Voltage threshold behaviors of ZnO nanorod doped liquid crystal cell*

Guo Yubing(郭玉冰)[1, †], Chen Yonghai(陈涌海)[1], Xiang Ying(项颖)[2], and Qu Shengchun(曲胜春)[1]

[1]Key Laboratory of Semiconductor Materials Science, Institute of Semiconductors, Chinese Academy of Sciences, Beijing 100083, China
[2]School of Information Engineering, Guangdong University of Technology, Guangzhou 510006, China

Abstract: With ZnO nanorods doped in only one poly (vinyl alcohol) (PVA) layer, we observed different threshold voltages with reverse DC voltages for a liquid crystal cell. The length and diameter of the ZnO nanorod used in our experiment were about 180 nm and 20 nm, respectively. When the PVA layer on the anodic side was doped, the threshold voltage was larger than that of the pure cell; conversely, when the PVA layer on the cathodic side was doped, the threshold voltage was smaller than that of the pure cell. These results can be explained by the internal electric field model. We also observed a resonance phenomenon with a low frequency AC voltage.

Key words: ZnO nanorods; liquid crystal; voltage threshold
DOI: 10.1088/1674-4926/32/10/102003 **EEACC:** 2520

1. Introduction

Effects of director reorientation in nematic liquid crystal (NLC) cells have been intensively researched over several decades because of their possible applications in optical processing. There is a threshold for the reorientation of molecules; only when external fields exceed some threshold can molecules of NLCs rotate from their original aligning direction. This is the so-called Freedericksz transition[1].

The Freedericksz transition can be introduced by the simultaneous application of a low-power optical field and comparatively weak electric field[2−4]. A lower electric Freedericsz threshold corresponding to a higher optical field has also been observed[2, 3, 5], which is attributed to the formation of a double charge layer at the liquid crystal (LC) interface. However, liquid crystal cells with only one poly (vinyl alcohol) (PVA) layer are seldom studied.

We chose ZnO, a semiconductor material, doped in pentyl-cyano-biphenyl (5CB). Many studies reveal that ZnO shows green or other visible emissions, which are related to defects[6−9], so we used a laser with a wavelength of 532 nm to excite ZnO. And we doped ZnO nanorods in only one PVA layer in order to study the change in voltage threshold and the surface properties of the liquid crystal layer.

2. Experiment and discussion

We fabricated two kinds of samples, which consist of similar layers in the following order: glass substrate, indium tin oxide (ITO), PVA, pentyl-cyano-biphenyl (5CB), PVA, ITO, and glass substrate. Sample 1 was a pure cell, without ZnO doped; sample 2 was a cell with one PVA layer doped with ZnO nanorods and the other undoped. The length and diameter of the ZnO nanorod are approximately 180 nm and 20 nm, respectively. The thickness of the liquid crystal layer was 10 μm for both samples.

An electric field above Freedericksz threshold, perpendicular to the cell surface, tends to reorient the nematic director to the direction parallel to the electric field, which is attributed to the positive dielectric anisotropy of 5CB[10]. The critical DC voltage, which causes the initial rotation of the nematic director, i.e., threshold voltage, can be detected with a linearly polarized probe beam transmitting through a cell sandwiched by two crossed polarizers[11, 12]. The LC cell was placed between two orthogonal polarizers, with its optical axis oriented at 45° to both the polarizer (P) and the analyzer (A). A pump beam with a wavelength of 532 nm and a probe beam with a wavelength of 632.8 nm were used. When DC voltage higher than threshold voltage was applied, the nematic director rotated from the original direction, which resulted in a change to the laser beam's polarization after the probe beam transmitted through the cell. By applying step changed DC voltage and detecting the change of transmitted probe beam intensity, we could achieve the threshold voltage. We took the voltage, under which the transmitted intensity changed by 10%, as the threshold voltage.

In this article, for sample 2, we take the voltage with a positive pole on the ZnO doped side as the forward voltage, and the voltage with a negative pole on the ZnO doped side as the reverse voltage.

Figure 1 shows the threshold voltage measured as a function of the laser power for samples 1 and 2. We note that in our experiment, two opposing DC voltages result in similar threshold voltages for sample 1. This is reasonable, since there is no evident difference between these two geometries. It can be seen that the threshold voltage exhibits the same trend for all three condition, that is, the threshold voltage decreases as the pump

* Project supported by the National Natural Science Foundation of China (Nos. 60625402, 60990313, 11074054, 10674033) and the State Key Development Program for Basic Research of China (Nos. 2006CB604908, 2006CB921607).
† Corresponding author. Email: ybguo@semi.ac.cn
Received 28 April 2011, revised manuscript received 15 May 2011

