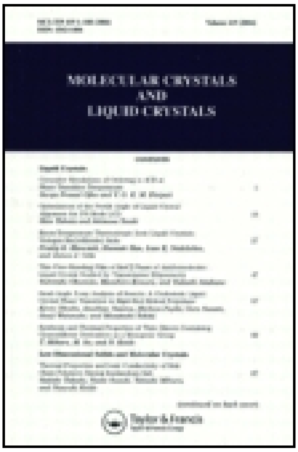

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Effect of Azo Dye Layer on Rewriting Speed of Optical Rewritable E-paper

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A new method to increase the operation speed for optical rewritable (ORW) liquid crystal alignment technology has been proposed. Conventionally, we prepared the azo dye layer by spin-coating solution of SD1 with different concentrations. The new method is to form a super thin azo-dye molecular alignment layer for LC display cell without spin-coating and rubbing processes. Compared to the conventional one, the new method provides much smaller azimuthal anchoring energy, and increases the rewriting speed a lot. Providing the advantages of conventional photoalignment methods, the use of super thin layer can obviously improve the operation speed of ORW technology for e-paper application.

Keywords Azobenzene dye; photoalignment; electronic paper; liquid crystals; displays; optical recording

1. Introduction

An ORW LC cell consists of two substrates with different aligning materials. One aligning material is optically passive and keeps aligning direction on one substrate. The other aligning material is optically active and can change its alignment direction being exposed with polarized light through the substrate [1]. Then we can obtain specified twist angle in the ORW LC cell and keep it with zero power consumption for a long time as the LC structure is always stabilized by the surface. Thus ORW LCD operates in ECB and TN liquid crystal configurations by IPS switching of alignment direction within aligning material, caused by a controlled exposure of a polarized light (figure 1) [2].

1.1 Prototype on Plastic

Single LC layer ORW e-paper is promising for two dimensional (2D) images. Simple structure makes ORW e-paper very durable, cheap and ready for the flexible challenge (figure 2).

ORW technique was first announced by us at the 13th International Display Workshop (IDW'05), where we demonstrated ORW liquid crystal display on glass. Then the

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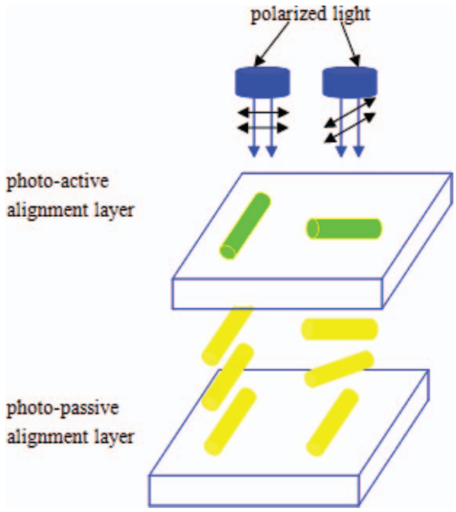

Figure 1. Internal principle structure and operation of ORW LC cell.

technology was developed to use plastic substrates. Cheap and low power consuming LED (450 nm) was used by investigating the operational regimes. On the 14th International Display Workshop (IDW'06) we reported ORW LCD with polarizer substrates that can be seen, written and rewritten (figure 3) through the polarizer.

By using the ORW principle, patterned alignment of LC can be obtained in a one-mask step exposure process. First, uniform alignment over the entire substrate surface is created. Then, a mask shadows the desired regions, and the alignment in the non-shadowed area is simply rewritten to a desired orientation. More masking steps to obtain sophisticated LC alignment may be used, but ORW saves one-mask step in comparison to nonrewritable photoalignment. The process is fully compatible with standard photolithography exposure equipped with adjustable polarizer.

We successfully implemented the device structure of ORW electronic paper (figure 2), in the experimental prototype based on polarizer and plastic substrates (figure 4), which was demonstrated on the 15th International Display Workshop, Japan 2007.

It operates by optically rewritable alignment technology, has no electrodes, possesses grey scale capability, is truly stable and does not require power to show the image with great viewing angles and high contrast.

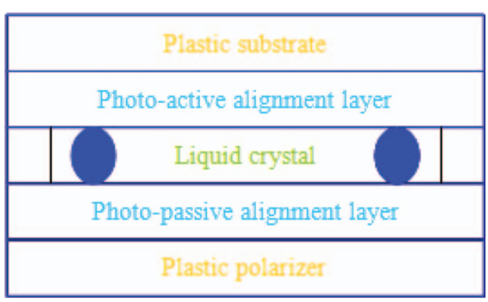

Figure 2. Structure of single side printable ORW electronic paper.

