# Photoalignment of Liquid Crystal on Silicon Microdisplay

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## *Abstract*

*Reflective mode liquid crystal on silicon (LCoS) microdisplay is the major technology that can produce extremely high-resolution displays. A very large number of pixels can be packed onto the CMOS circuit with integrated drivers that can be projected to any size screen. Large size direct-view thin film transistor (TFT) LCDs becomes very difficult to make and to drive as the information content increases. However, the existing LC alignment technology for the LCoS cell fabrication is still the mechanical rubbing method, which is prone to have minor defects that are not visible normally but can be detrimental if projected to a large screen. In this paper, application of photo-alignment to LCoS fabrication is presented. The alignment is done by three-step exposure process. A MTN 90° mode is chose as to evaluate the performance of this technique. The comparison with rubbing mode shows the performance of photo-alignment is comparable and even better in some aspect, such as sharper RVC curve and higher contrast ratio.*

## 1. Introduction

Reflective mode liquid crystal microdisplay, which uses active matrix on crystalline silicon technology, competes directly with large size direct-view thin film transistor (TFT) LCDs. The advantages are the better electronic properties of crystalline silicon and the more matured fabrication technology. The sophisticated diver circuitry can be easily integrated into periphery of the display. However, the alignment of LC on this panel is mainly done by the mechanical brushing process, which may generate the dust, electrostatic charges and scratches, which normally will not be visible, but become visible if enlarged by projection means. It will greatly affect the performance of microdisplay, since the much smaller pixel size compared with TFT LCDs.

Photo-Alignment is a well-developed technology to solve these problems, as a non-contacting LC alignment. It aligns the photosensitive material using the polarized UV light. Also, photo-alignment technique would be an easier process to control the anchoring energy compared to rubbing process because it is possible to vary the reaction density of photopolymer film and so as its anchoring power.

The results of uniform alignment using photo-alignment materials containing azo dye structures on transmissive liquid crystal cell has been reported before [1]. For liquid crystal on silicon (LCoS) microdisplay with topography surface, the discontinuity of the device and the reflective surface is the main consideration for the LC device design. In this paper, we will study the results of using a three-step exposure of azo-dye film on LCoS using normally incident polarized light followed by oblique non-polarized light and then normally incident polarized light again.

## 2. Photo-alignment technology

The photo-aligning phenomenon can be explained by both photo-chemical and photo-physical transformations in photosensitive layers under the action of a polarized UV-light. The photo-alignment material used here is dye-containing material, which is known as SD1. The chemical structure is shown in Fig. 1. The dye molecule is synthesized using azo-coupling between 2,2'-benzidinedisulfonic acid and salicylic acid. The product is purified by re-crystallization.

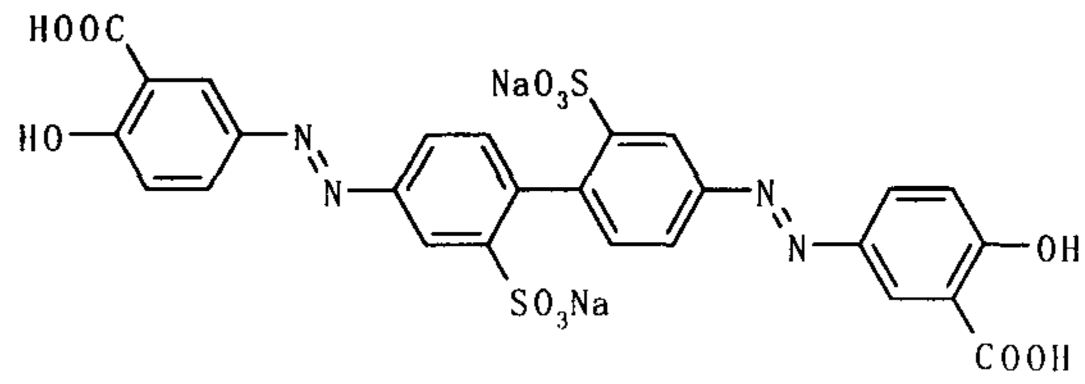

**Figure 1**. SD1 molecule

The mechanism can be explained by the reorientation of the azo dye molecules due to the action of the UV-polarized light illumination. The stable configuration is characterized by the dye absorption oscillator perpendicular to the induced UV-light polarization. The contribution of cis-trans isomerization process can be neglected. When the azo dye molecules are optically pumped by a polarized light beam, the probability for the transformation is proportional to the square of the $cos\theta$, where $\theta$ is the angle between the transition dipole moments of the molecules and the direction of the polarization of the activated light. Therefore, the azo dye molecules that have their transition dipole moments parallel to the direction of the polarized light will most probably get the excess in energy, which results in their reorientation from the initial position. This process can be described statistically as a diffusion motion of the dye molecules in the potential field of the polarized light.

