Electrically tunable diffraction grating based on liquid crystal film

Chi-Ting Horng[1], Han-Yin Sun[2,3], Shuan-Yu Huang[2,3*]

[1]Department of Ophthalmology, Kaohsiung Armed Forces General Hospital, Kaohsiung, Taiwan, ROC
[2] School of Optometry, Chung Shan Medical University, Taichung 402, Taiwan, ROC
[3]Department of Ophthalmology, Chung Shan Medical University Hospital, Taichung 402, Taiwan, ROC
syhuang@csmu.edu.tw

Abstract: This study investigates an electrically tunable grating based on homogeneously aligned liquid crystals (LCs) film with a periodic electrode. The first order diffraction can be controlled by applying external voltage, and reaches to a maximum value (~18%) at a voltage of 5. 0 V. The first order diffraction depends on the polarization of the probe beam is also discussed, and the diffraction intensity decays when the polarization angle increases.

[Chi-Ting Horng, Han-Yin Sun, Shuan-Yu Huang. **Electrically tunable diffraction grating based on liquid crystal film.** *Life Sci J.* 2013;10(4):2029-2031] (ISSN:1097-8135). http://www.lifesciencesite.com. 268

Keywords: liquid crystals (LCs), the first order diffraction, polarization

1. Introduction

Liquid crystals (LCs) gratings have potential applications in optical processing, optical interconnects, projection displays, optical data storage, and optical switches [1-10]. Since their optical properities can be controlled by applying external voltage, such molecular orientation patterns can be treated as phase gratings and give rise to characteristic diffraction patterns[11-21].

In this study, the grating is formed by the application of a spatially periodic electric field to a uniformly aligned liquid-crystal layer. The diffraction characteristics of this liquid crystals gratings are measured by using the incident polarized beam. The first order diffraction depends on the polarization of the probe beam is also discussed

2. Sample preparation and experimental setups

The nematic liquid crystals (E7) cell is constructed with two indium-tin-oxide (ITO) coated glass plates. One of the two plates is etched with a grating ITO pattern as an upper electrode that comprises equally spaced electrode stripes with a width of 20 μm. The other plate serves as a common bottom electrode. These two plates are also coated with polyimide film and rubbed anti-parallel to the ITO electrode stripes. The sample cell which was assembled from pairs of glass plates with transparent 38 μm thickness spacer. The extraordinary and ordinary refractive indices (n_e and n_o) of E7 are, respectively, 1.7354 and 1.5175 (measured at a wavelength of λ = 644 nm, and a temperature of T = 20 ^oC). The planar alignment of the NLC cell is further verified by using the conoscopic method.

The geometry of the sample cell and laser beam is depicted in the Fig. 1. The cell substrates are in the x-y plane and the molecular director $\hat{n}$ of NLC is along the x-axis. A cw He-Ne laser at 632.8nm is used as a normally incident probe beam that passes through a half wave plate and a polarizer (x-axis) on the sample. The first order of diffraction is detected with a photodiode and recorded as a function of time with a digital multimeter as applying ac voltage (1 kHz) between the electrode substrates.

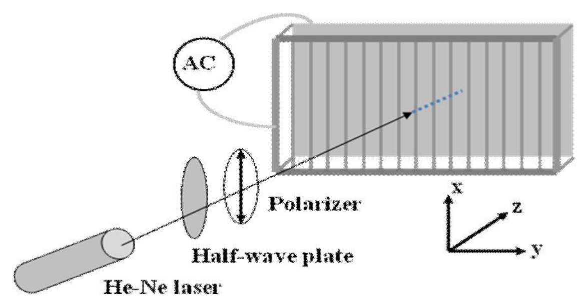

Fig. 1 The geometry of the sample cell and the expermental setup.

3. Results and disscussions

Figure 2 shows the plotting of the variations in the first order diffraction efficiency (η_1) of the grating with increased *ac* voltage (V). The first order diffraction efficiency gradually increases with increased external vlotage before V= 5V, and the first order diffraction reaches to a maximum value (18%) at V= 5V. The mechanism of grating formation is presented as follows: when an external *dc* voltage is applied to the LC cell, it causes a periodically distributed electric field to be formed between the upper-electrode with a grating-like ITO film and the bottom electrode with a uniform ITO film. Then, the reorientation of LC molecules induces the refractive index to be periodically distributed.

To examine the electrically controlled diffracted characteristics of the grating at different voltages, the voltage-dependent diffraction efficiency of the first order are measured. The first order diffraction efficiency of the grating is defined as follows:

$$\eta = \frac{D_{+1}}{D_0}, \qquad (1)$$

where D_{+1} is the diffracted intensity of the first order beams, and D_0 is the intensity of the incident beam. The first order diffraction efficiency of the grating (η) depends strongly on the modulation of the refractive index $\triangle n$, η increases with $\triangle n$. At V = 0 to 2.5 V, η= 0%. The LC molecules can not be reoriented when the external voltage is smaller than 2.5V. When the applied voltage increases from 2.5 V to 5.0 V, η significantly increases to a maximum value of ~18%. The LC molecules in the electrode regions are reorientated toward the surface normal of the cell, leading to a large variation in $\triangle n$ and results in the maximum diffraction efficiency. When the applied voltage exceeds 5.0 V, the fringing effect of electric field at a higher voltage causes the bent electric field partially to reorient the LC molecules. The variationin $\triangle n$ is decreased and η gradually decays.