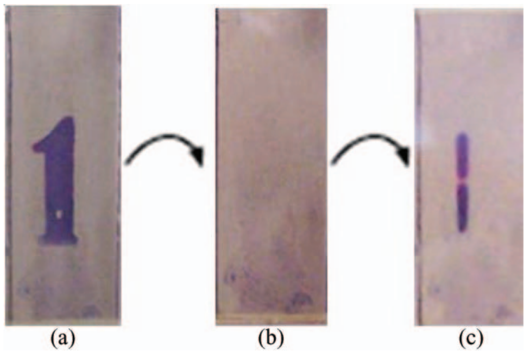

Figure 3. Two-step Process of rewriting image on flexible LC cell. (a) First image writing, (b) Image erasing, (c) Second Image writing.

The cell-gap for ORW e-paper with flexible substrates is about 10 μm. If assume that the gap will not change over 100% due to bending, then the image pixel size is limited by $20 \times 20\ \mu m^2$, as the resolvable LC structure pattern is comparable to LC cell-gap. Thus the resolution of ORW e-paper can be as high as 1270 dpi.

However, ORW technology is still limited to the labratory mainly for it has long rewriting time. The operational time of the ORW e-paper was about 11 seconds exposed by 125 mW/cm^2 polarized light from a high-pressure Hg lamp filtered with a peak at 440 nm.

In the paper, we investigate the effect of LC on the rewring speed of ORW e-paper and demonstrate the rewriting speed that can be increased by selecting LCs and by using a new substrate preparing method.

2. Conventional experiment procedure

The cell (10 μm thickness) is confined by two pieces of bare glass for transmission applications. The top and bottom aligning layers are spin coated with different aligning materials.

The bottom layer is coated with 2% PI3744 whose aligning directions after rubbing are stable under light exposure. The top layer is coated with SD1 of different concentrations whose anchoring energy will increase with the exposure time. The SD1 aligning directions

Figure 4. ORW E-paper on plastic substrates.

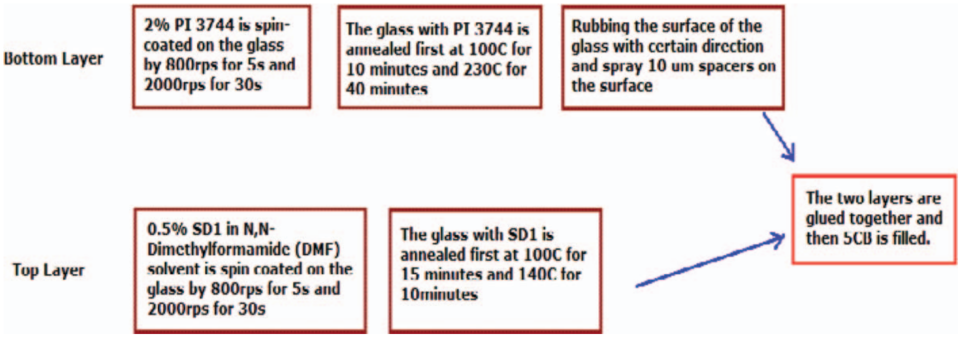

Figure 5. Conventional experiment procedure method.

will also change with respect to the polarization of the LED blue light. The conventional cell preparing process is shown in figure 5.

3. New method for preparing substrate alignment

The new method is to produce a super thin layer. To produce such super thin alignment layer, the procedure is as following (figure 6). First, draw the original thick azo-dye layer, e.g. 0.3% SD-1 in N,N-Dimethylformamide (DMF) solvent, onto the substrate with ITO to make sure that surface is completely covered by azo-dye layer. Then, anneal of this original dye layer up to high temperature to increase the molecular quantity of azo-dye molecules which generated chemical bonding with ITO surface. Use pure solvents, e.g. DMF, to remove SD-1 molecules in the bulk. So only the super-thin SD-1 layer which is chemically adsorbed on the ITO surface remains. The new super-thin SD-1 layer is exposed with a polarized UV-light to form alignment layer. Finally, anneal of the photo-aligned SD-1 layer for increasing the order parameter of the azo-dye molecules.

