High Efficiency Optical Rewritable Device

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ABSTRACT

We developed new Optical Rewritable (ORW) liquid crystal technology and utilize it to create display. ORW display carries no electrodes on board and uses polarizer as substrates. Its simple construction secures durability and low cost. The on screen information is changed in writing unit that consists of LCD-mask and exposure source based on LED, low power and cheap solution in comparison with Hg-lamps or lasers. The main target of Optical Rewritable device is the plastic card display application.

INTRODUCTION

Although nowadays displays are almost everywhere there is an obvious spare niche – a potentially large unoccupied market – of a plastic displays for plastic cards. The truth is that it is a very tough trial for contemporary well-developed display technologies to fulfill technological requirements of the application [1].

Strict bending requirements, strong thickness limitations and simply absence of available space make the trail almost impossible to stand. Plastic bending eliminates electrical connections rejecting the durability of standard electronics. On card space and size limitations refuse in battery capacity sacrificing the life-time of the device. Needless to say that photolithography as well as other processes on plastic is still far from being perfect. However, LCD for plastic card display application becomes very efficient with a new invention of Optical Rewritable (ORW) Technology [2] and its further developments [3-5].

OPTICAL REWRITABLE TECHNOLOGY

Optical Memory in LCD

The ability of liquid crystal display to change and stabilize its LC structure under light exposure and thus memorize the surface distribution of incident light is a very attractive for image recording. Several points of these phenomena can be distinguished.

First, the structure of liquid crystal can only be truly stabilized by the surface of the substrates. So all changes that LCD undergo under light exposure should happen in the aligning layer and effect the surface ability to align LC only. The bulk induced LC reorientation in electric field [6] or in high intensity light [7] without external impact (electrical field or light exposure) cannot memorize LC structure so the recorded image disappears, when the voltage is off.

Second, in order to see birefringent image of LCD screen polarizers should be at the surface of the substrates. In final product polarizer cannot be removed from the surface to write or erase the image, so all optical memory effect should be realizable through the commercially available LCD polarizer. Thus an LCD based on azo dye-doped liquid-crystal [8] faces polarization problems those are hard to overcome. As image writing is performed with linear polarized light, but image erasing requires circular polarized light. Besides LC aligning mechanism by surface adsorption of guest azo-dye (dissolvable in liquid crystal) is hard to control to receive reproducible rewriting cycles.

Third, careful consideration of the light source emitting spectrum, material absorption spectrum and substrate transmission spectra is required. To achieve high efficiency and low operation doses the emitting spectrum should fit the absorption spectrum with respect to the cost and the life-time of the light source and material sensitivity. Finally, regular LCD polarizers may have built-in UV-cut function that cuts almost all light below 400nm.

Continuous grey scale is another possible benefit of optical 'multi-stability'. Excellent results were achieved by Akita University group [9, 10] by the control of surface distribution of azimuthal anchoring energy of PVCi film. The approach requires the amplitude mask control of the exposure dose and in case of overexposure the image is erased and cannot be rewritten again.

The other development of Akita – several image writing on the LCD using unpolarized UV light [10, 11], requires preliminary rubbing of AR-G crosslinking aligning film materials. It is hardly compatible with plastic substrates as the substrate bents under mechanical treatment. Also it requires solving the polarizer problem.

Rewritable Benefit

Optical LC display can be called rewritable, when even in case of complete decay of the image due to exposure under direct sunlight, the image can be simply restored or changed in exposure device through a rewriting cycle.

Photo stability requirements of such optical rewriteable LCD are significantly lower as the display unit does not undergo irreversible changes.

Optical Rewritable Technology in use

Optical Rewritable Technology [2] is a modified method of azo-dye photoalignment [12] 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 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. In comparison with electrically controlled plastic display ORW can be significantly thinner and requires no ITO photolithography on plastic substrate because electrodes are not needed.

ORW LCD operates in ECB and TN liquid crystal configurations by IPS switching of alignment direction within aligning material, caused by controlled exposure of polarized light (Fig.2). So the LC structure is always stabilized by the surface.

Switching and continuous grey scale are achieved by control of aligning direction of photoaligning azo-dye layer, which is insoluble in liquid crystal. We successfully implemented a polarization controller system [13] to write, erase and rewrite image on ORW LCD. It is based on double LCD phase-mask that can rotate the linear polarization direction of transmitted light at any angle from 0 to π. The construction of LCD-mask is as simple as TN LCD and it can be both passive and active matrix.

