P-40: Photo-Aligned VAN LCD

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Abstract

Photo-aligned VAN-LCD was developed using the photosensitive polyimide (PI) JALC 2021-R2, illuminated by obliquely incident non-polarized light. It has been shown that the combination of these aligning materials with newly developed derivative of sodium salt of benzidine –3,3'-disulfonic acid (SD-1) gives a reliable and a good electro-optical performance. The response time, contrast ratio and VHR of photo-aligned VAN-LCD were comparable with the conventional VAN-LCD, where the common "rubbing" technique was used.

1. Introduction

The "rubbing" technique of liquid crystal (LC) aligning in liquid crystal displays (LCD) is widely used and provides the reproducibility and uniformity over large area of the surface. However the corresponding impurities and electrostatic charges are inevitable and the mechanical damage may result in the destruction of active elements in active matrix (AM) LCDs. Therefore, an alternative photoaligning technique has been proposed to provide a homogeneous and oblique LC alignment [1-2]. Later this method was applied for a vertical aligned (VAN) LCD with the initial slightly tilted homeotropic alignment [3-4]. VAN-LCD became most popular because of the high contrast and wide viewing angle. VAN-LCD can be aligned even with unpolarized light that makes this technique very promising for the mass production application [5-6]. The photodegradation of the commercially available aligning material JALS-696-R2 [5] or polyamic acid polymers [6] during the exposure of obliquely incident unpolarized light is believed to be the main process, which is responsible for the alignment in this case. Unfortunately it results in a decrease of the voltage holding ratio (VHR), which is the very important parameter especially for TFT-LCD fabrication. Moreover notwithstanding the efforts the VAN-LCDs prepared by photoaligning technique have not yet reached the appropriate quality (response time, contrast ratio) in comparison with conventional LCDs, prepared by rubbing technology.

We suggest that the application of modern commercial VAN materials with high resistivity to UV light in a combination with some newly developed photosensitive materials is the key factor in overcoming the above-mentioned drawbacks. So the main goal of this report is to reach simultaneously the good contrast ratio and fast response time together with a high VHR for VAN-LCDs varying the conditions of illuminations and applying the proper composition of photoaligning materials.

2. Results

2.1 Experimental

In all the cases unpolarized UV light was used to make the process of alignment cheaper. The incident angle of the activating UV-light and the exposure time was also varied. The incident light angle θ was defined as the deviation of the incident light from the normal to the surface and it shown below (Fig.1). The testing cells were assembled with the thickness of LC layer of 3,5 ±0,1 μm and opposite direction of the substrates illumination. MLC-6609 (Merck) with a negative dielectric anisotropy and without chiral dopant was used as the LC mixture.

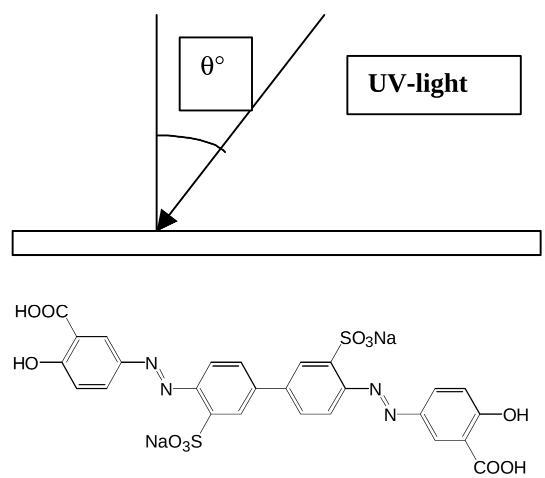

Figure 1. Plot on the top shows the definition of the incident angle θ of the activating UV-light. On the bottom the chemical formula of photosensitive derivative of sodium salt of benzidine –3,3'-disulfonic acid (SD-1) is provided.

Collimated UV light beam source with the wavelength of 365 nm and energy of 14mW/sm^2 has been chosen for the substrate illumination. The substrates were coated of JALS-2021-R2 (PI) (Japan Synthetic Rubber Co., Ltd) as aligning layers with the thickness of 30 nm by spinning method at 3000pr/min. The films were cured at 180° during 1.5 hour. It was shown earlier that the derivative of the sodium salt of benzidine –3,3'-disulfonic acid (SD-1) can be an effective reagent for homogeneous photoaligning process (Fig.1) [7]. SD-1 was used as a dopant to JALS 2021-R2 for varying the pretilt angle. The pretilt angle was measured by a crystal rotation method changing of the retardation of LC layer between –20° +20° and the subsequent fitting with the accuracy of ±0,1°[8]. The contrast ratio and response time has been measured at λ=632.8 nm and registered by HP "Infinum" oscilloscope at square driving voltage ±5V with the frequency of 1 kHz.

