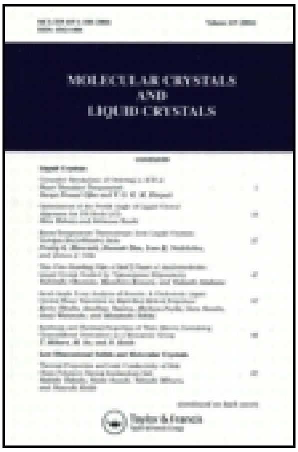

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Electrically Controlled 1D and 2D Cholesteric Liquid Crystal Gratings

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Electrically Controlled 1D and 2D Cholesteric Liquid Crystal Gratings

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Electrically induced and controlled gratings in large pitch cholesteric liquid crystals were investigated. Specially selected surface anchoring conditions together with well defined properties of cholesterics allow the formation of a stable periodic structure in the presence of a suitable external electric field. Polarization properties of first diffraction orders have been investigated as a function of the angle between the laser linear polarization and the grating direction. We propose to use two 1D gratings to create a 2D electrically controllable diffraction pattern, suitable for application in 3D optical devices.

Keywords cholesteric liquid crystals; diffraction grating; electro-optics

Introduction

Among liquid crystal materials, Cholesteric Liquid Crystal (CLC) phases present mesoscopic helical ordering, where the molecules arrangement gives rise to a periodic modulation of the refractive index. Consequently, CLCs can be regarded as 1D photonic crystals. The central wavelength of the CLC photonic band gap is determined by, $\lambda = \bar{n}p$ where $\bar{n}$ is the average refractive index and p is the length of the helical pitch [1]. The periodic helical structure leads to specific optical properties, which are determined by the pitch and the arrangement of the helical axis itself and these materials are well known for optical and electro-optical applications, such as low-voltage light modulators [2–4], smart reflectors [5] and mirror-less lasers [6, 7].

CLCs can also be used to produce diffraction gratings with two possible optical configurations: reflection gratings, when in the Bragg diffraction regime, and transmission gratings, in the Raman–Nath diffraction condition. The first regime is defined when the helix axis is perpendicular to the walls of the CLC cell, while the Raman–Nath regime occurs when the helix axis is parallel to them [8]. The transition from Bragg to Raman-Nath-regime can be achieved by applying an electric field as it was well investigated in [9, 10]. Several techniques and materials have been used to produce diffraction gratings in Raman–Nath regime, such as the phase separation of LC in polymer matrix [11, 12] and the spatial patterning of LC alignment layers [13–16].

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In this work we report electrically switchable and controllable CLC gratings obtained by applying an appropriate electric field to a planar cell. Moreover, we investigate the polarization properties of first diffracted orders for a laser beam passing through the CLC cell. Then we present the 2D diffraction pattern obtained by orthogonally overlapping of two CLC gratings.

Generally, in a planar cell with a sandwich geometry with the liquid crystal films contained between to planar glasses, the helix axis of a CLC is aligned perpendicular to the surface defined by the glass plates of the liquid crystal cell. If the CLC has a positive dielectric anisotropy, when an electric field is applied, a "fingerprint" texture appears, in which the helix axes are randomly distributed parallel to the confining surfaces. If the confinement ratio $C = d/p \approx 1$, where d/p is the cell thickness to natural pitch ratio, one observes a uniform strip texture [10]. These strips have a uniformly modulated structure with a period depending on the cell thickness. They occur when the magnitude of the applied voltage varies between two transition voltages: $U_{PC} = \pi/p\{[k_{11}(p/d)^2 + 4k_{33}]/\Delta\varepsilon\varepsilon_0\}^{1/2}$ and $U_{CH} = (\pi^2 d/p)(k_{22}/\Delta\varepsilon\varepsilon_0)^{1/2}$. U_{PC} is the voltage necessary for the transition from planar to cholesteric fingerprint texture [17] and U_{CH} is the voltage necessary for the transition from fingerprint texture to a homeotropic configuration [18]. k_{11}, k_{22} and k_{33} are the splay, twist and bend elastic constants, respectively, ε_0 is the vacuum permittivity, and $\Delta\varepsilon$ is the dielectric anisotropy of the liquid crystal.

