Increasing the rewriting speed of optical rewritable e-paper by selecting proper liquid crystals*

Geng Yu(耿 煜)[a)b)†], Sun Jiatong(孙嘉瞳)[b)], Anatoli Murauski[b)], Vladimir Chigrinov[b)], and Kwok Hoi Sing(郭海成)[b)]

[a)] *Center for Display Research, Department of Electrical and Electronic Engineering, Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong, China*

[b)] *Department of Electrical and Electronic Engineering, Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong, China*

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The effect of interaction between liquid crystal (LC) and photoalignment material on the speed of optical rewriting process is investigated. The theoretical analysis shows that a smaller frank elastic constant K_{22} of liquid crystal corresponds to a larger twist angle, which gives rise to a larger rewriting speed. Six different LC cells with the same boundary conditions (one substrate is covered with rubbed polyimide (PI) and the other with photo sensitive rewritable sulfuric dye 1(SD1)) are tested experimentally under the same illumination intensity (450 nm, 80 mW/cm^2). The results demonstrate that with a suitable liquid crystal, the LC optical rewriting speed for e-paper application can be obviously improved. For two well known LC materials E7 (K_{22} is larger) and 5CB (K_{22} is smaller), they require 11 s and 6 s corresponding to change alignment direction for generating image information.

Keywords: azo-dye, optical rewritable, photoalignment, rewriting speed

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1. Introduction

E-paper, which can store and display information generated by computer, is a display designed to mimic ordinary paper. Ultra-low or zero power consumption is highly desired, which means that it does not use any backlight and is capable of holding text and images without applying any electricity, while allows the image to be changed later. The e-paper application of nematic liquid crystal (NLC) suffers from high level complexity of driving electronics,[1−11] which often fails to flexibly display, owing to the insufficient durability of the flexible conductor and contact bonding. We developed the optically rewritable (ORW) display[12−21] by separating the e-paper display unit from the driving electronics, significantly reducing the complexity of the ORW e-paper structure. This separation makes the ORW e-paper very durable and cheap and ready for the flexible challenge.

At the 14th International Display Workshop (IDW'06) we reported on the ORW liquid crystal (LC) with polarizer substrates that can be seen, written, and rewritten through the polarizer.[14] The writing, erasing, and rewriting results can be seen in Fig. 1.

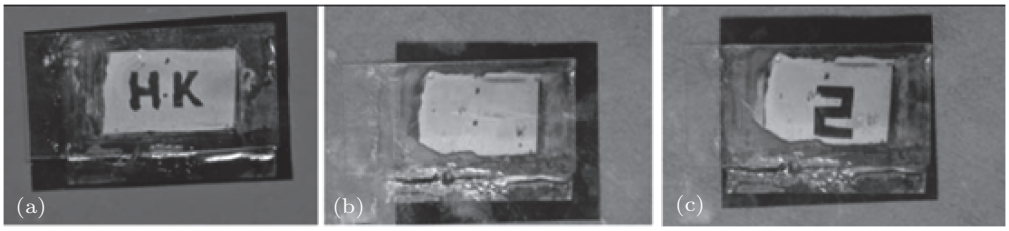


Fig. 1. Two-step process of rewriting an image on a flexible reflective TN LC cell. (a) first image, (b) erasing, (c) second image.

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†Corresponding author. E-mail: ygeng@ust.hk

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By using the ORW principle, a 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 than to obtain nonrewritable photoalignment. The process is fully compatible to standard photolithographic exposure equipped with an adjustable polarizer.

However, ORW technology is still limited to the laboratory mainly because of long rewriting time. The operational time of the ORW e-paper using E7 was about 11 s exposed by 125 mW/cm^2 polarized light from a high-pressure Hg lamp filtered with a peak at 450 nm.[15]

In this study, we investigate the effect of LC on the rewriting speed of ORW e-paper and demonstrate the rewriting speed that can be increased by selecting proper LCs.

