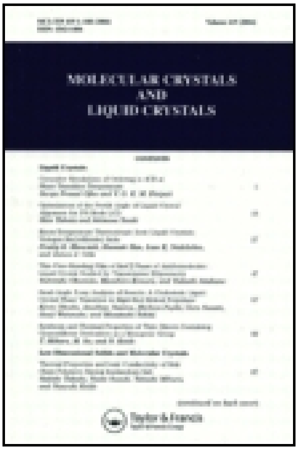

Molecular Crystals and Liquid Crystals

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

Polarization Grating of Photoaligned Liquid Crystals with Oppositely Twisted Domain Structures

Chang-Jae Yu [a], Jinyool Kim [a], Dong-Woo Kim [a] & Sin-Doo Lee [a]

[a] School of Electrical Engineering, Seoul National University, Kwanak, Seoul, Korea

Version of record first published: 31 Aug 2006

To cite this article: Chang-Jae Yu, Jinyool Kim, Dong-Woo Kim & Sin-Doo Lee (2005): Polarization Grating of Photoaligned Liquid Crystals with Oppositely Twisted Domain Structures, Molecular Crystals and Liquid Crystals, 433:1, 175-181

To link to this article: http://dx.doi.org/10.1080/15421400590955000

Mol. Cryst. Liq. Cryst., Vol. 433, pp. 175–181, 2005

ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421400590955000

Taylor & Francis
Taylor & Francis Group

Polarization Grating of Photoaligned Liquid Crystals with Oppositely Twisted Domain Structures

Chang-Jae Yu
Jinyool Kim
Dong-Woo Kim
Sin-Doo Lee
School of Electrical Engineering, Seoul National University, Kwanak, Seoul, Korea

We demonstrate a polarization grating of a liquid crystal (LC) in an oppositely twisted configuration using the photo-alignment technique. The polarization-modulated nature of the LC polarization grating is produced by a single-masking process with two step-exposure of a linearly polarized ultraviolet light. The LC polarization grating presented here produces high diffraction efficiency and polarization independence.

Keywords: binary configuration; photoalignment; polarization grating; twisted nematic liquid crystal

INTRODUCTION

Polarization gratings play a key role in various optical systems for data storage, ellipsometers, optical modulation applications, and three-dimensional (3D) displays [1–4]. Recently, liquid crystals (LCs) have been widely used for constructing the polarization gratings owing to large optical anisotropies and the associated electro-optical effects [3–8]. In order to obtain the polarization-independent feature of the LC polarization grating, in general, an elaborate photolithographic technique for multiple alignments of the LCs, a double-photoinduced

This work was supported in part by the Ministry of Science and Technology of Korea through the 21st Century Frontier Research and Development Program at the Information Display Center.

Address correspondence to Sin-Doo Lee, School of Electrical Engineering, Seoul National University, Kwanak, P.O. Box 34, Seoul 151-600, Republic of Korea. E-mail: sidlee@plaza.snu.ac.kr

alignment technique, or a polarization holographic technique for the periodic polymer-dispersion in the polymer-LC composite was used [5,8–12]. Except for the double-photoinduced alignment technique [11,12], however, such techniques inevitably involve the difficulty and complexity in precise modulation of the LC director.

In this work, we demonstrate a LC polarization grating in an oppositely twisted configuration using a single-masking process of the photo-alignment technique. In order to achieve the oppositely twisted nature, the photosensitive polymer, repeatedly altering the direction of the LC alignment on the substrate, was used for aligning the LC molecules homogeneously. The diffraction properties of the LC polarization grating were insensitive to the polarization of the input beam and the phase retardation depending on the cell thickness and the wavelength of light.

POLARIZATION GRATING CONFIGURATION

The basic structure of the LC polarization grating proposed in this study is described in Figure 1 where the LC molecules are twisted periodically in an alternating oppositely twisted configuration. In the Mauguin limit [13], the incident light through the uniformly aligned surface emerges from the cell alternatively rotated by an angle of 45° or $-45°$ with respect to the y-axis. The nature of the alternating rotation of the polarization vector naturally gives the LC polarization

