Photo-stable Azo Dye Photoalignment Polymer Surface for In Plane Switching Liquid Crystal Displays

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Abstract

A photo-stable azo dye photoalignment surface for liquid crystal is proposed and demonstrated. The alignment surface has a structure of stacking a thin photo-polymerisable liquid crystal polymer on top of an azo dye photoalignment layer. The liquid crystal polymer acts as a passivation layer for the azo dye alignment layer. The alignment direction of the azo dye cannot be rewritten once the liquid crystal polymer is polymerized. Hence, the synthetic alignment surface is robust, highly reproducible and has excellent stability. In addition, measurement results show the alignment properties of this synthetic alignment surface are comparable to conventional polyimide. As a result, the proposed alignment layer is suitable for in plane switching liquid crystal display which requires high anchoring energy and very small residual direct current.

1. Introduction

Photoalignment surfaces for liquid crystal (LC) alignment have been being attractive to the researchers and manufacturers in recent years. Photoalignment have shown not only promising alignment properties as traditional rubbed polyimides, but also many advantages of replacing mechanical rubbing [1-4]. First, photoalignment has a better uniformity as it avoids mechanical rubbing defect lines and static charging problem created by the rubbing cloth. Second, photoalignment can be applied to non-uniform substrate as it does not require direct contact. Third, multi-domains display can be easily fabricated by exposing photoalignment material with a patterned mask. Hence, many applications have been made available by the advancing of photoalignment materials, e.g. PVA, microdisplay, optical communication devices and etc.

One of the commonly used photoalignment materials is azo dye. Azo dye is one of the azo compounds and as a consequence of pi-delocalization, the azo dye has vivid colors. Like the azobenzene, azo dye also experiences the photoisomerization of trans and cis isomers. Hence, the azo dye molecules can be oriented by using linearly polarized ultraviolet light easily. Many previous publications have shown that these azo compounds have excellent alignment properties for liquid crystal molecules [5-8], for example, thin alignment layer, low exposure dose, good thermal-stability, high anchoring energy, small residual direct current and large voltage holding ratio. However, the main problem of azo dye is the stability problems, especially the poor photo-stability [9]. Unlike the photo-crosslinkable materials, the alignment direction of azo dye can be reoriented due to the reversibility of the photoisomerization. Although such rewritable phenomenon can be used by some e-paper applications [10], it is unfavorable for most of the liquid crystal displays and is needed to be avoided.

In this work, we demonstrate a photo-stable azo dye photoalignment surface for liquid crystal devices. The alignment surface has a structure of stacking a thin photo-polymerisable liquid crystal polymer (LCP) on top of an azo dye photoalignment layer. The liquid crystal polymer acts as a passivation layer for the azo dye photoalignment layer. The alignment direction of the azo dye cannot be changed once the liquid crystal polymer is polymerized. Hence, this synthetic alignment surface is robust, highly reproducible and has excellent stability, including photo-stability, thermal-stability and aging-stability. In addition, measurement results show the alignment properties of this synthetic alignment surface are comparable to conventional polyimide. As a result, the proposed alignment layer is suitable for in plane switching liquid crystal display which requires high anchoring energy and very small residual direct current in order to have fast response time and avoid image sticking.

2. Azo Dye Photoalignment with Passivation

The structure of the proposed alignment surface is shown in Figure 1. The alignment surface consists of two layers stacked together. The bottom layer is an azo dye photoalignment polymer which is indicated by red color. In addition, there is a thin photo-polymerisable liquid crystal polymer continuously covered on top and is indicated by blue color. The photo-polymerisable liquid crystal polymer layer acts as a passivation layer for the azo dye photoalignment polymer. This passivation layer should be as thin as possible to avoid the birefringence effect and affect the alignment quality. However, the layer needs to completely cover the bottom layer and cannot occur dewetting.

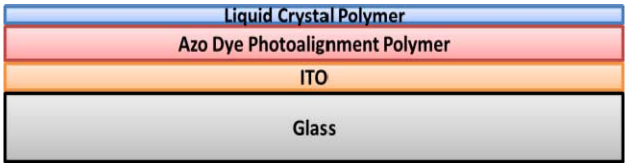


Figure 1. An overview of the proposed alignment layer.

