15.1: Optically Rewritable Liquid-Crystal Technology: A New Green E-Paper Approach

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Abstract

Optical rewritable E-paper is a valuable contribution to the green technology, as E-paper replaces usual paper with the same quality of image. The light printable rewritable paper is based on liquid crystal photoalignment and is suitable for labels and plastic card displays, price labels, E-albums, E-advertisements.

1. Introduction

The idea of the electronic paper (E-paper) is to store and display information generated by computer on a light weight thin flexible and robust, paper-like carrier with good brightness, high contrast and full viewing angle. It can be reach by two ways: One is using electrically addressed bistable devices [1] based on LC such as cholestreric LCD [2], bistable device (ZBD) [3] and bistable nematic (BiNem) [4]. Other is optically addressed devices: good results were achieved by Yamaguchi et al. [5,6] by the control of surface distribution of azimuthal anchoring energy of photoaligned polymer film. The approach requires amplitude mask control of the exposure dose and in case of overexposure the image is erased and can hardly be rewritten again. The image recording photoaligning technology was successfully applied for optical security device [7]. Photoswitchable bistable reflective liquid crystal display based on an azo-dye doped LC film was successfully demonstrated by Lin et al. [8] (a dye-adsorbed polymer film with a writing beam intensity of 150 mW/cm^2 yielded a writing time of 60 s). The alignment induced on a nematic LC by a photoaligned polymer film with azo-dye side groups was investigated [9]. The orientation of the LC molecules was be manipulated in a reversible manner by irradiating the film with a polarized light. The reversibility of the photo-induced alignment may allow recording and erasing of information in a LC display.

The works mentioned above [5-9] have some limitations for the writing and erasing capabilities. The *reversible writing-erasing process* can be obtained only by the rotation molecules photoalignment in solid films observed in azo-dye layers, pioneered by us such as sulfonic azo-dye SD1 [10-13]. Optical rewritable technology (ORW) is a modified method of azo-dye photoalignment that possesses traditional high azimuthal anchoring energy, and has a unique feature of reversible in-plane aligning direction reorientation, i.e. rotation perpendicular to the polarization of an incident light. An ORW LC cell consists of two substrates with different aligning materials (Fig.1). 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. By this mean one can obtain a specified twist angle in the ORW LC cell that corresponds to the transmission level defined by the initial polarizers configuration (Fig. 1). ORW is very tolerable to the cell gap variation as even 50% changing of the cell gap will not cause noticeable change in LC transmission value, while achromatic switching of all ORW grey levels can be obtained [10-12]. Every transmission level is stable and visualizes information with zero power consumption for a long time.

We will consider (i) development of new highly sensitive ORW photoaligning materials and layers; (ii) implementation of ORW liquid crystal structures, that are very durable, cheap and ready for the flexible challenge, contact printing of the polymer spacers and lamination; (iii) investigations of regimes of operation to allow to use cheap and low power consuming high efficient light sources such as blue LED as an alternative exposure light source instead of expensive and high power consuming mercury lamps or lasers.

2. Results and Discussion

Structure of ORW e-paper and them optical properties was investigated in our previous papers. In order to "print" some image on ORW e-paper, linear polarized light should be used [13] (Fig.2). We investigate possibility to use LC display to specify the polarization direction for incident light. LC display should rotate polarization of input light and has On and Off possible states which should have for both states the linear polarization for output light and difference in orientation of the direction polarization. Though many kinds of LC display can achieve this function, passively driven TN and STN LC display are suitable for low resolution light printer (Fig.2). When applying active matrix TFT TN LC display, high resolution images can be obtained on ORW E-paper. However, in this case, the low aperture ratio leads to large losses of uncontrollable light, which causes the problem of increasing operation time of the light printer for ORW E-paper.