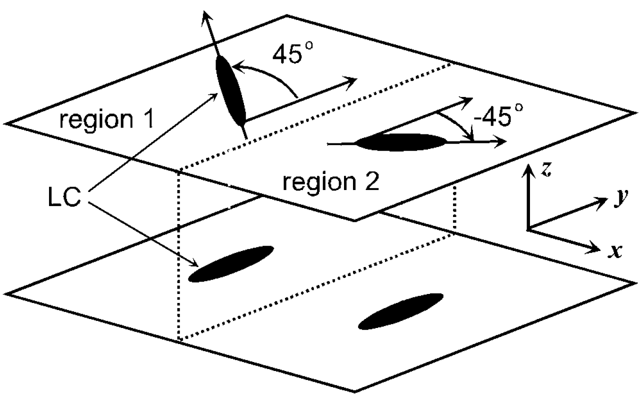

FIGURE 1 Schematic diagram of a LC polarization grating with oppositely twisted domains. At one substrate, the LC director is uniform along the y-axis and at the other one, the directors make angles of $\pm45°$ alternatively with respect to the y-axis.

grating in which the polarization modulation appears. Using the Jones matrix formalism [14], the emerging optical fields in the regions 1 and 2 are obtained by [8].

$$\mathbf{E}_1^{out} = \begin{pmatrix} A_x \exp(-i\varphi) + A_y \\ -A_x \exp(-i\varphi) + A_y \end{pmatrix} \text{ and } \mathbf{E}_2^{out} = \begin{pmatrix} A_x \exp(-i\varphi) - A_y \\ A_x \exp(-i\varphi) + A_y \end{pmatrix}, \qquad (1)$$

where A_x and A_y represent the x- and y-components of the incident light. The phase retardation is depicted by $\varphi = 2\pi\Delta nd/\lambda$ where Δn, d, and λ are the birefringence of the LC, the cell thickness, and the wavelength of light, respectively.

Let us now describe the diffraction properties of the LC polarization grating with the above polarization modulation. Within the Fraunhofer diffraction formalism for the binary anisotropic grating [7], the zeroth and first order diffraction efficiencies, η_0 and η_1 are

$$\eta_0 \propto \left\| \mathbf{E}_1^{out} + \mathbf{E}_2^{out} \right\|^2 \text{ and } \eta_1 \propto \left\| \mathbf{E}_1^{out} - \mathbf{E}_2^{out} \right\|^2. \qquad (2)$$

It should be noted that both diffraction efficiencies are expressed as certain constants independent of the polarization of incident light and the phase retardation through the LC cell.

In the presence of an applied voltage, the LC molecules with positive dielectric anisotropy are reoriented out of the substrates in the both domains, regions 1 and 2. In the vertically aligned region of the LC cell, the polarization modulation disappears and the diffracted beams disappear. This switchable features of our LC polarization grating are generally applicable for a switchable 2-dimensional/3-dimensional (2D/3D) display system where in the 3D mode, the switchable polarization grating divides the 3D images into the left- and right-images in a stereoscopic display [4]. On the other hand, in the 2D mode, the switchable grating passes the 2D images with no modulation.

EXPERIMENTS

The LC polarization grating with oppositely twisted domain structures was fabricated using glass substrates coated with the photopolymer of LGC-M2 (LG Cable Ltd., Korea). The photopolymer, aligning the LC molecules homogeneously under the illumination of a linearly polarized ultraviolet (LPUV) light and repeatedly alters

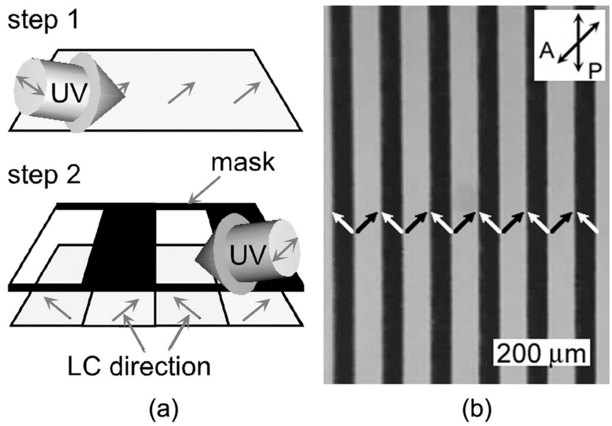

FIGURE 2 (a) Fabrication processes of a substrate having an alternatively aligned domains and (b) the microscopic texture of the LC polarization grating showing two alternating stripes. White and black arrows represent the LC director in the two domains.