By this mean we can obtain specified twist angle in the ORW LC cell that corresponds to transmission level predefined by initial polarizers configuration. Every transmission level is stable and visualizes information with zero power consumption for a long time. Acting the same way it is possible to obtain angles over 90º degree twist for NLC without chiral dopants [4]. High reproducibility is achieved due to the saturation of twist angle dependence and careful spectral analysis of azo-dye. Figure 3 presents a typical ORW LCD saturation of twist angle dependence on exposure time with 125 mW polarized light of high pressure Hg-lamp filtered with peak at 440nm. Polarization angle was selected to obtain saturation for 12º and 62º degrees LC twist angle. Aligning direction of SD1 rotates in-plane continuously with saturation at the direction perpendicular to the polarization of the incident light; while twist angle of LC cell changes from 12º to saturation at 62º and vice versa from 62º to saturation at 12º degrees.

We build ORW LCD without any electronics and electrodes inside. All electronics is located in writing device – double LCD that works as a polarization controller and can be 2D array like LCD pixels. This approach is reasonable for plastic cards as it makes the ORW LCD unit cheap and durable. The rewritable display image is mechanically stable with precisely controlled and highly reproducible grey scale levels through twist angle saturation.

EXPOSURE LIGHT SOURCE

Optimal exposure wavelength

We remark that azo-dye aligning films absorption spectrum has two absorption peaks at 450nm and 365nm. We studied the importance of both peaks in detail.

In our experiments with polarized light of filtered 365nm mercury line of final output intensity 60 mW/cm^2, after 55 rewriting cycles complete irreversible change of initial alignment into VA alignment was observed. Similar mechanism of homeotropic alignment and pretilt angle formation was observed after the exposure of azo-dye photoalignment material with non-polarized 365nm light [14].

When we changed filter to 440nm mercury line cutting off all UV light below 400nm (the final output intensity became 125mW/cm^2), highly reproducible in-plane reorientation only was observed. After 55 rewriting cycles no change of pretilt angle or deviation from planar alignment was observed.

The reasonable explanation of this phenomenon may lie in quantum nature of light absorption. If assume the presence of the energy threshold for azo-dye molecules in the aligning layer to reorient perpendicular to the substrate. Then we can explain that the absorption of 365nm photon brings enough energy to the molecule to overcome the threshold and molecular rotation in plane perpendicular to the polarization of incident light happens. While 440nm photon brings insufficient amount of energy for a molecule to leave the substrate plane and molecular rotation in the substrate plane only is possible. Thus after each 365nm rewriting cycle more molecules stay perpendicular to the surface and to the polarization of incident light [12]. In case of normal light incidence LC vertical (VA) alignment is formed. The anisotropy of rotational energy can be estimated as

$$\Delta E < hc\left(\frac{1}{\lambda_1}-\frac{1}{\lambda_2}\right) \approx 9.3\times10^{-20}J = 0.58eV$$

where *h* – Plank's constant, *c* – the speed of light, λ_1=365nm and λ_2=440nm. *ΔE* characterizes energy required for an azo-dye molecule to leave the substrate plane and may be helpful in description of image sticking effect.

LED exposure

Azo-dye optical sensitivity of 440nm light is only 4 times smaller than of 365nm light. Meanwhile, in comparison to 365nm UV LED the optical output of blue LED is significantly larger and the price lower. We build LED exposure system based on 40 pieces of blue LED and wire-grid polarizer [15]. We found out that for ORW LCD the exposure time of the LED system is comparable to mercury lamps or lasers while electrical power consumption is much lower. So we are able to use high power blue LED for ORW technology.

ORW PLASTIC DISPLAY

Polarizers as Substrates

Extremely simple design of reflective ORW LCD, shown on figure 1, allows fabrication of the device using polarizers itself as substrates, instead of plastic substrates with polarizers attached. We faced no problems with transfer of our technology to bottom reflective polarizer and top regular PES plastic substrates. We used low temperature cross-linking photoaligning material that does not require rubbing as stable aligning layer at the bottom reflective polarizer-substrate. Such configuration is suitable for low-end security applications as the top polarizer is needed to read the image.

More attractive is the configuration where both top and bottom polarizers are used as the LCD substrates. In such configuration the image can be read directly from the display with the human eye. We successfully solved the problem of image writing, erasing and rewriting by polarized light through the commercially available polarizer, NPF-F1225DU from Nitto Denko Co, Japan, which we used as the top substrate. The specific characteristic of this polarizer is that for blue light of the wavelength about ~460nm there is no polarization effect and transmittance of crossed and parallel polarizers is the same, while for green and red light it is a common polarizer. Such peculiar property allows operation of ORW LCD through the polarizer in 450-470 nm wavelength window that best suits for blue LED light source.