Sample Preparation

For our experiments, several CLC mixtures are prepared by doping a left-handed chiral agent ZLI-811 with a highly birefringent nematic BL-006 (both from Merck). The optical and dielectrical anisotropy of BL-006 at T = 20C°, λ = 589 nm, and $f = 1$ kHz are $\Delta n = 0.28$ and $\Delta\varepsilon = +17.3$ respectively. The mixtures are stirred in the isotropic phase, in order to make the constituents uniformly mixed, and then capillary filled into a cell. The inner surfaces of the cell are coated with a thin polyvinyl alcohol (PVA) layer and rubbed to provide uniform in-plane molecular orientation. The empty cell thickness is measured by optical interference methods and then the helical pitch of the cholesteric mixture is adjusted to match the cell gap via doping an adequate concentration of the chiral agent ($d/p \sim 1$). After the temperature is gradually cooled down to room temperature, the cholesteric texture appears. All measurements are performed in cells with average thickness $d = 12\ \mu m$. The instrument for observing the grating is a polarizing microscope (DMRX, Leica).

Results and Discussion

The cell filled with the CLC mixture shows the typical texture observed when the helical axis is perpendicular to the substrates. By applying a proper electric voltage the grating structure is obtained with the helix axis now parallel to the cell substrates. Figure 1 shows the typical grating visible when a polarized polychromatic light beam enters normally to the surface of a cell containing the mixture 99.6% BL-006 + 0.4% ZLI-811.

The stripes are oriented along the rubbing direction when the applied voltage is U = 4.1 V at 1 kHz. The grating is uniform, stable in applied electric field, and with a periodicity of about 20 um. This periodicity is due to the modulation of the refractive index. It should be noted that the orientation of the stripes strongly depends on the angle β between the rubbing directions of the two plates and the ratio d/p (*19*). For $\beta = 0°$ and $d/p = 1$ the stripes are oriented along the rubbing direction [10, 19].

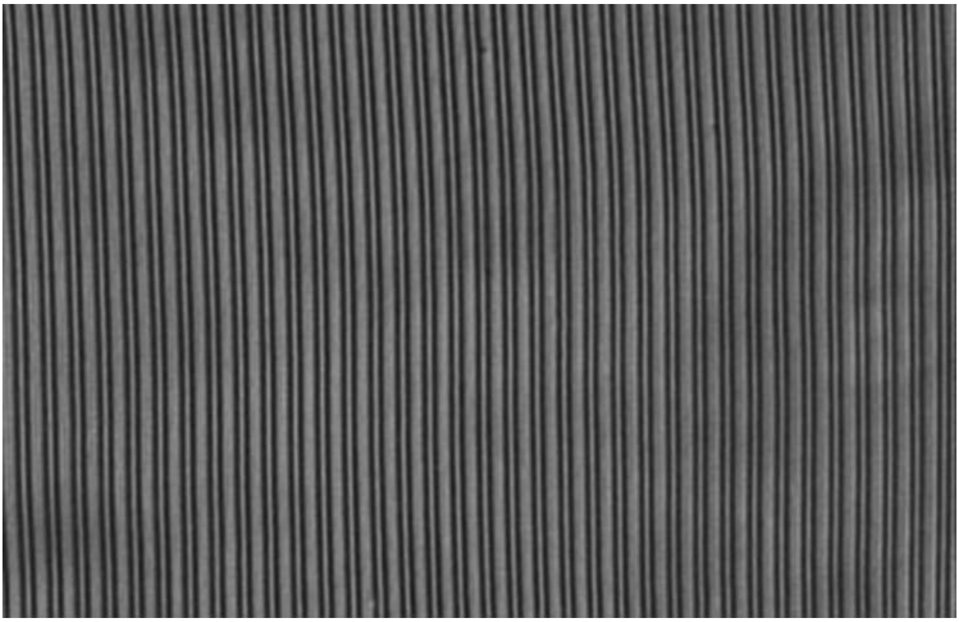

Figure 1. 1D grating observed under a polarizing optical microscope.