the direction of the LC alignment depending on the polarization of the LPUV, has cinnamate-containing photosensitive groups attached to the polypyranose backbone. The substrate having alternately aligned LC domain structures was prepared with a single-masking process with two step-LPUV illumination as shown in Figure 2(a). After the LPUV exposure onto the whole region, the LPUV light through an amplitude photomask, whose direction of the modulation made an angle of 45° with respect to the initial LC director, was illuminated for aligning the LC molecules perpendicular to the initial director. The grating period was 100 μm and the cell thickness was maintained using glass spacers of 9.48 μm. The LC material used in this study was MLC-6012 of Merck. The dielectric anisotropy, the ordinary and extraordinary refractive indices of MLC-6012 are $\Delta\varepsilon = 8.2$, $n_o = 1.4620 + 5682/\lambda^2$, and $n_e = 1.5525 + 9523/\lambda^2$, respectively. Here λ is the wavelength of the light in nm.

A photodetector mounted on a motorized translation stage [15] and a He-Ne laser of 632.8 nm were used for measuring the diffraction intensities profiles. The microscopic texture of the LC polarization grating with oppositely twisted LC configuration is shown in Figure 2(b). The photograph showing two alternating stripes was taken with a polarizing optical microscope (Nikon, Optiphotpol II) under the analyzer rotated by 45° with respect to the polarizer. Here, white and black arrows represent the LC directors. In bright domains, the

LC molecules are aligned parallel to the analyzer, while in dark domains, they are perpendicular.

RESULTS AND DISCUSSION

Figure 3 shows the diffraction intensity profiles of the LC polarization grating for different polarizations of the incident light. Here, the normalized distance represents the unit distance for each order of diffraction in the grating along the x-axis. Open circles and triangles represent the diffraction intensities at the applied voltages of 0 V and 10 V, respectively. As shown in Figures 3(a) and (b), in the absence of an applied voltage, the incident light experiences the polarization modulation and the diffraction property appears on passing through the LC cell with oppositely twisted configurations. In the presence of an applied voltage, however, the LC molecules are reoriented homeotropically in both regions and the polarization modulation disappears.

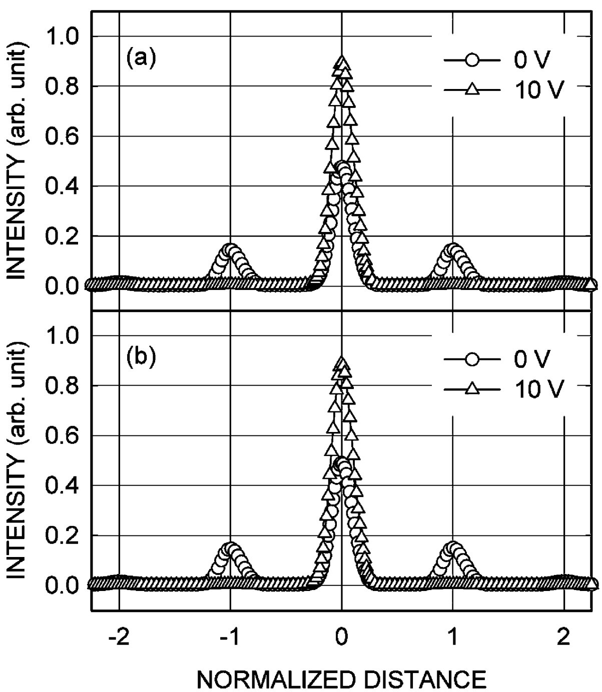

FIGURE 3 Diffraction profiles of the LC polarization grating as a function of the normalized distance at different applied voltages for the incident polarizations (a) parallel and (b) perpendicular to the x-axis.

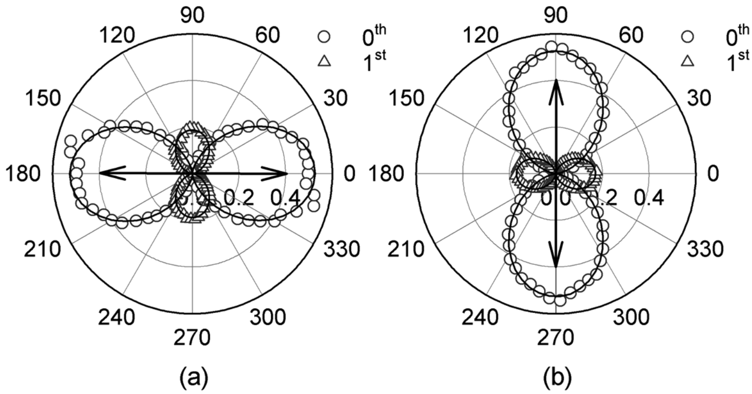

FIGURE 4 Polarization states of the zeroth-order (open circles) and first-order (open triangles) diffraction beams at the incident polarizations (a) parallel and (b) perpendicular to the x-axis. Solid lines represent the least-squares fits of the data to the case of a linearly polarized light and solid arrows represent the polarizations of the incident light.