## 3. Liquid Crystal Microdisplay Cell Fabrication

### 3.1 Microdisplay Panel Preparation

A 0.56 inch Microdisplay panel was designed and fabricated as the substrate of the Microdisplay cell. It consists of a data driver on the top, a scan driver on the side and an active matrix in the center as reported in our previous work[2]. The resolution for this panel is $512\times320$ and pixel size is around 10um. 1-poly, 3-metal, 0.8um technology is adopted to design and fabricate this panel for the high information density in the display. After the fabrication process a thin passivation layer is deposited and reflowed to reduce the topography of the device surface, which will degrade the optical performance of device[3]. The SEM picture of the cross-section of such display panel is shown in Fig.2.

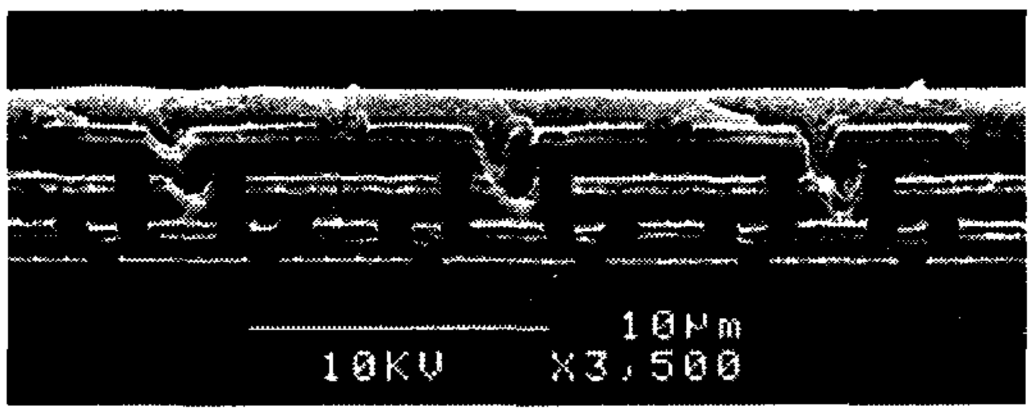

**Figure 2.** SEM of the LCoS wafer

### 3.2 Photo-Alignment Layer Preparation and Cell Assembly

The azo dye SD1 was dissolved in N,N-dimethylformamide (DMF) at a concentration of 1 wt%. The solution is spin coated onto both glass substrate with ITO electrode and the reflective microdisplay panel. The solvent is then removed by heating at 100°C for 10 minutes. The thickness of the spin-coated film is about 100 Å. UV light is irradiated onto the surface of the film using super-high pressure Hg lamp through an interference filter at 365 nm. The light intensity on the surface of the film is 4.8mW/cm$^2$ for polarized light and 12.5mW/cm$^2$ for non-polarized light. After the illumination of UV light, the cell is sealed thermally with 3.3μm cell gap. MTN90° mode[4] is adopted to evaluate the performance of display. And the LC88Y1104 ($\Delta n=0.0752$) from Merck is filled by capillary action to make the retardation around 0.248μm.

## 4. Experimental Results

### 4.1 One Step Exposure

As the Beginning of the experiment, only one step UV light exposure is done to align SD1 molecules, which is shown in Fig. 3(a). As the polarized light with intensity about 4.8mW/cm$^2$ shining on the alignment layer for 3 minutes, all the molecules of SD1 will change their random azimuthal orientation to perpendicular to the polarization of incident UV light. After the cell assembly, many alignment defects are found in the display picture during the voltage transition. However, it is disappeared on the cell with only one side using photo-alignment and the counter part using mechanical rubbing alignment. So it is believed that the non-pretilt of SD1 alignment layer to LC molecule causes the reverse tilt domain in the display.