4. Results and Discussion

4.1 Liquid Crystal Selection to Improve the Rewriting Speed

The operational speed of ORW e-paper is represented by operational time, which is definded as the time when the normalized dose-dependent transmittance reaches 90% through the ORW LC cell. For a TN cell operated in the Mauguin regime, the light transmittance can

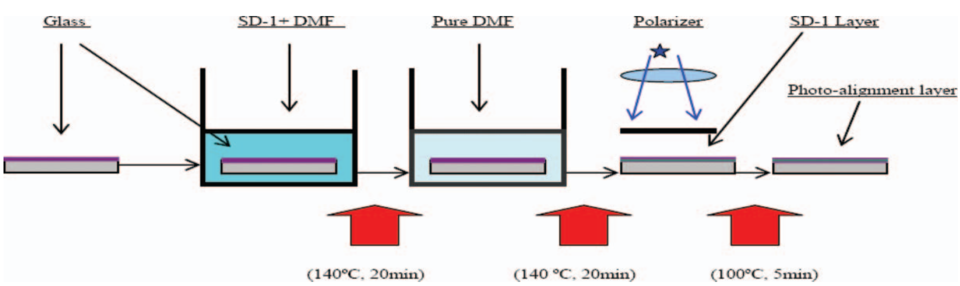

Figure 6. Illustrates the formation of a super thin azo-dye alignment layer on ITO glass substrate.

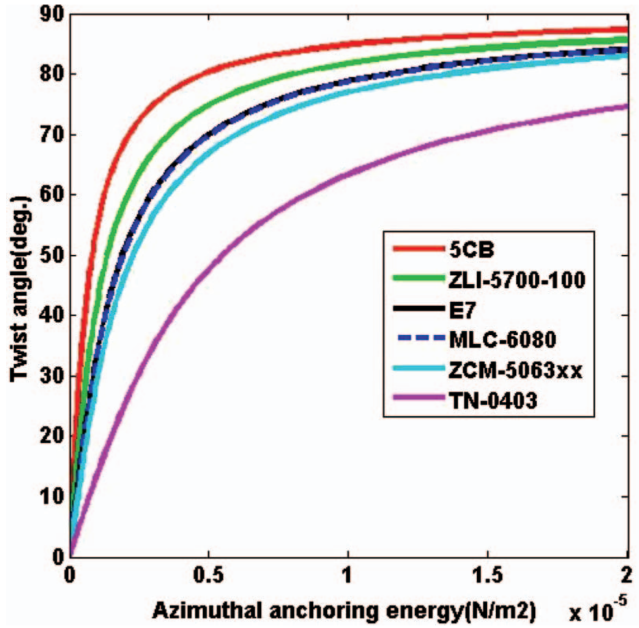

Figure 7. Relation between azimuthal anchoring energy and twist angle. (theoretical results) ($K_{22} = 3\times10^{-12}$N, 5×10^{-12}N, 7×10^{-12}N, 7.1×10^{-12}N, 8.4×10^{-12}N and 20.21×10^{-12}N, d = 10 um.)

be written as [1]:

$$T = T_0 \sin^2 \varphi \tag{1}$$

where ϕ is the twist angle of LC. From the above equation, it can be seen that the dose-dependent transmittance is directly related to twist angle ϕ.

Meanwhile, the twist angle ϕ is a key parameter determined by the azimuthal anchoring energy of the alignment layer, relation between twist angle and azimuthal anchoring energy can be written as [1]:

$$A_\varphi = \frac{2K_{22}\varphi}{d \sin(\Phi - \varphi)} \tag{2}$$

where Φ, ϕ, K_{22}, and d are the angle between defined directions of orientation LC on the top and bottom substrates, twist angle, twist elastic constant of LC and cell gap, respectively. It can be seen that for a given ORW LC cell, the azimuthal anchoring energy is determined by two parameters: ϕ and K_{22}. A_ϕ is dose dependent before saturation and K_{22} is related to property of LCs. For a given LC, larger twist angle can be realized with larger anchoring energy (figure 7).

For ORW cells with same photoalignment material and different LCs of similar structure, the azimuthal anchoring energy is mainly dependent on the order parameter of the photoalignment material molecules, which is dependent on the dose of exposure. Azimuthal anchoring energy A_ϕ and twist angle ϕ are increased when the order parameter of the photoalignment material molecules is increased. Then with the same dose, the azimuthal anchoring energy is the same. In the process of exposure, as K_{22} is different for different LCs, twist angle ϕ should be also different for the same azimuthal anchoring energy. According to equation 1, this different twist angle ϕ results in different transmittance (figure 8). With smaller K_{22}, the ORW rewriting speed should be faster.