It should be noted that the diffraction intensities for both polarizations of the incident lights, x- and y-polarized beams, are equivalent to each other. In principle, an arbitrary polarized light experiences the same polarization modulation in our LC polarization grating with oppositely twisted configurations where the twisted angle in two regions are symmetric and the adjacent angle between two twisted regions is perpendicular to each other.

The polarization states of the diffracted beams for x- and y-polarized cases of the incident light are shown in Figures 4(a) and (b). Here, open circles and triangles represent the zeroth-order and first-order diffraction intensities depending on the rotational angle of the analyzer with respect to the x-axis, respectively. Solid lines represent the least-squares fits of the data to the case of a linearly polarized light and solid arrows represent the polarizations of the incident light. The polarizations of the zeroth- and first-order diffractions were linearly polarized for both x- and y-polarized cases of the incident light. The polarization of the zeroth-order diffraction was coincident with that of the incident light, whereas the polarization of the first-order diffraction is perpendicular to that of the incident light. For the x- or y-polarized incident light, in principle, the zeroth- and first-order diffraction beams are linearly polarized and perpendicular to each other. Moreover, they are independent of the phase retardation, governed by the cell thickness and the wavelength of light, through the LC cell since the x- or y-polarized light is fully guided on passing through the oppositely twisted LC grating.

CONCLUSION

We demonstrated a LC polarization grating in an oppositely twisted configuration using the single-masking process with two step-exposure of the LPUV light. The diffraction patterns of our LC polarization grating with high diffraction efficiency were insensitive to the polarization of the input beam. Moreover, the zeroth- and first-order diffraction beams were linearly polarized and perpendicular to each other for both x- and y-polarized lights. The LC polarization grating presented here is expected to be applicable for various optical systems and a switchable 2D/3D display system.

REFERENCES

[1] Hasman, E., Bomzon, Z., Niv, A., Biener, G., & Kleiner, V. (2002). *Opt. Commun.*, *209*, 45.
[2] Ivanov, M. & Eiju, T. (2001). *Proc. SPIE*, *4580*, 664.
[3] Park, J.-H., Yu, C.-J., Kim, J., Chung, S.-Y., & Lee, S.-D. (2003). *Appl. Phys. Lett.*, *83*, 1918.
[4] Jung, S., Park, J.-H., Choi, H., & Lee, B. (2003). *Appl. Opt.*, *42*, 2513.
[5] Chen, J., Bos, P. J., Vithana, H., & Johnson, D. L. (1995). *Appl. Phys. Lett.*, *67*, 2588.
[6] Titus, C. M. & Bos, P. J. (1997). *Appl. Phys. Lett.*, *71*, 2239.
[7] Doucen, M. L. & Pellat-Finet, P. (1998). *Opt. Commun.*, *151*, 321.
[8] Wen, B., Petschek, R. G., & Rosenblatt, C. (2002). *App. Opt.*, *41*, 1246.
[9] Cipparrone, F., Mazzulla, A., & Russo, G. (2001). *Appl. Phys. Lett.*, *78*, 1186.
[10] Fuh, A. Y.-G., Lee, C.-R., & Mo, T.-S. (2002). *J. Opt. Soc. Am. B*, *19*, 2590.
[11] Gibbons, W. M., Shannon, P. J., Sun, S. T., & Swetlin, B. J. (1991). *Nature*, *351*, 49.
[12] Schadt, M., Schmit, K., Kozinkov, V., & Chigrinov, V. (1992). *Jpn. J. Appl. Phys.*, *31*, 2155.
[13] de Gennes, P. G. & Prost, J. (1993). *The Physics of Liquid Crystals,* Oxford University, Press: New York.
[14] Yeh, P. (1988). *Optical Waves in Layered Media*, Wiley: Chichester, U.K.
[15] Yu, C.-J., Park, J.-H., Kim, J., Jung, M.-S., & Lee, S.-D. (2004). *Appl. Opt.*, *43*, 1783.