2. Theoretical analysis of ORW operational speed

The operational speed of ORW e-paper is represented by operational time, which is defined 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 be written as

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

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 the twist angle φ.

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

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

where Φ, φ, K_{22}, and d are the angle between defined directions of orientation of LC on the top and bottom substrates, twist angle, twist elastic constant of LC, and cell gap, respectively. Therefore, 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 the property of LCs. For a given LC, a larger twist angle can be realized with larger anchoring energy which can be seen in Fig. 2. The parameters of the LCs can be seen in Table 1.

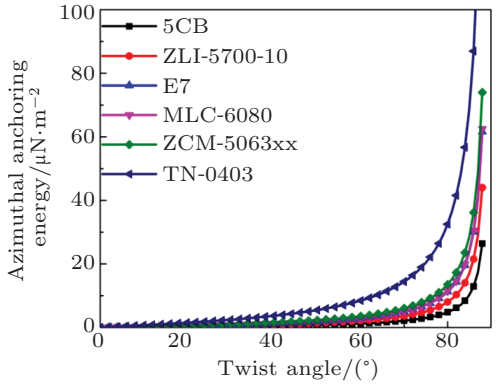


Fig. 2. (colour online) Relation between azimuthal anchoring energy and twist angle (cell gap is 10 μm).

In the process of exposure, as K_{22} is different for different LCs, the values of the twist angle φ should also be different for the same azimuthal anchoring energy. According to Eq. (1), this difference in twist angle φ results in different transmittances as shown in Fig. 3. With smaller K_{22}, the ORW rewriting speed should be faster.

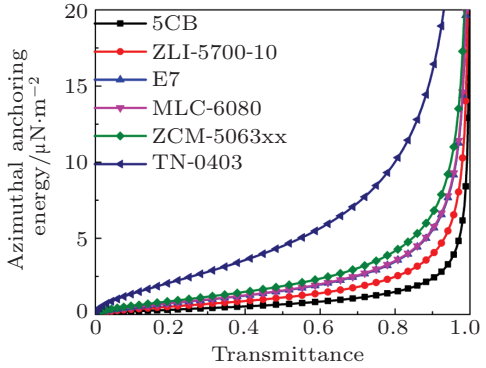


Fig. 3. (colour online) Relation between azimuthal anchoring energy and transmittance (cell gap is 10 μm).

3. Experiment

3.1. LC selection

Six different liquid crystals have similar structures and the parameters of these LCs are shown in Table 1.

Table 1. Parameters of six liquid crystals.

Parameters LCs	Δn	K_{11}/pN	K_{22}/pN	K_{33}/pN
5CB	0.1918	6.4	3	10
ZLI-5700-100	0.1581	11.3	5	15.3
E7	0.225	11.6	7	7.5
MLC-6080	0.2024	14.4	7.1	19.1
ZCM-5063xx	NA	6.1	8.4	20.2
TN-0403	0.258	12.6	20.21	20.286

From the above analyses, the Frank elastic constant K_{22} is important for rewriting speed and the magnitudes of this constant are different for these six different LCs. So we choose these six LCs to test the relation between K_{22} and rewriting speed.

3.2. Photoalignment material and preparation

The substrates of the LC cells were bare glass without indium–tin oxide (ITO). One substrate of the cells was rubbed polyimide 3744 (PI 3744) and other was azo-dye sulfuric dye 1(SD1) layer; the chemical structure of SD1 is shown in Fig. 4. PI 3744 is optically passive and keeps the aligning direction in the whole optical writing process. SD1 is optically active and is sensitive to blue light but not sensitive to red light. As a result, 450-nm wavelength polarized LED light was selected as the rewriting light to change its aligning direction as shown in Fig. 5 and 650-nm wavelength polarized laser was used as the probe to inspect transmittance of the LC cell.