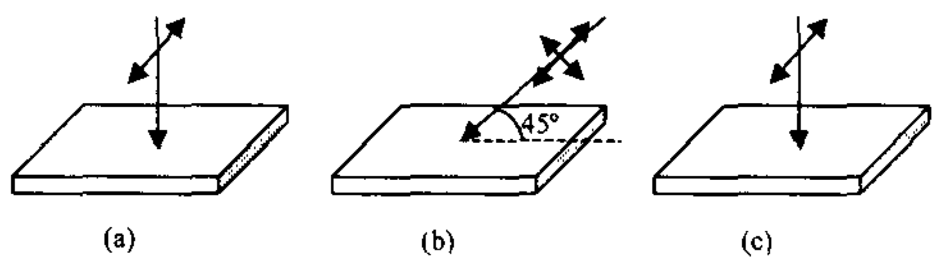

**Figure 3.** Exposure methods

### 4.2 Three Step Exposure

Pretilt angle generation for photo-alignment layer on the transmissive substrate can be done by adding a second exposure of non-polarized UV light with oblique incident angle[1]. The fundamental idea for it is to use the p-polarized light to orient all the SD1 molecules, which are still randomly oriented in the incident plane after first step exposure, to perpendicular to the p-polarized light. The s-polarized light still keeps the molecules parallel to the incident plane. That means SD1 molecules are perpendicular to the propagation direction of incident light in the incident plane. However, it is quite complicated in reflective substrate pretilt generation as the reflection of UV light on the reflective surface. The geometry of UV light exposure on reflective substrate is shown in Fig. 4. As shown in the figure, the reflected p-polarized light conflicts with the incident p-polarized light. It affects the pretilt angle generation and may disturb the alignment performance of SD1 for the even worse case.

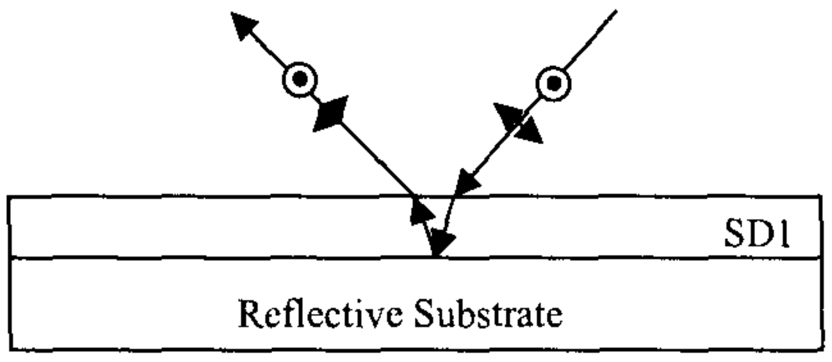

**Figure 4**. Exposure details

There are two methods to minimize this problem. One is to find an optimal angle for oblique incidence of light to minimize the reflection of p-polarized light, while the other one is to increase the thickness of alignment layer, which will increase the absorption of UV light in SD1. For the former case, the optimal angle of oblique incidence is 45°, which is achieved experimentally. At this angle incidence, 5° pretilt angle can be obtained when the thickness of SD1 is around 100Å.

For the latter case, 80% of light transmits through SD1 with the thickness of 100Å at 365nm wavelength in normal incidence. That means 80% of UV light can reach the surface of the aluminum and be reflected. However, when we increase the thickness of SD1 to 300Å, only 50% UV light can transmit through it in normal incidence, as measured by a UV light power meter. So there is almost no reflected UV light coming back to the surface of SD1 after reflection. Also, when the sample is tilted to 45°, the optical path will increase to $\sqrt{2}$ times as the normal incidence. The result is even better.

After the first two steps of exposure, an extra low energy (0.3J/cm$^2$) exposure of UV light with the same alignment direction as the first step is added. This third step basically fine tunes the alignment of the SD1 molecules for a better uniformity, which is a fundamental requirement of reflective mode microdisplay.