We used SD1, a commercial azo dye photoalignment polymer provided by DIC Corporation, Japan, as our photoalignment material. Figure 2 shows the chemical structure of the SD1 molecule. The azo dye photoalignment material SD1 has the nature of reorientation to the direction perpendicular to the polarization of ultraviolet light, which peaks at 372nm and can be extended to 450nm. The lowest exposure dose is about 0.4J/m^2 to form the orientation direction of the nematic liquid crystal molecules. Despite of the poor photo-stability, SD1 can give very good alignment properties to liquid crystal molecules. For the liquid crystal polymer, we used a reactive mesogen (RM) material RM257 provided by Merck Corporation, Germany. Reactive mesogens are polymerisable liquid crystals. The liquid crystalline monomers carry, for example, reactive acrylate end groups, which polymerize with one another in the presence of photo-initiators and ultraviolet light to form a rigid network. The orientation of the liquid crystal molecules is fixed after photo-polymerization due to the mutual polymerization of their groups. It has been proven that these reactive mesogens liquid crystal polymers are extremely unreactive, inert and highly resistance to heat. Hence, it is the best material for passivation.

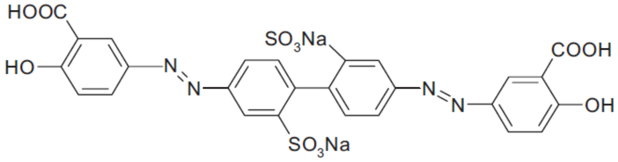
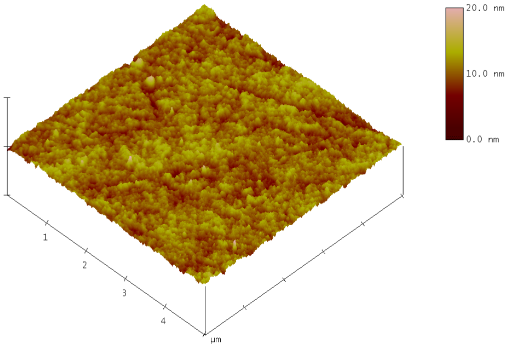


Figure 2. Chemical structure of azo dye photoalignment material SD1.

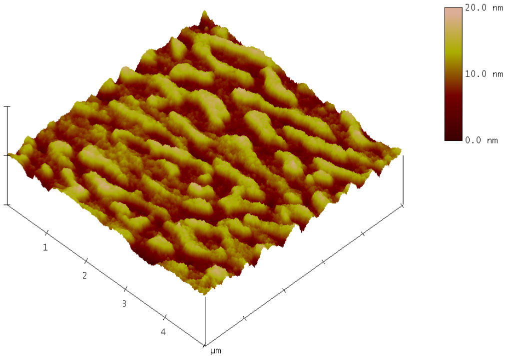
3. Experimental Results

The following describes the details of the fabrication procedures of the proposed alignment surface. Firstly, a 1wt% concentration SD1 was dissolved in Dimethylformamide solvent and spin coated on a well cleaned ITO glass substrate. The substrate was soft-baked on a 150˚C hot plate for 10 minutes. The substrate was then exposed under a polarized blue LED light source to orient the SD1 molecules. The alignment direction would be orthogonal to the polarization direction of the blue LED. Secondly, reactive mesogen material RM257 with photo-initiator 2,2-Dimethoxy-2-phenyl-acetophenone was dissolved in toluene solution. Five samples with different concentrations of RM257 (0.0625wt%, 0.125wt%, 0.25wt%, 0.5wt% and 1wt%) had been tested. The mixed solutions were further spin-coated on top of the aligned SD1 layer to act as the passivation layer. After spin coating, the reactive mesogen was polymerized by a linearly polarized UV lamp with 310nm wavelength for 10 minutes immediately. The power of the UV lamp was 6mJ/cm^2 and the polarization direction should be perpendicular to the bottom SD1 alignment direction. Finally, the substrate was soft-baked on a 60 ˚C hot plate for 10 minutes to dry out the residual solvent.