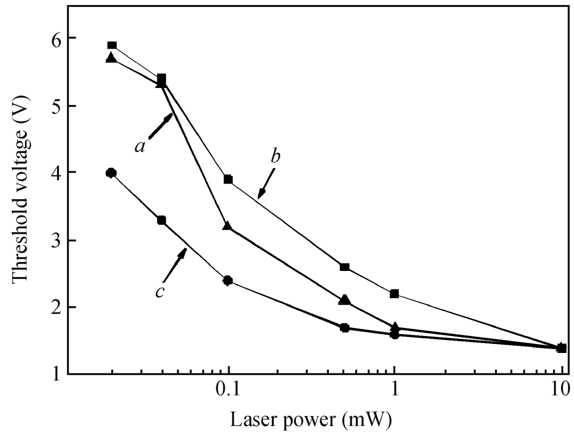

Fig. 1. Threshold voltages in different configurations. (*a*) Sample 1. (*b*) Sample 2 with forward voltage. (*c*) Sample 2 with reverse voltage.

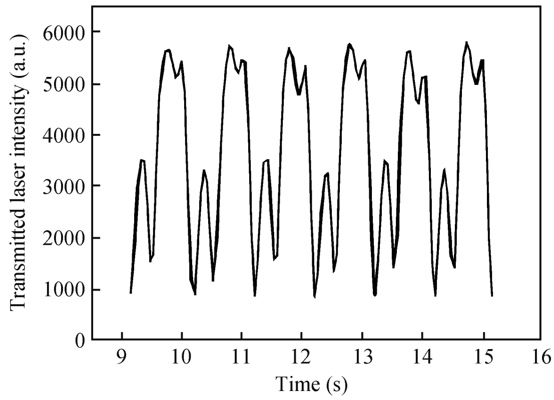

Fig. 2. Time evolution of the relative transmitted intensity of the probe beam for sample 1 when an AC voltage with a frequency of 0.5 Hz is applied.

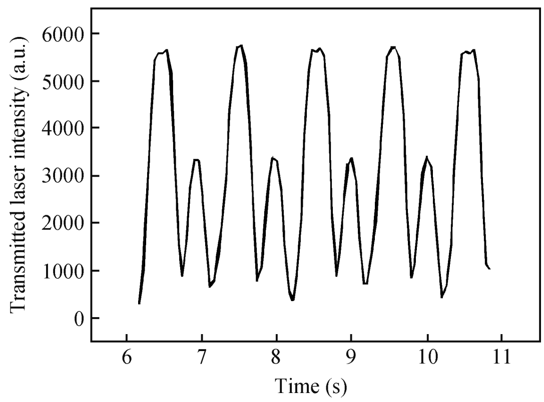

Fig. 3. Time evolution of the relative transmitted intensity of the probe beam for sample 2 when an AC voltage with a frequency of 0.5 Hz is applied.

laser power increases. In addition, the threshold voltage for curve b is always the highest while the threshold voltage for curve c is always the lowest among these three curves at the same laser power, which means that the doping of ZnO in the PVA layer on the anodic side increases the threshold voltage, while the doping of ZnO in the PVA layer on the cathodic side decreases the threshold voltage. Since the voltage threshold is an important factor in many liquid crystal devices, the results in our experiment, especially the decrease in voltage threshold, have potential applications in some liquid crystal devices.

In our experiment, when negligible optical field was applied, the threshold voltage for sample 1 was about 6 V, which is much larger than the value of about 1 V for the threshold voltage derived by computing[13, 14]. Similar abnormal threshold behavior has been reported[2–4] and is attributed to the formation of an internal electric field, which partly screens the applied DC voltage. However, when AC voltage instead of DC voltage is applied, there is no formation of an internal electric field; as a result, the threshold for AC voltage is much lower than that for DC voltage. We also measured the threshold voltage with AC voltage, the frequency of which is 500 Hz; for sample 1, sample 2 with forward voltage, and sample 2 with reverse voltage, the AC threshold voltages were all about 0.85 V, and they did not change with different laser powers[4]. And, this AC threshold voltage was a little lower than 1 V, which might be attributed to the weak-anchoring condition[15] of our sample.

The experimental results in Fig. 1 can be explained by an internal electric field[2, 3]. There is an interfacial energy barrier at the PVA/LC interface, which decreases with the application of illumination[16]. When illumination is applied, the interfacial barrier decreases, leading to the neutralization of charges near the PVA/LC interface. Then the charge density decreases and so does the internal electric field, which results in a lower threshold voltage. Greater laser power corresponds to a lower interfacial energy barrier and thus a smaller internal electric field, which leads to a lower threshold voltage. For sample 2 with forward voltage, when illumination is applied, the ZnO nanorods in the PVA layer near the anodic side produce free electrons and positive charged ZnO. Free electrons enter the LC layer, increasing the charge density in the LC layer near the interface, which results in a higher internal electric field and thus a larger threshold voltage. For sample 2 with reverse voltage, when illumination is applied, free electrons produced by the ZnO nanorods in the PVA layer near the cathodic side enter the LC layer and netralize with positive charges near the interface, which decreases the charge density and results in a lower internal electric field and thus a smaller threshold voltage. The above discussion is in good agreement with experimental results in Fig. 1. From Fig. 1 we can also see that when the laser power is 10 mW, the threshold voltages for all three conditions are almost the same, which might be related to some other effects.