CLC gratings diffract a non polarized light into several beams traveling toward different directions. The directions of these beams depend on the spacing of the gratings and the wavelength of the incident light, so that the gratings act as a dispersive element. The grating shown in Fig. 1 splits an incident non-polarized polychromatic beam into its constituent wavelength components, from blue to red, as shown in Fig. 2.

To study the diffraction properties of the CLC gratings, a He–Ne polarized laser is used. The cell is mounted on a rotary stage, normally oriented with respect to the laser beam

Figure 2. Light dispersed due to the grating structure.

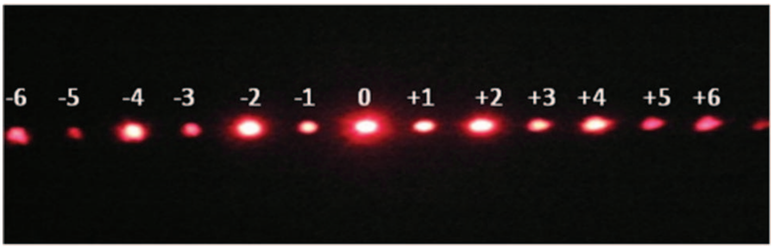

Figure 3. 1D diffraction pattern of CLC grating probed by He-Ne laser.

and a linear polarizer whose orientation is controlled by another rotary stage placed behind the cell. The laser beam is polarized parallel to the grating axis. When the applied voltage exceeds the first threshold voltage $U_{PC} = 1.4$ V, a diffraction pattern appears, visible until the third order. When the voltage exceeds the second threshold $U_{CH} = 5$ V, the diffraction pattern disappears due to the cholesteric-homeotropic nematic transition. Figure 3 shows a picture of the diffraction pattern of the CLC grating in Fig. 1 obtained at U = 4.1 V. It exhibits up to 6th orders of diffraction, depending on the intensity of the applied voltage.

The intensity of the diffraction pattern is rather unusual, thus the strongest maxima are the even-orders (±2, ±4, ±6) whereas the odd-orders diffraction maxima (±1, ±3, and ±5) are significantly weaker. This unusual diffraction pattern has been studied experimentally as well as theoretically in pure cholesterics [10, 20] and in polymer doped cholesterics [21]. To measure the diffraction intensity, we fix the cell between crossed polarizers (polarizer: the polarization of laser beam, analyzer at 90° with respect to the polarizer) and then we rotate the cell with an angle α, which varies from $-90°$ to $+90°$. The angle α is the angle between the direction of the stripes in the grating and the axis of the polarizer. The intensity of the first orders against α is measured using a power meter placed behind the analyzer (Model 70260, Spectra-Physics). Figure 4 shows the intensity of 0, ±1 and ±2 orders. As expected, the minimum intensity of the 0 order is visible at -90°, 0°, and +90° because at these angles the grating direction is parallel to one of the polarizers. The maximum intensity is recorded at ±45°. For the 2nd order of diffraction the curve of the intensity vs. α has the same shape as for the 0th order but at lower intensities. The behaviour of the 1st order not only exhibits less intensity than the 2nd order but also shows an opposite dependence from