Tradeoffs

Even though we managed to use polarizer substrate and can see and rewrite the image, polarizer transmittance light losses of about 54% for blue light is the price we have to pay. At the same time such polarizer makes reflected image look purple or violet instead of black in the white light, but still tolerable for plastic card display application. Also TAC polarizer require additional protection layer to withstand chemical activity of azo-dye solvent.

All these tradeoffs are related only to the case when we want to use front polarizer as the substrate. ORW Technology faces no difficulties if use top PES plastic and bottom reflective polarizer substrates for low-end security application.

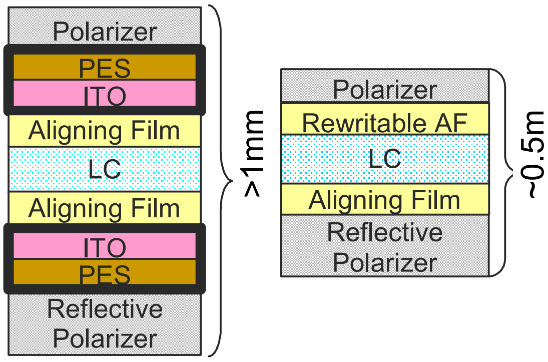

Fig. 1 Structure of electrically controlled (left) and ORW (right) plastic displays

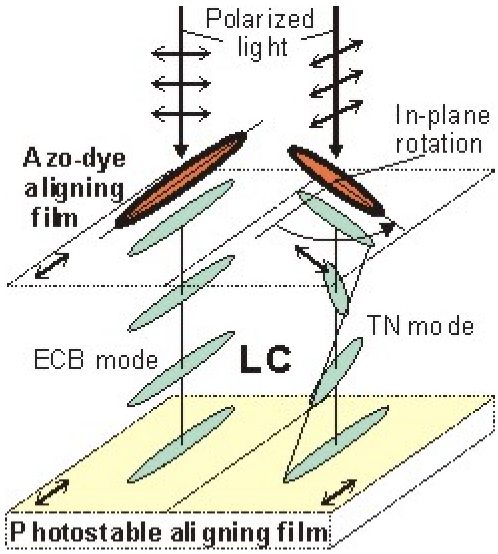

Fig. 2 Operation principle of ORW LCD
Azo-dye aligning film rotates its aligning direction in-plain keeping perpendicular to the polarization of writing light. LC follows top aligning direction switching between ECD and TN modes.

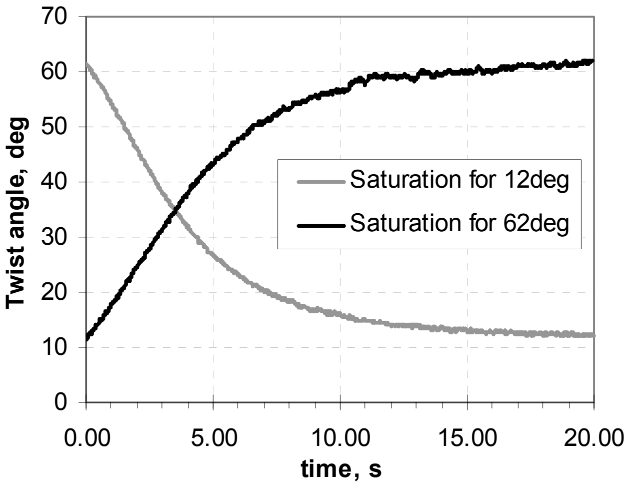

Fig. 3 In-cell LC twist angle change during exposure process with 125mW/cm^2 polarized light of high pressure Hg-lamp filtered with peak at 440nm. Polarization angle was selected to obtain saturation for 12º and 62º LC twist angle.

CONCLUSIONS

We developed an extremely simple design of Optically Rewritable liquid crystal display for plastic cards directly on polarizers. No backlight is required as reflective type polarizer is used as the bottom substrate. The image is truly stable, can be written to grey level with saturation and rewritten a large number of times with high reproducibility of properties. Finally, we come out with low power consuming high efficiency ORW-device that consists of three major parts developed by us: Optically Rewritable LCD with polarizer-substrates, LED-exposure light source and phase-mask LCD polarization rotator.

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