We also observed a resonance phenomenon of the transmitted laser intensity for samples 1 and 2 with low frequency AC voltage, which is depicted in Figs. 2 and 3, respectively. The experimental arrangement is almost the same as the voltage threshold experiment; the only difference is that AC voltage is applied instead of DC voltage. The AC voltage is in the form of a square wave with a frequency of 0.5 Hz and an amplitude of 5 V. The transmitted intensity of the probe beam is detected as a function of time. It can be seen that the oscillating period is about 2 s, which is the same as the period of the AC voltage applied. And each period consists of two similar processes, corresponding to two opposing voltages applied on the cell. In our experiment, the highest frequency of AC voltage leading to this resonance phenomenon was about 2 Hz. For sample 2, the resonance phenomenon was similar to that of sample 1, except that the two processes in a period showed more differences, which is reasonable because of the different voltage threshold behaviors for sample 2 with forward and reverse voltages. This resonance phenomenon is related to the rotation of liquid crystal molecules. When the frequency of AC voltage is greater than 2 Hz, the rotation of liquid crystal molecules is slower than direction changes of AC voltage, so this resonance phenomenon will disappear.

3. Conclusion

In conclusion, we observed different threshold voltages with reverse DC voltages applied to a cell with ZnO nanorods doped in only one PVA layer. ZnO nanorods doped in the PVA layer on the anodic side increase the threshold voltage, while ZnO doped in the PVA layer on the cathodic side decrease the threshold voltage. We explain these experiment results with the internal electric field model. We also observed a resonance phenomenon with low frequency AC voltage, which can also be attributed to the threshold behavior.

References

[1] DeGennes P G. Physics of liquid crystals. Oxford: Clarendon Press, 1974

[2] Boichuk V, Kucheev S, Parka J, et al. Surface-mediated light-controlled Friedericksz transition in a nematic liquid crystal cell. J Appl Phys, 2001, 90: 5963

[3] Kaczmarek M, Dyadyusha A, Slussarenko S, et al. The role of surface charge field in two-beam coupling in liquid crystal cells with photoconducting polymer layers. J Appl Phys, 2004, 96: 2616

[4] Khoo I C, Chen K, Williams Y Z. Orientational photorefractive effect in undoped and CdSe nanorods-doped nematic liquid crystal-bulk and interface contributions. IEEE J Sel Topics Quantum Electron, 2006, 12: 443

[5] Lucchetti L, Gentili M, Simoni F, et al. Surface-induced nonlinearities of liquid crystals driven by an electric field. Phys Rev E, 2008, 78: 061706

[6] Wu X L, Siu G G, Fu C L, et al. Photoluminescence and cathodoluminescence studies of stoichiometric and oxygen-deficient ZnO films. Appl Phys Lett, 2001, 78: 2285

[7] Garces N Y, Wang L, Bai L, et al. Role of copper in the green luminescence from ZnO crystals. Appl Phys Lett, 2002, 81: 622

[8] Abdullah M, Morimoto T, Okuyama K. Generating blue and red luminescence from ZnO/polyethylene glycol nanocomposites prepared by in-situ method. Adv Func Mater, 2003, 13: 800

[9] Shan F K, Liu G X, Lee W J, et al. Aging effect and origin of deep-level emission in ZnO thin film deposited by pulsed laser deposition. Appl Phys Lett, 2005, 86: 221910

[10] Husiung H, Shi L P, Shen Y R. Transient laser-induced molecular reorientation and laser heating in a nematic liquid crystal. Phys Rev A, 1984, 30: 1453

[11] Khoo I C, Shin M Y, Wood M V, et al. Dye-doped photorefractive liquid crystals for dynamic and storage holographic grating formation and spatial light modulation. Proc IEEE, 1999, 87: 1897

[12] Lin Z Y, Jue S, Xiang Y, et al. An azo-isomerization-induced Freedericksz transition of a nematic liquid crystal. Phys Lett A, 2000, 270: 326

[13] Khoo I C. Liquid crystals: physical properties and nonlinear optical phenomena. New York: Wiley Interscience, 1995

[14] Khoo I C, Lindquist R G, Michael R R, et al. Dynamics of picosecond laser-induced density, temperature, and flow-reorientation effects in the mesophases of liquid crystals. J Appl Phys, 1991, 69: 3853

[15] Khoo I C, Simoni F. Physics of liquid crystalline materials. Gordon and Breach Science Publishers, 1991

[16] Sun X D, Yao F G, Pei Y B, et al. Light controlled diffraction gratings in C_{60}-doped nematic liquid crystals. J Appl Phys, 2007, 102: 013104