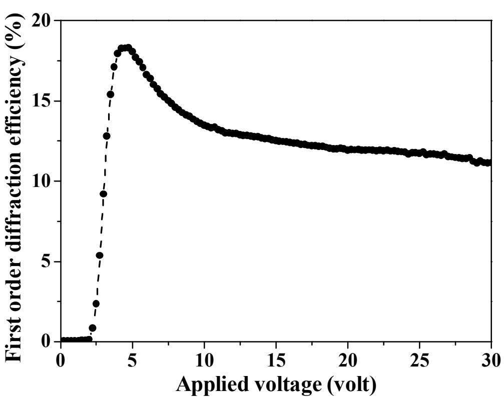

Fig. 2. The first-order of diffraction efficiency depends on the external voltage.

Figure 3 presents the first order diffraction efficiency of grating with various polarizations of the incident beam at a voltage of 5.0V. The polarization of the incident beam is adjusted from 0° to 90° corresponding to changing the polarization of the incident beam from *x* polarized to *y* polarizedd. The polarization angles of the incident beam are 0°, 15°, 30°, 45°, 60°,75° and 90°, respectively. In the case of the *x*-polarized beam, the incident beam experiences extraordinary and ordinary refractive indices. The difference between these refractive indices $\triangle n$ results in the maximun diffraction efficiency . As the polarization angle is increased from 0° to 90°, $\triangle n$ is reduced and results in the decay of the first order diffraction efficiency.

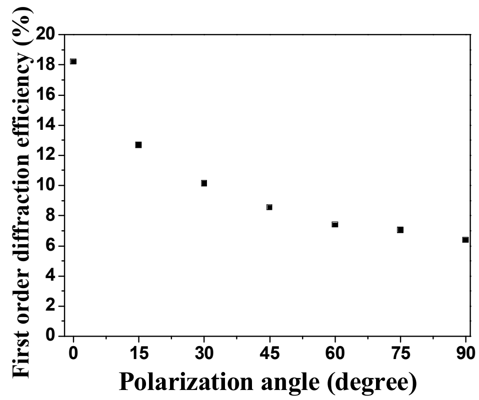

Figure 3. The first order diffraction efficiency of gratingwith various polarizations of the incident beam at a voltage of 5.0V.

4.Conclusion

In summary, an electrically tunable grating based on homogeneously aligned liquid crystals (LCs) film with a periodic electrode has been studied. The first order diffraction can be controlled by applying external voltage, and the maximum diffraction efficiency (~18%) was achieved at a voltage of 5. 0 V. The first order diffraction depends on the polarization of the probe beam is also discussed, and the diffraction intensity decays when the polarization angle increases from 0° to 90°.

Acknowledgments: The authors would like to thank Chung Shan Medical University(Contract No. CSMU-INT-101-07) for the financial support.

Corresponding Author:
Shuan-Yu Huang
School of Optometry, Chung Shan Medical University, Taichung 402, Taiwan, ROC
Department of Ophthalmology, Chung Shan Medical University Hospital, Taichung 402, Taiwan, ROC
E-mail:syhuang@csmu.edu.tw

References

1. W. M. Gibbons and S. T. Sun, "Optically generated liquid crystal gratings," Appl. Phys. Lett. 65, 2542–2544 (1994).
2. R. L. Sutherland," Electrically switchable volume gratings in polymer-dispersed liquid crystals," Appl. Phys. Lett. 64, 1074-1076 (1994).
3. J. Chen, P. J. Bos, H. Vithana, and D. L. Johnson," An electro-optically controlled liquid crystal diffraction grating," Appl. Phys. Lett. 67, 2588-2590 (1995).
4. D. P. Resler, D. S. Hobbs, R. C. Sharp, L. J. Friedman, and T. A. Dorschner," High-efficiency

liquid-crystal optical phased-array beam steering," Opt. Lett. 21, 689-691 (1996).
5. H. Okada, P. J. Bos, and H. Onnagawa," In-Plane Liquid Crystal Beam Steering Devices with a Beam Separation Structure," Jpn. J. Appl. Phys., 37, 2576-2580 (1998).
6. P.G. de Gennes, The Physics of Liquid Crystals, Oxford University Press, Oxford (1974).
7. B.Bahadur, Liquid Crystals - Applications and Uses, World Scientific Press, Singarpore (1990).
8. Pochi Yeh and Claire Gu, Optics of Liquid Crystal Displays, (1999).
9. Andrew J. Lovinger, Karl R. Amundson and Don D. Davis, Chem. Mater. 6, 1726 (1994).
10. Grant R. Fowles, Introduction to Modern Optics, 2nd ed., University of Utah, New York (1975).
11. A. Yariv, Quantum Electronics, John Wiley &Sons Press, New York(1989).
12. Iam-Choon Khoo, Liquid Crystals-Physical Properties and Nonlinear Optical Phenomena, John Wiley & Sons Press, New York (1995).
13. Amnon Yariv, "Optical Electronics in Modern Communications,Fifth E", Oxford University Press.
14. P.Yeh,"Introduction to Photorefractive Nonlinear Optics", John Wiley & Sons,New York(1993).
15. Gray P. Wiederrecht, Michael R. Wasielewski, Appl. Phys.Lett. Vol 74, No 23(1999).
16. H. J. Eichler, P. Gunter, and D. W. Pohl, Laser-Induced Dynamic Gratings, Springer-Verlag Berlin Heidelberg (1986).
17. R. Magnusson and T. K. Gaylord, J. Opt. Soc. Am., Vol. 68, No. 6(1978)
18. R. Riehl et al. Chemical Physics Letters, 245, 36(1995).
19. P. C. Yeh and C. Gu, Optics of Liquid Crystal Displays, (John Wiley and Sons, New York, 1997).
20. H. Kogelnik, Bell Syst. Tech. J. 48, 2909(1969).16. E. Jakeman and E. P. Raynes: Phys. Lett. A 39, 69 (1972).

10/21/2013