2.2 Alignment quality of pure PI films

At first the JALS 2021-R2 films were illuminated at the exposure angles varied from 10° to 80° during 20 min. It has been found that the increase of the incident light angle up to 60° leads to the faster response time of VAN LC cells (Fig.2).

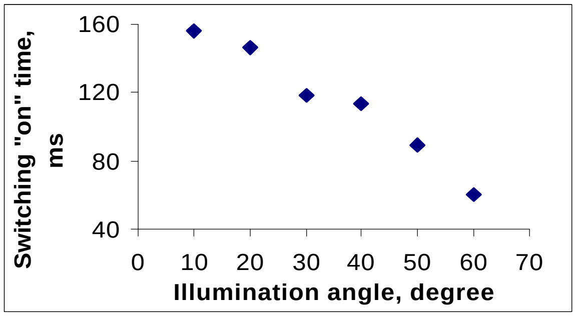

Figure 2. Switching "on" time of VAN LC cell with PI aligning layer versus the angle of UV-light illumination. Exposure time is 20 min.

This means, that the quality of the alignment is also improving. At the incident angle higher than this value the response time drastically slows down. One of the reasons of this is the decrease of the light energy that reaches the photo-aligning substrate. The measured LC pretilt angle for the cell illuminated at 60° during 20 min was 0.18°. Studying of this cell under the microscope has shown that this value of the pretilt angle is not enough to switch the LC molecules to the plane of substrate by a unidirectional way. At the beginning of this process a lot of small areas with different direction of switching have appeared and only after a sufficiently long period of time the uniform "on" state occurs (Fig.3).

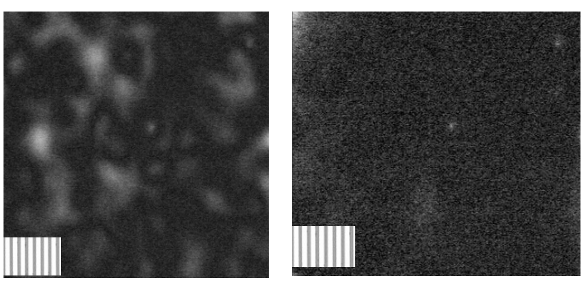

Figure 3. Dynamics of switching "on" process in VAN LCD cell is presented. On the left the chaotic structure has appeared immediately after applying of ±6V driving voltage. On the right is the photo of the same structure after 1 sec time. The pitch of dark lines in the patch is 8 μm. The direction of the illumination is from the left to the right and coincide with one of the axis of the crossed polarizers.

The increase of the exposure time up to 50 min and than to 60 min at 60° illuminations angle enlarges the LC pretilt angle up to 0,3°. In this case the VAN LCD response time $\tau_{res} = \tau_{on} + \tau_{off}$ decreases to 36,4 ms and 22,9 ms accordingly. The fact that VAN LCD switching "off" time remains the same for all the testing cells (τ_{off} ≈8 – 8,2 ms) can be explained if we suggest that the polar part of the anchoring energy remains almost the same. This means that the azimuthal part of the anchoring energy considerably increases during the exposure, thus providing the most important contribution to the diminishing of switching "on" time τ_{on}.

From this point of view it is interesting to compare the "effective" contrast ratio in the "on" VAN LCD state between the two positions of the cell between the crossed polarizers at 0° and 45° with respect to the plane of incidence of the slantwise activating UV-light (Fig.4). The more these values the less the deviation of the LC director from the illumination plane and consequently less the response time.

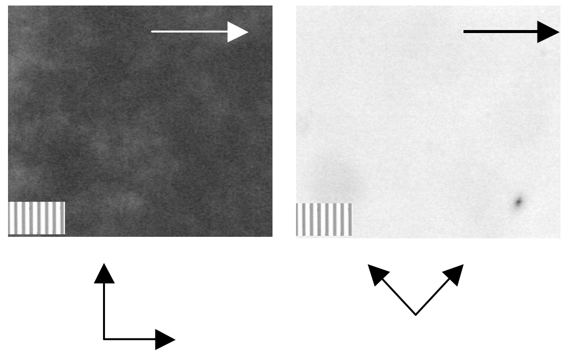

Figure 4. 20 min exposed photo-aligned VAN LCD in "on" state (5V) between the two crossed polarizers. The arrows in the pictures are the projections of the direction of illumination. The arrows under the photos are the direction of cross polarizers. "Effective" contrast ratio is 5.5:1. The pitch of dark lines in the patch is 8 μm.