We investigate the influence of the optically addressing conditions on the stability and the speed for the reorientation process and describe optimal configuration of the STN cells for it. Best results are shown by thick TN LC cells with the thickness close to the third Mauguin minimum. Such TN cell rotates polarization plane on the angle equal to the twist angle of this cell for any wave length (wave guiding regime). Disadvantage this type display is small information capacity and very low resolution for graphic type display. STN LC display has larger information capacity and can be used for produce graphical information but such type cell requires a special optimization of its effective birefringence to obtain the optimal condition for operation in a blue region (440±10 nm), where the LED writing and erasing is the most efficient (Fig. 3)

High reproducibility is achieved due to the saturation of twist angle dependence and careful spectral analysis of azo-dye (Fig.4). At zero intensity level the time should tend to infinity and at high intensity the time decreases. When the exposure intensity exceeds ~80mW/cm^2 level the rewriting time is better than 15s which is tolerable for long time image keeping applications. At the same time such an intensity level can be easily reached by a contemporary blue LED. Optical rewritable LC alignment is a good base for new types of LC displays, especially on plastic substrates, when no ITO films and electrodes are needed [10-13]. Table 1 provides a comparison of optical rewritable technology based on azo-dye layers pioneered by us [11] and other optically rewritable ORW LC displays.

As seen from Table 1, azo-dye rotation is a new very attractive LC display technology with a maximal sensitivity to the activating light, which is optically rewritable, does not require rather expensive polarized UV light and not involve any photochemical transformations of the substance, including cis-trans isomerization [10], i.e. very reliable.

The photoaligned dyes used in experiment are shown in Fig.5. The variation of E-paper transmittance in the process of writing/erasing the image is shown in Fig. 6. We have shown that most of the materials completed the reorientation process for the exposure dose less than 1.5 J/cm^2. We have also shown, that it is possible considerably decrease the E-paper writing/erasing time, if we use a mixture of azo-dye materials. In particular, the SD1:FD1 mixture in relations of 4:1 decreases the processing time almost twice. Further work is needed to provide the photoalignment material with a maximum sensitivity for the used LED light.

3. Conclusion

Recent developments of optically rewritable (ORW) LC photoaligning display and progress in LC photoalignment has made it possible to separate e-paper display-unit and driving optoelectronics part together with the significant reduction of complexity of our ORW e-paper structure making device properties and cost both paper-like [11-13]. That makes the ORW e-paper very durable and cheap and ready for the flexible challenge. More investigations of regimes of operation have allowed to use cheap and low power consuming high efficient blue LED as an alternative exposure light source instead of expensive and high power consuming mercury lamps or lasers. The device structure of ORW electronic paper in the experimental prototype based on polarizer and plastic substrates was successfully implemented. 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 wide viewing angles and high contrast. The possible but not limiting applications of the new e-paper based on photoaligning are light printable rewritable paper, labels and plastic card displays, price labels, E-albums, E-advertisements.

4. Acknowledgements

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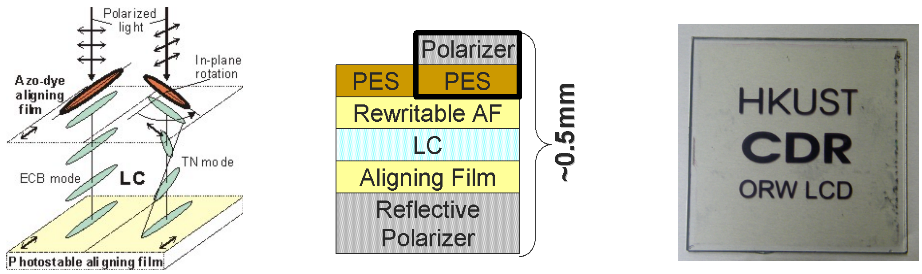

Figure 1. Left to right: Operation principle of optical rewritable ORW LC cell. Azo-dye aligning film rotates its aligning direction in-plain keeping perpendicular to the polarization of writing light, LC follows top aligning direction switching between homogeneous and twisted states; Structure of ORW plastic displays (PES-plastic substrate, AF-aligning film); Image of ORW LC display.

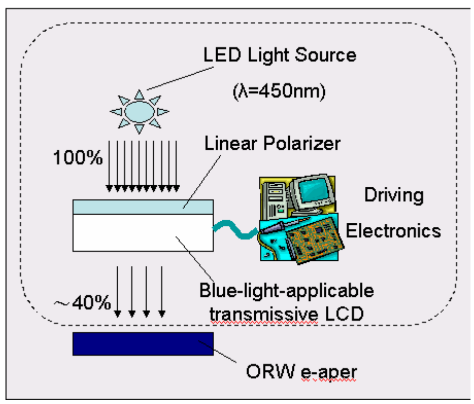

Figure 2. ORW E-paper light printer. LED array produced polarized light with λ= 450nm. The intensity of light is modulated by the blue – sensitive transmissive LCD and is recorded as a LC rotation angle dependence in ORW E-paper.