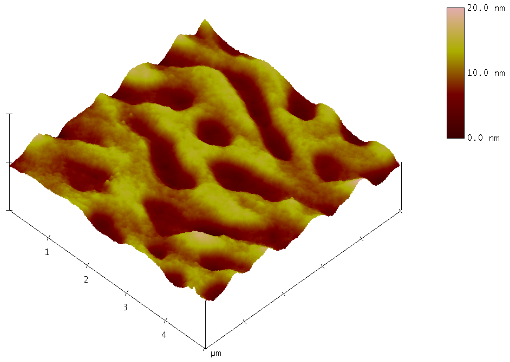
In order to verify the continuity of the passivation thin film, atomic force microscope (AFM) pictures had been captured with the four concentrations of RM257 and are shown in Figure 3. The scan size is 5um x 5um. The bright area corresponds to the peak while the dark area corresponds to the trough. From Figure 3(a), the RM257 film cannot be observed and the AFM picture shows the profile of bottom SD1 alignment layer only. As the concentration of RM257 increases, the thickness of RM257 film is also increased accordingly. However, discontinuous patterns can be clearly seen from Figure 3(b) and 3(c); the coated films were unstable and dewetting occurred. In other words, the concentrations of RM257 were insufficient. As the concentration achieve 0.5wt%, the RM257 film continuously cover the bottom SD1 layer. The thickness of the corresponding 0.5wt% RM257 film was measured by an ellipsometer and found to be about 13nm on average. Though the surface is not completely flat, the surface roughness of the profile is found to be less than 8nm from the AFM picture. Hence, it can be concluded that the 0.5wt% RM257 film is continuously stacked on top of the SD1 alignment film. For Figure 3(e), it shows that the 1wt% RM257 film fully cover the bottom SD1 layer and the thickness of the RM257 film was measured which is about 20nm.



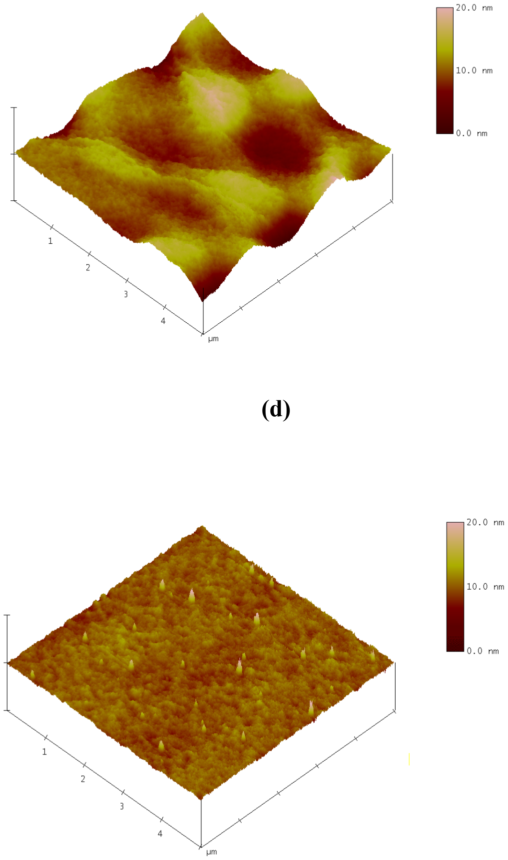
(a)



(b)



(c)

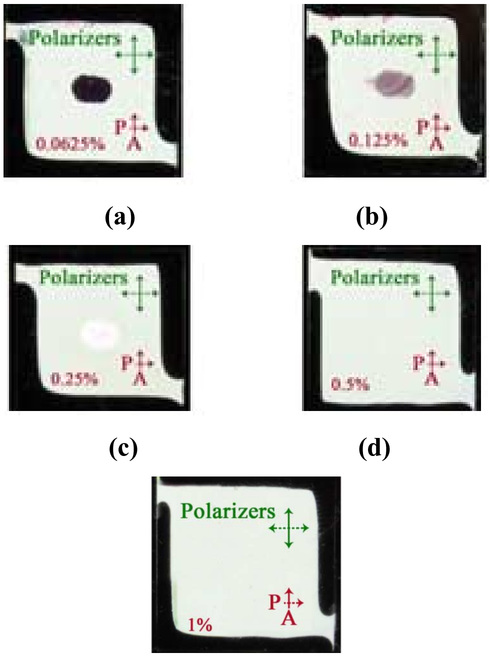


(d)