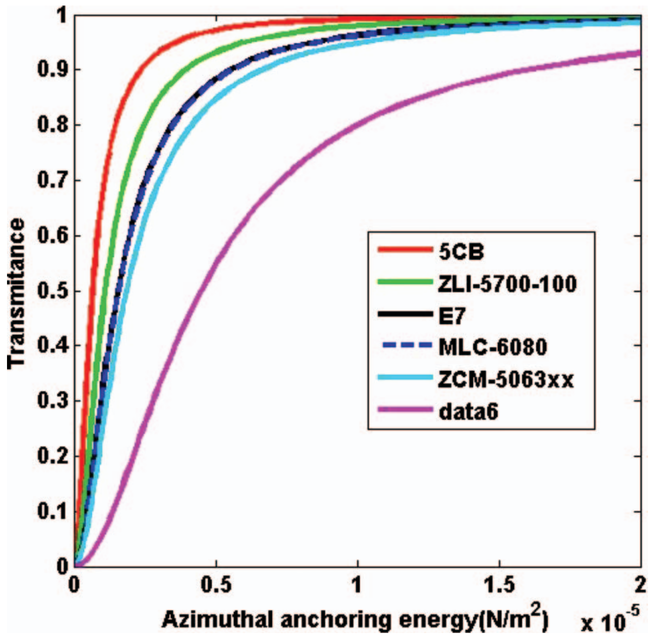

Figure 8. Relation between azimuthal anchoring energy and transmittance. (theoretical results) (K_{22} $= 3\times10^{-12}$N, 5×10^{-12}N, 7×10^{-12}N, 7.1×10^{-12}N, 8.4×10^{-12}N and 20.21×10^{-12}N, d = 10 um.)

4.2 Rewriting Speed of Super Thin Layer Method Compared to Different SD1 Concentration Selection

We use three different SD1 concentration solutions (0.3%, 0.5% and 0.8%) to test the rewriting speed of the ORW E-Paper. Liquid crystal E7 is used. As you can see in figure 9, smaller concentration SD1 will cause smaller saturation azimuthal anchoring energy. However, smaller concentration SD1 will cause faster azimuthal anchoring energy

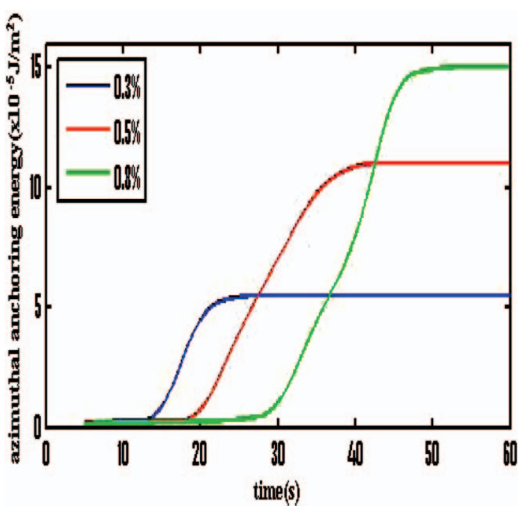

Figure 9. Azimuthal anchoring energy vs. time for different SD1 concentrations.

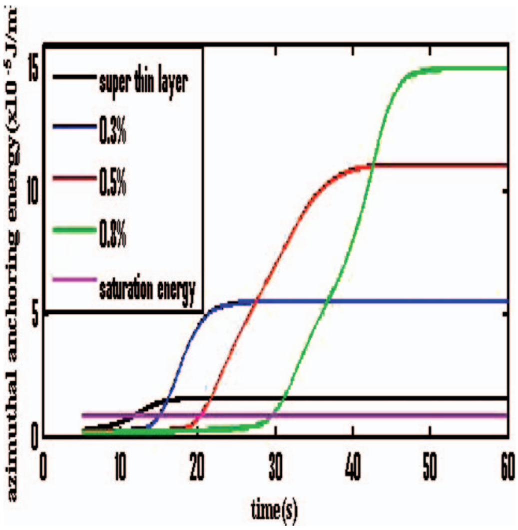

Figure 10. Azimuthal anchoring energy vs. time for different SD1 concentrations and new method.

absorption (the photoalignment layer energy absorption which cause the planar rotation) in the beginning. So figure 10 shows that, actually, when the normalized dose-dependent transmittance reaches 90%, the azimuthal anchoring energy is only about 0.5×10^{-5} J/m^2 (pink line in figure 10). That is because smaller concentration SD1 forms thinner photo-alignment layer on the substrate, and thinner photo-alignment layer absorbs blue light energy more efficiently. And as shown in figure 10, super thin layer method makes the fastest rewriting speed, because the super thin layer is more uniform and no "island" effect on the substrate compared to conventional method.

5. Conclusion

In this paper, we proposed a new method to increase the rewriting speed of ORW E-Paper. Conventionally, we prepared the azo-dye layer by spin-coating solution of SD1 with different concentrations. The new method is to form a super thin azo-dye molecular alignment layer for LC display cell without spin-coating and rubbing processes. Compared to the conventional one, the new method provides much smaller azimuthal anchoring energy, and increases the rewriting speed a lot.

Acknowledgment

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