from 1wt% to 4wt%.

Figure 6. Applied voltage dependence of pretilt angle. The concentration of monomer B was varied from 1wt% to 4wt%.

Figure 7 compares photos showing LC alignment texture for a conventional VA sample fabricated only by a photo-alignment method (a) and a VA sample by a BPS method with monomer B (b), where the pretilt angles of two samples are 83.6deg. for (a) and 83.1deg. for (b). From the photos, it is clear that the LC alignment defect observed for a conventional VA sample is drastically improved by using a BPS method, which indicates the usefulness of the BPS method to fabricate defect-free VA samples with a low pretilt angle.

3.4 Temperature Dependence of Pretilt Angle Produced by BPS method

In Fig.8, we compare the temperature dependence of the pretilt angle for a conventional and two BPS samples with monomer A (2wt%) and monomer B (1wt%).

The room-temperature pretilt angles for a conventional sample, a BPS sample with monomer A (A-BPS) and a BPS sample with monomer B (B-BPS), respectively, are 85.5deg., 82.7deg. and 81.4deg. As seen in Fig.8, the pretilt angle of a conventional VA sample is gradually decreased from ~85deg. to ~76deg. as the temperature is increased. On the contrary, for an A-BPS sample, the pretilt angle was gradually increased from ~83deg. to ~87deg. with the sample temperature. The drastic improvement is seen in a B-BPS sample; the temperature dependence of the pretilt angle almost disappears, which contributes to the improvement in the stability of device operation in the B-BPS sample.

Figure 8. Temperature dependence of pretilt angles of a conventional and two BPS-VA samples.
As mentioned above, monomer B is a diacrylate type, which indicates the existence of two photo-cross-linking parts in the monomer and the monomer B may form a firmer polymer-network in a LC medium than monomer A. This firm polymer network formed by monomer B may prevent a large temperature dependence of the pretilt angle.

In Fig.9, we indicate schematic models showing a liquid crystal/polymer network complex formed near a substrate surface. Comparing Figs.8(B) and 8(C), a polymer network formed by monomer A may show a simple one-dimensional network structure, while the network formed by monomer B is two-dimensional.

Since a two-dimensional network structure is considered to be more stable than one-dimensional one, the pretilt angle induced by the two-dimensional structure gives very weak temperature dependence observed in Fig.8.

3.5 Variation in VT curves with monomer concentration

Figure 10 shows the VT curve of BPS-VA-LCDs with different monomer concentrations of 1, 2 and 4wt%, where monomer B was used. It is clear that a BPS-VA-LCD with the lowest concentration of 1wt% provides very low light leakage at a low applied voltage (an off state), and the contrast ratio obtained is very high so that it is over 600. When the monomer concentration is increased up to 2wt%, the light leakage at an off state gradually increases and an ON voltage at which the transmittance starts to increase becomes large. A further increase in the monomer concentration to 4wt% drastically degrades the light leakage at an off state with increasing the ON voltage of the sample.

The above results indicate that the concentration of monomer B more than 2wt% degrades the device performance of BPS samples and thus the monomer concentration of 1wt% is the optimum for obtaining BPS-VA-LCDs with a good contrast ratio.

In order to investigate the reason why the VT curve degrades with increasing the monomer concentration, we observed the microscopic texture of the BPS-VA-samples.

Figure 9. Schematic drawings showing LC alignment near the substrate surface: (A) conventional VA, (B) BPS-VA with monomer A, and (C) BPS-VA with monomer B.

Figure 10. VT curves of BPS-VA-LCDs for three different acrylate monomer concentrations of 1, 2 and 4wt%.
Figure 11 shows the results for three BPS-VA samples with the monomer concentrations of 1 (a), 2 (b) and 4wt% (c). It is seen that, by increasing the monomer concentration up to 2wt%, some inhomogeneous texture starts to appear and the texture is more clearly seen with a further increase in the monomer concentration of 4wt%. This texture may indicate the formation of the polymer network in LC bulk region, which impedes the LC director motion during the voltage application and also causes a light scattering.

Figure 11. Microscopic textures of BPS-VA-LCDs (1, 2 and 4wt%) in the off state.

4. Conclusion
A polymer-stabilized technique with a bias voltage (BPS) combined with a photo-alignment method was applied for a vertical LC alignment to achieving stable and uniform pretilt angle as low as 80deg. An initially-pretilted vertically-aligned LC medium produced by a photo-alignment method, which is doped with a small amount of UV-curable monomer, is followed by a BPS method for further increase of the pretilt angle. Two types of UV-curable monomers were examined for a BPS method, and it was clarified that a monomer of diacrylate type was more effective to produce low and stable pretilt angle than monoa crylate type. Throughout this study, it was clearly demonstrated the usefulness of the present BSP method to achieve very low pretilt angle for vertical LC alignment.

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