(e)

. **Figure 3.** AFM pictures of the passivation layer with different concentrations of RM257. **(a)** 0.0625wt%, **(b)** 0.125wt%, **(c)** 0.25wt%, **(d)** 0.5wt%, **(e)** 1wt%

The photo-stability of the proposed alignment surface was examined by following testing procedure. One substrate with proposed alignment surface and another substrate with conventional rubbed planar polyimide were assembly to cell with perpendicular alignment (90˚-TN) directions. The cell gap was 5um. Liquid crystal MLC-6080 from Merck Corporation was filled into the cell by capillary. The cell was end-sealed by epoxy. Again five sample cells with different concentrations of RM257 (0.0625wt%, 0.125wt%, 0.25wt%, 0.5wt% and 1wt%) were fabricated. The samples were in normally white TN structure and appeared bright placed in between a pair of crossed polarizers. Then, a polarized blue laser with wavelength 400nm was then used to reorient the alignment direction of the photoalignment SD1 film. The cells were placed under the blue laser and with the alignment directions of the SD1 layers parallel to the polarization direction of the blue laser. The power of the blue laser is 5mJ/cm^2. The alignments of the cells were checked again after 3 minutes exposure. Figure 4 shows the captured photos of the five samples after the laser exposure and placed in between a pair of crossed polarizers. The polarization directions of the polarizers were parallel to the alignment directions of the cells (e-mode). A dark spot could be seen in Figure 4(a), as the alignment direction of the photoalignment layer had been reoriented by the blue laser. The dark area indicates the cell is in ECB structure with parallel alignment directions of both the polyimide and photoalignment layers. Figure 4(b) and 4(c) also shows the alignment directions of the samples were partially reoriented by the blue laser. The results are matching well with the AFM pictures, as the passivation layers were discontinuous. Hence, the alignment direction of the unprotected SD1 region can be reoriented easily. Once the RM257 film is completely covered the surface, the alignment direction becomes photo-stable and uniform, as shown in Figure 4(d) and 4(e). Samples with 0.5wt% and 1wt% of RM257 had been further exposed by the blue laser for 12 hours. The alignment direction remained the same throughout the test and found no degradation of alignment quality.



(a) **(b)**

(c) **(d)**

(e)

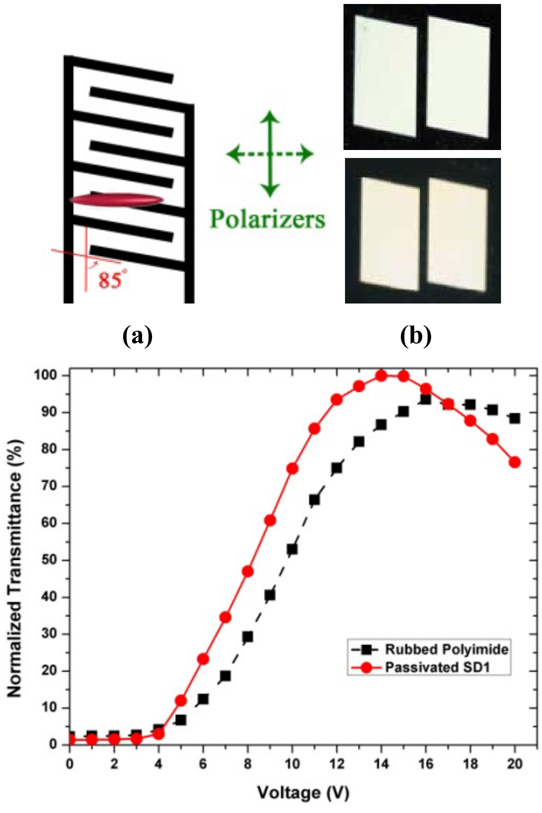
Figure 4. Photo-stability of TN cells fabricated by different concentrations of RM257 placed in between of a pair of polarizers. **(a)** 0.0625wt%, **(b)** 0.125wt%, **(c)** 0.25wt% **(d)** 0.5wt%, **(e)** 1wt%. Red dashed arrows 'P' and solid arrow 'A' indicate the alignment directions of the rubbed polyimide and photoalignment layer respectively