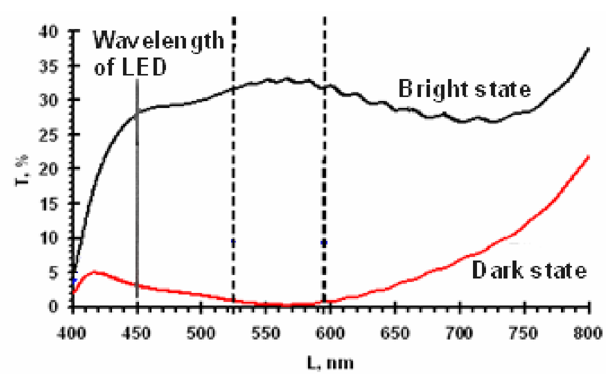

Figure 3. Transmitive spectrum for Off & On states transmissive standard FSTN LCD. Dash lines show wave length range for linear polarization output light.

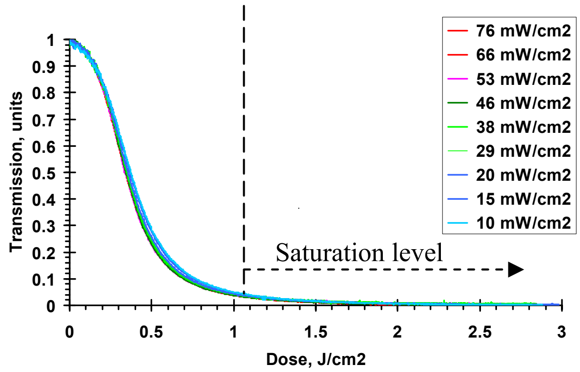

Figure 4. Dose dependence of the switching from bright to dark state for ORW e-paper (operation in transmissive mode). Photoalignment material was SD-1. LC is E7, cell gap is 9 um.

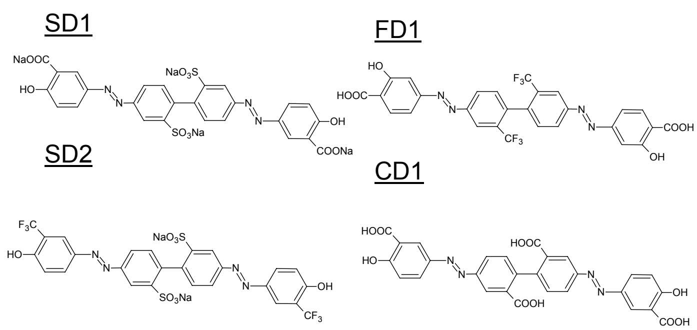

Figure 5. Photoaligned azo-dyes used in experiment for ORW E-paper.

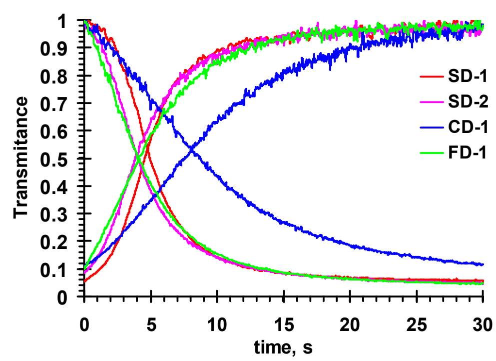

Figure 6. The varaiation of LCD transmittance in writing/erasing process in LCD E-paper for different azo-dye structures. The LED power used was 80 mW/cm^2.

Table1. Reported optical image writing by photo-alignment .

Mechanism	Re-write	Light State	Dose J/cm^2	Source
Photo -crosslinking Akita University, Japan	No	non -polarized amplitude mask	2-3	**365nm** Hg -lamp
Azo -dye adsorption NCKU, Taiwan	Yes	polarized phase mask	~9	**532nm** Laser
Cis -trans isomers KENT, USA			1-9	**514nm** Laser
Azo -dye rotation HKUST, Hong Kong	**Yes**		**0.3 -0.8**	**450nm** **LED**