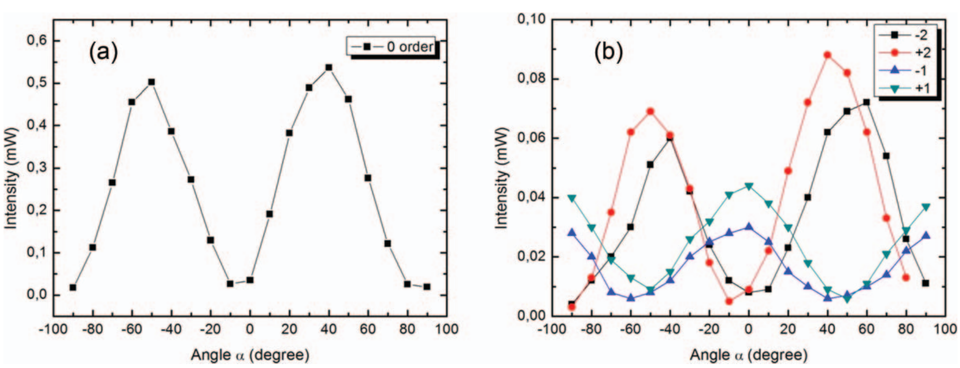

Figure 4. Angular dependent intensity of the diffracted beams for: a) zero diffraction order, b) first and second diffraction orders.

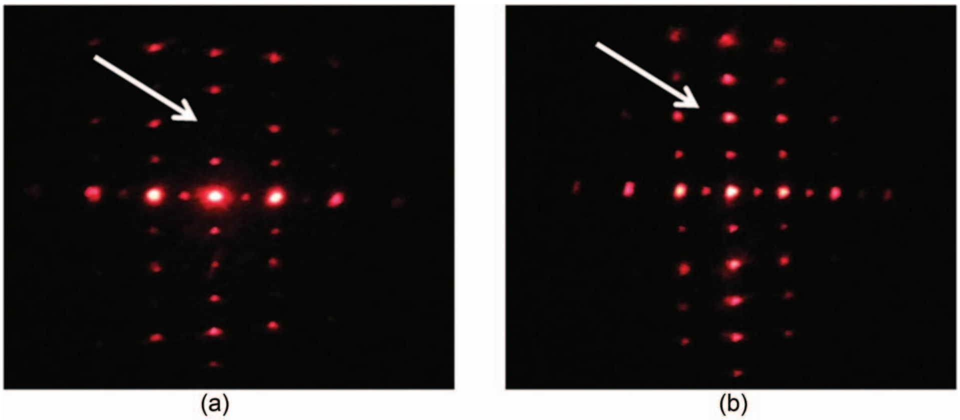

Figure 5. 2D diffraction pattern from two orthogonal overlapped CLC gratings probed by He-Ne laser at: a) $\gamma = 0°$, b) $\gamma = 90°$.

the angle α. At $\pm 45°$, the intensity peak for the 2nd order is higher than the 1st order of about 60%. From the intensity variation we can conclude that the polarization of the orders is not circular, but we can suppose it is linear or elliptical.

In order to obtain a 2D grating we have overlapped orthogonally two 1D structures. To analyze the overall diffraction pattern, we fix the cells between crossed polarizer. The 2D diffracted pattern is displayed on a screen as it is shown in Fig. 5. The polarization properties of the diffractive pattern are complicated to investigate. Therefore, instead of rotating the cell we rotate the analyzer of an angle γ with respect to the polarizer. γ varies from $-90°$ to $+90°$.

Figure 5 exhibits two pictures taken at $\gamma = 0°$, and $\gamma = 90°$. It is clearly shown that some order completely disappear at $\gamma = 0°$, and others at $\gamma = 90°$ as indicated by arrows in the Fig. 5. Seemingly this is due to the fact that each of these orders has a different polarization and can be manipulated separately. Interestingly, the same result, switching on/off of some order, is obtained by applying electric fields of proper amplitude to both cells. Then the 2D diffraction pattern can be electrically controlled.

Conclusion

We have experimentally shown an electrically induced and dynamically controlled 2D CLC grating system consisting of two spatially separated and orthogonally overlapped 1D CLC gratings. This kind of architecture gives some advantages over the existing 2D gratings. In fact, an electric field applied to only one of the two 1D grating gives opportunity to dynamically switch a 2D grating into a 1D grating and vice versa. Moreover, by changing the applied voltage to each of the cells, one can control intensity of the 2D pattern and switch on or off some orders of the 2D diffraction pattern. These kinds of facilities will open new pathways for the fabrication of 3D optical effect based devices for applications such as 3D movies and 3D photography, image conversion, optical data storage and communication.

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