Indeed the increasing of the exposure time from 20 min to 50 min and than to 60 min leads to the growth of the "effective" contrast ratio from 5.5:1 to 20.4:1 and finally to 96:1. It should be kept in mind that this "effective" contrast is also defined by the presence of defects in the aligning film that can drop its value. It should be mentioned that the measured value of the contrast ratio between "off" and "on" states in all the cases exceeds 1000:1 in the monochromatic light (λ=632.8nm).

Unfortunately the oblique irradiation of a pure PI layer by an unpolarized UV light results in a low VHR value of VAN-LCD [6]. The measured values of VHR for the cells irradiated during 50 min and 60 min were drastically small, i.e. 71,3% and 63% accordingly. The VHR measurements were done by a standard technique, when the voltage pulse of V_o=5V was applied during 64 μsec and the voltage V(t) on LC cell dropped down during τ=16 μsec after the pulse is switched off at t=0.

2.3 Effect of azodye on the aligning quality

The new photoaligning mechanism was proposed for photochemical stable azo dye film [7]. The photoaligning takes place due to the pure reorientation of the molecular absorbtion oscillators perpendicular to the UV-light polarization.

The composition of 1% of SD-1 in solution of JALS 2021-R2 (PI) was prepared and the photo-aligning films were treated as described above. It has been found that the increase of the illumination time results in the higher pretilt angles up to 0,53°, which is better than for pure PI layers. The "effective" contrast ratio in "on" state of VAN LCD was also increased up to 171 at the exposure time of 60 min. The VAN LCD response rate was strongly dependent on the illumination time (Fig.5). The fastest response time is observed, when exposure period reaches 60 min (Fig.6).

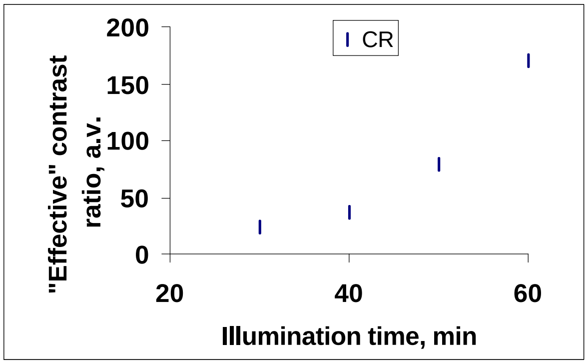

Figure 5. Dependence of "effective" contrast ratio on the illumination time for the cells doped with the 1% SD-1 in PI films.

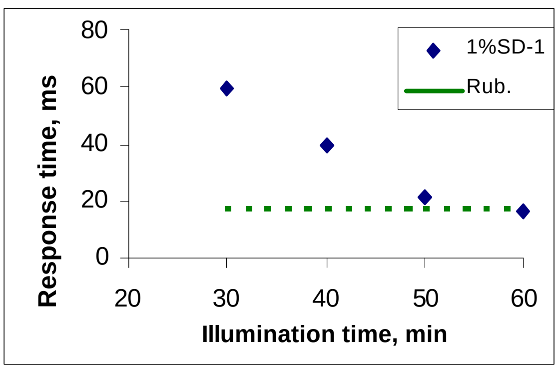

Figure 6. VAN LCD response time versus the illumination time. The discrete line is the response time of the cell obtained by rubbing.

2.4 Comparison with rubbing technology

To compare the electro-optic properties of photo-aligned and conventional "rubbed" VAN-LCD, the testing cell was prepared. The aligning film of a pure JALS 2021-R2 was deposited by spin coating and prepared by the thermal treatment described above. Instead of illumination the rubbing technique has been used to align the LC molecules to homeotropic state with some pretilt angle. The measured value of the pretilt angle was about 1.4° , which is higher than in photo-aligned VAN LC cell (0,53°). However the response time of the photo-aligned and conventional VAN LCD was almost the same $\tau_{on} + \tau_{off}$ = 7,8ms + 9 ms and $\tau_{on} + \tau_{off}$ =8,1 ms + 8,9 ms accordingly (Fig.7).