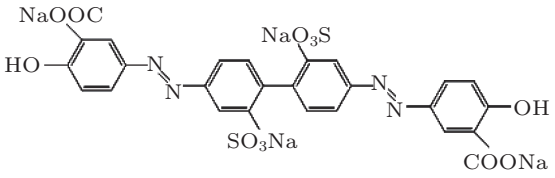


Fig. 4. Chemical structure of SD1 azo-dye material.

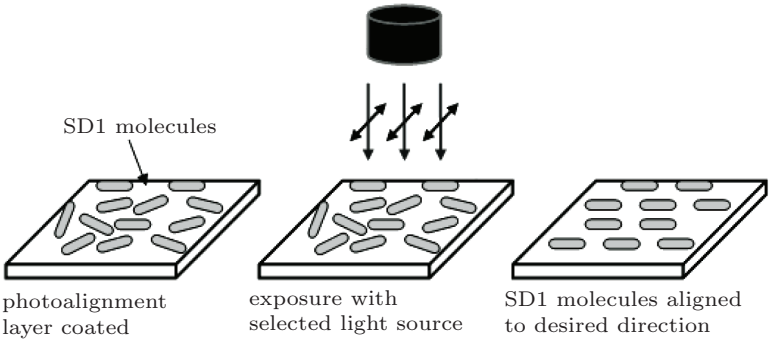


Fig. 5. SD1 photoalignment by 450-nm wavelength polarized LED light.

3.3. LC cell preparation

The azo-dye SD1 was dissolved in N, N-dimethylformamide at a concentration of 1% and then spin-coated on a bare glass substrate with 800 rpm for 2 s followed by 3000 rpm for 30 s. The coated substrate was baked at 140 °C for 15 min. The other substrate was spin-coated with PI 3744 and first baked at 100 °C for 5 min and then baked at 230 °C for 1 h.

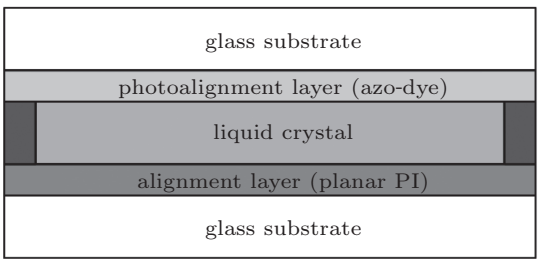


Fig. 6. Structure of the ORW LC cell used in the experiment.

This procedure provided thin homogeneous solid dye films onto bare glass surfaces. The LC cells were obtained by filling the empty cell in a vacuum with the six kinds of liquid crystals as can be seen in Fig. 6.[22,23] The cell gap was 10 μm.

3.4. Experimental setup

Figure 7 shows the experimental setup. The blue light (450 nm, 80 mW/cm^2) from the blue light emitting diode (LED) module was polarized by the wire-grid polarizer, and then illuminated the LC cell in order to align the SD1 molecules, which would align LC in the cell. He–Ne laser (650 nm), which passed through a hole at the centre of the LED module and was polarized by the same wire-gird polarizer, acted as a probe to inspect transmittance of the LC cell *in-situ* of the image-rewriting process.

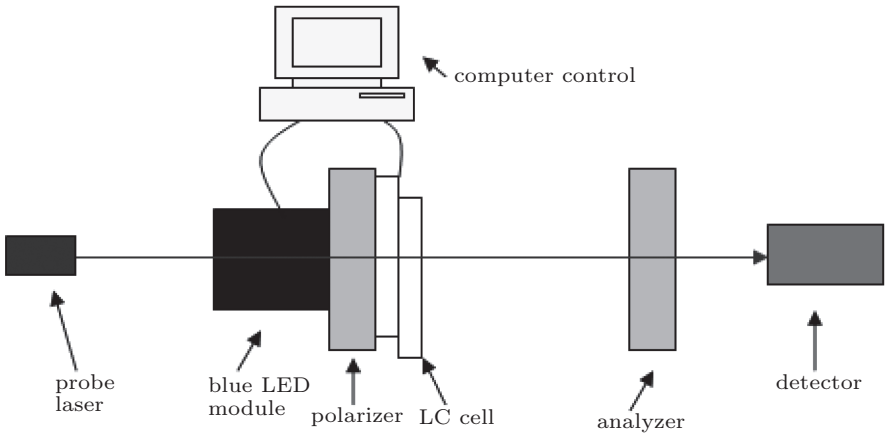


Fig. 7. Scheme of experimental setup used for transmission-time measurement.