### 5. Discussions

Just as the the requirements of large size TFT LCDs, the material used in microdisplay, such as liquid crystal material, thermal epoxy and micro-spacers, etc. must exhibit high electrical resistivity to guarantee the high VHR ratio to maintain the pixel select voltage during the subsequent driving frame. For the LC alignment layer, since it is directly in contact with the LC material, its ion concentration must be extremely low to avoid ionic contamination of the LC material. It can be easily figured out by measuring the VHR ratio of microdisplay cell with SD1 photo-alignment layer. The VHR ratio of the display cell is around 98%.

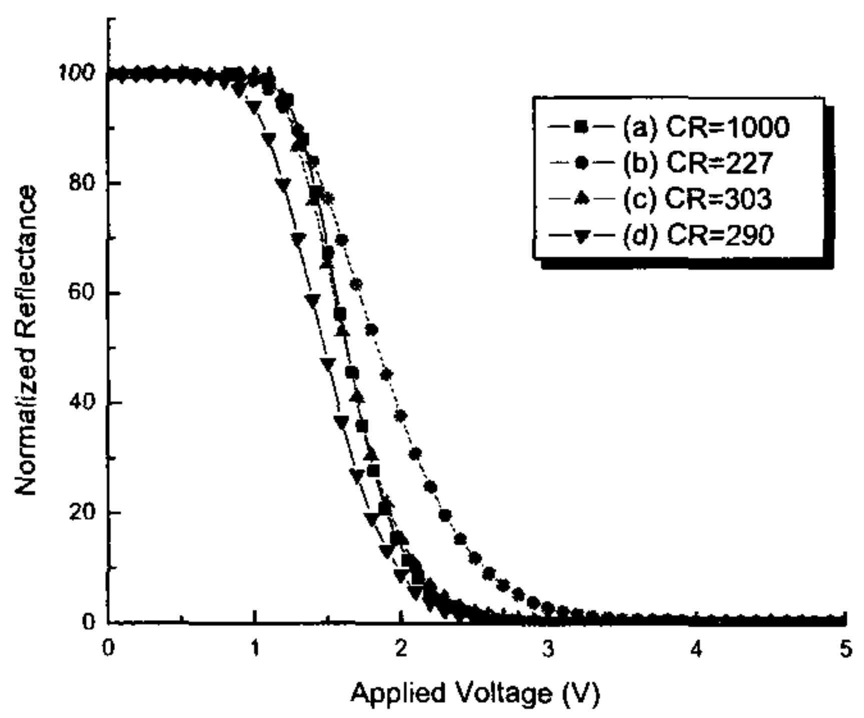

**Figure 5.** RVC curves for various cells

A 90° MTN mode liquid crystal cell is fabricated to evaluate the performance of the SD1 photo-alignment layer. The comparison of RVC curve with different alignment methods is shown in Fig. 5. Curve (a) is the simulation result by DIMOS (CR=1000); curve (b) is the RVC with mechanical rubbing method (CR=227); curve(c) is the RVC with 100Å SD1 (CR=303) and the curve (d) is the RVC with 300Å SD1 (CR=290) as alignment layer. It can be seen from the diagram that the shape of the curves is the same for all cases. But for the photo-alignment, the contrast ratio is higher than the mechanical rubbing one since the RVC is shifted to lower voltages.

The sharper electro-optical response for photo-alignment shows that the alignment is improved over mechanical rubbing. Also photo-alignment produces less static charge to the LC molecules.

Comparing the two photo-alignment curves, which have different SD1 layer thicknesses, the thicker one results in a larger shift to low voltages. It is believed that the thicker film has more absorption of alignment UV light and reduces reflection, which improves the quality of the alignment layer.

## 6. Conclusion

In this paper, we have reported the application of photo-alignment technology to reflective mode liquid crystal microdisplay. The main challenge for this application is the reflection of UV light on the aluminum surface when generating pretilt angle of photo-alignment layer to eliminate the reverse tilt domain. It has been solved by irradiating the SD1 layer with an optimal oblique incident angle (45°) and increasing the thickness of SD1 layer to absorb more reflected UV light. This procedure reduces the reflection of p-polarized UV light is minimized. After the third step UV exposure to fine tune the alignment defect, a uniform alignment can be achieved. A 90° MTN mode LCOS is used to evaluate the performance of this photo-alignment technology. The comparison of photo-alignment with mechanical rubbing alignment shows that photo-alignment is actually better than mechanical rubbing. The contrast ratio increases to 300 for photo-alignment, while the mechanical rubbing one is only around 200.

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