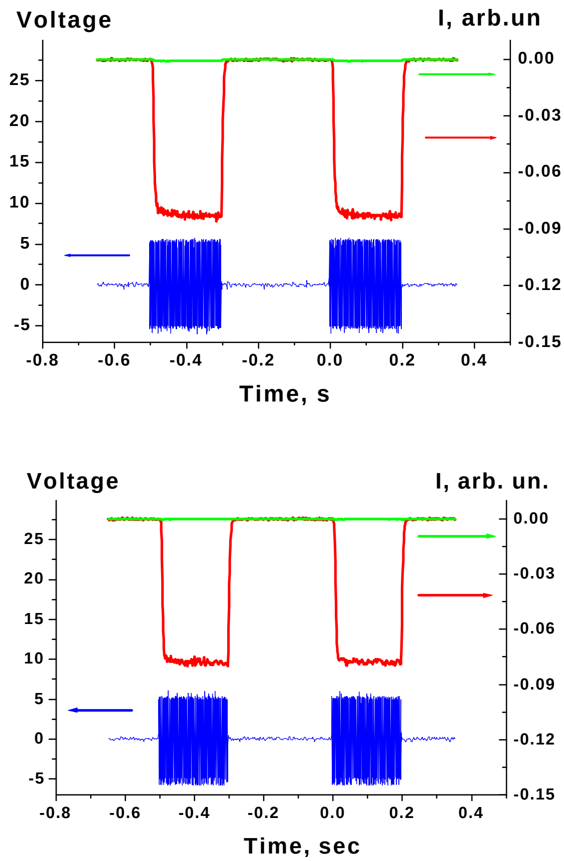

Figure 7. Electro-optic response of the photo-aligned VAN-LCD (on the top) and conventional rubbed VAN-LCD (on the bottom).

Probably this means that SD-1 as a dopant in PI has increased further the azimuthal anchoring strength in the photo-aligned VAN-LCD cells. Moreover this increase takes place not only by the photo-degradation of PI in the UV light, but the pure reorientation of both SD-1 and PI molecules in such a manner that their absorption oscillators become perpendicular to the polarization of the activating UV-light.

The high values of VHR for the photo-aligned VAN-LCD using SD-1/PI composition of 94 –96% (contrary to the conventional rubbed VAN-LCD with VHR=88%) testify to the point. The contrast ratio for both cells between "on" and "off" states was more then 1000:1.

To measure the electro-optic response the square driving voltage with the amplitude of ±5V and duration of 200 ms was applied (bottom part of each parts in figure 7). The cells were arranged at 45° (middle curves) and 0° relative to the cross polarizers (upper lines). The similar behaviour has been found for VAN-LCD prepared by both techniques.

3. Conclusion

Homeotropic alignment with a small uniform pretilt angle was developed by the oblique illumination of unpolarized UV light of commercially available and UV light stable aligning material JALC 2021-R2. The electro-optic performance strongly depends on exposure time and the illumination angle of the UV light. It has been shown that the combination of UV light stable aligning materials with newly developed derivative of sodium salt of benzidine –3,3'-disulfonic acid (SD-1) gives even more reliable and perfect electro-optical parameters. This combination allows to obtain the same parameters of VAN-LCD response as conventional rubbing technique without the deterioration of VHR. The photoalignment mechanism in our materials includes not only the photo degradation, but also the reorientation of both SD-1 and PI molecules in such a manner that their absorption oscillators become perpendicular to the polarization of obliquely incident UV light.

5. Acknowledgements

Financial support from RGC grant HKUST6004/01E is gratefully acknowledged.

6. References

[1] W.M. Gibbons, P.J. Shannon, S.-T.Sun. and B.J. Swetlin, Nature **351**, 49, (1991).

[2] M.Schadt , K.Schmitt , V.Kozenkov and V.Chigrinov, Jpn. J. Appl. Phys., **31**, 2155, (1992).

[3] J.-Y.Hwang, D.-S Seo , Liq. Cryst., **28 ,** 1065, (2001).

[4] J.-Y.Hwang, D.-S Seo, Jpn. J. Appl. Phys., **40**, 4160, (2001).

[5] D.-S. Seo, D.-S.Park , H.-J.Jeon Liq. Cryst., **27,** 1189, (2000).

[6] H.Yoshida, Y.Koike , Jpn. J. Appl. Phys., **36**, L428, (1997).

[7] V.G. Chigrinov, H. S.Kwok, W.C. Yip, V.M. Kozenkov, E.K. Prudnikova, B.Z. Tang, F. Salhi, Proceedings of SPIE, **4463**, 117 (2001).

[8] V.G. Chigrinov, Liquid Crystal Devices: Physics and Applications, *Artech-House,* Boston, 1999.