3.5. Measurement process

The measurement process was controlled and synchronized by computer. The first was the initial process. The cell was exposed to the rewriting light (polarized blue light) for 30 s to give it an initial alignment and the cell was rotated 70° by the motor, then exposed to the rewriting light. After the initial process, the rewriting time of the ORW cell began to be measured. The motor rotated the cell by 70°, then the rewriting light was switched on and the detector began to detect the intensity of the transmitted probe light (polarized red light), at the same time the data were stored by the computer. Within this rewriting process, the SD1 alignment layer changed its aligning direction into being perpendicular to the polarization of the rewriting light. Thus the twist angle of the LC changed from 0° to 70° or from 70° to 0°. As a result, the transmitted probe light was changed from dark to bright or from bright to dark. This process can be repeated many times, thereby achieving the rewriting of the e-paper application.

3.6. Experimental results

In one rewriting process, the LC cell changes from a dark state to bright state as shown in Fig. 8. The curve of dose-dependent transmittance is shown in Fig. 9. It is clear that the rewriting time of 5CB (K_{22} is smaller) is shorter than that of other LCs (K_{22} are larger) and for E7 and MLC-6080 with about the same value of K_{22}, they have approximately the same rewriting speeds. It is about 6 s for 5CB, 11 s for E7, and 25 s for TN-0403. For an LC display device, like e-paper, the response time plays a crucial role. The total response time usually refers to the sum of the rise and decay times, which are the same for the optical rewritable LC devices. The response time of the optical rewriting process for 5CB is 10 s, which is much shorter than that of LCs with larger K_{22}.

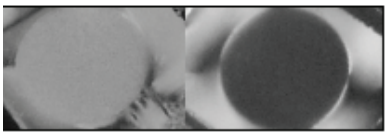


Fig. 8. Bright and dark state of the ORW cell.

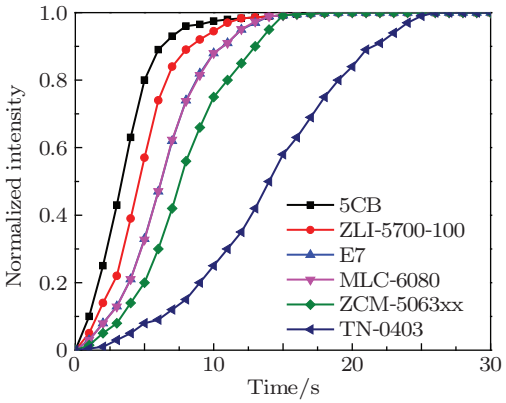


Fig. 9. (colour online) Half rewriting cycle for different LCs.

For other types of LCs with approximately the same value of K_{22}, like E7 and MLC6884, the rewriting times are the same, both around 11 s whereas LCs with approximately the same values of K_{11} and K_{33} have different rewriting times.

The above analyses show that K_{22} is the key parameter to reduce optical rewriting time. With smaller K_{22}, the rewriting speed of ORW e-paper could be significantly increased.

4. Conclusions

Six species of LC cells with the same conditions (the same boundary conditions, illumination intensity, and temperature) but with different LC materials demonstrate different rewriting times. Both positive and negative LCs are tested and it is shown that whether the LC is positive or negative does not affect the rewriting speed, whereas K_{22} is the key parameter which affects the azimuthal anchoring energy. The rewriting speed could be increased greatly by reducing K_{22}. These results will improve the operation speed of ORW technology for e-paper application by selecting a suitable LC mixture, more sensitive photoalignment material and high power blue LED, making ORW technology promising for industrial applications.

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