We had also checked the alignment properties of the new passivated SD1 alignment surface. A commercial planar polyimide JALS-9203 from JSR Corporation, Japan; and a non-passivated SD1 alignment surface were also measured as a comparison. The measured results are summarized in Table 1. The proposed passivated SD1 alignment surface clearly has a better alignment quality than the non-passivated one and is comparable with conventional polyimide. The liquid crystal polymer layer not only maintains the photo-stability, but also isolates the SD1 from moisture to give good aging-stability. In addition, the polymer chains of the reactive mesogen can be strongly connected with the liquid crystal molecules so that the alignment quality is improved.

As the new alignment surface has strong azimuthal anchoring energy, it can be used for fabricating the fast response time in-plane-switching displays. IPS samples had been fabricated using the proposed alignment surface and conventional rubbed polyimide as comparison. The cells were 4um thick and filled with MLC-6080 from Merck Corporation. The Δn and $\Delta\varepsilon$ of the liquid crystal are 0.2024 and +7.2 respectively. Figure 5(a) draws the IPS finger electrodes structure. The angle between the electrodes and the liquid crystal molecules is 5˚. The width of the electrode and spacing are 8um and 12um respectively. Figure 5(c) plots the measured normalized transmittance voltage curve (TVC). The passivated SD1 sample had 7% higher transmittance compare with rubbed polyimide. The measured rising and falling times were 65ms and 5.1ms at 16V for the rubbed polyimide sample. While, the measured rising and falling times were 13.4ms and 4.6ms at 14V for the passivated SD1 sample. The total response time of the passivated SD1 was reduced by almost 75% compare with the rubbed polyimide due to its high azimuthal anchoring energy.

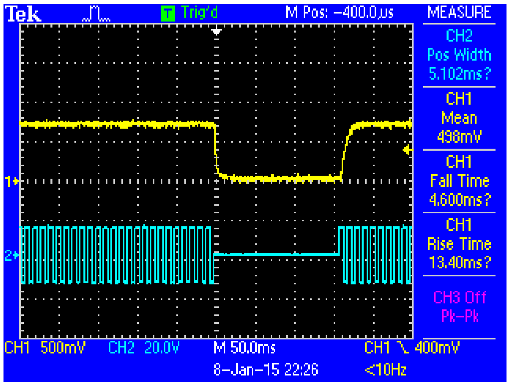
Table 1. Measured alignment properties of different alignment surfaces.

	Polyimide	Non-passivated SD1	Passivated SD1
Azimuthal Anchoring Energy	$1x10^{-4}J/m^2$	$0.8x10^{-4}J/m^2$	$1.2x10^{-4}J/m^2$
Voltage Holding Ratio	99.5%	92%	99.1%
Residual Direct Current	0.002V	0.09V	0.01V



(a) (b)

(c)



(d)

. **Figure 5. (a)** Schematic of the IPS finger electrode and the alignment direction of LC molecule. **(b)** Photo of the passivated SD1 sample at 14V (Top) and rubbed polyimide sample at 16V (Bottom). **(c)** Measured TVC of the IPS samples. **(d)** Measured optical response of the passivated SD1 IPS cell cell.

4. Conclusion

A photo-stable azo dye photoalignment surface for liquid crystal is proposed and demonstrated. The azo dye material is passivated by a continuous thin reactive mesogen layer to prevent reorientation of the alignment direction. The synthetic alignment surface shows not only excellent stability, but also improved alignment properties. Such passivation method indeed can be applied to any photoalignment materials, not limiting to azobenzene compounds, to enhance the stability, reliability and as well as the alignment quality. Experiments have proved that, in-plane-switching display that made use of the passivated alignment surface has a faster response time due to its better anchoring energy and electrical characteristics.

5. Acknowledgement

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6. References

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