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ЗАПИСЬ ДИНАМИЧЕСКИХ ПОЛЯРИЗАЦИОННЫХ РЕШЕТОК В ЧИСТОМ НЕМАТИЧЕСКОМ ЖИДКОМ КРИСТАЛЛЕ

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Посвящена экспериментальной реализации записи поляризационных динамических решеток в чистом нематическом жидком кристалле. Механизм регистрации основан на фоторефрактивном эффекте в ячейке, заполненной чистым кристаллом нематика, под действием приложенного постоянного электрического поля. Это явление не требует наличия фотовозбужденных носителей заряда в жидком кристалле и объясняется экстремально высокой анизотропией жидкого кристалла. Приведена элементарная теоретическая модель данного процесса. Исследованы зависимости процесса записи решетки от пространственной частоты интерференционного поля и интенсивности записывающих пучков. Обнаружено, что пространственно решетка не совпадает с интерференционным полем, т. е. отклик среды нелокальный. Однако мы не связываем подобное свойство с аналогичным в фоторефрактивных кристаллах. В нашем случае более вероятен механизм чисто геометрического рассогласования в силу особенности механизма записи. Одним из фундаментальных свойств описываемых процессов является их независимость от длины волны записывающего излучения, что подтверждает выбранную нами модель механизма записи.

Ключевые слова: жидкие кристаллы; фоторефрактивный эффект; голография.

RECORDING THE DYNAMIC POLARISATION GRATINGS IN PURE NEMATIC LIQUID CRYSTAL

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We report on experimental realisation of polarisation dynamic gratings recording in pure nematic liquid crystal. This work is devoted to the experimental implementation of writing polarisation dynamic gratings in a pure nematic liquid crystal. The registration mechanism is based on the photorefractive effect in a cell filled with a pure nematic crystal under the action of an applied constant electric field. This phenomenon does not require the presence of photoexcited charge

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carriers in the liquid crystal and is explained by the extremely high anisotropy of the liquid crystal. The article provides an elementary theoretical model of this process. The dependences of the grating writing process on the spatial frequency of the interference field and the intensity of the recording beams are investigated. It was found that the spatial grating does not coincide with the interference field – the response of the medium is non-local. However, we do not associate this property with that in photorefractive crystals. In our case, a mechanism of purely geometric mismatch is more likely due to the peculiarity of the recording mechanism. One of the fundamental properties of the described processes is their independence from the wavelength of the recording radiation, which confirms the model of the recording mechanism we have chosen.

Keywords: liquid crystals; photorefractivety; holography.

Introduction

Liquid crystals (LC) with their unique ability to be reoriented by small electrical fields are promising photorefractive media. It should be noted that the formation of permanent diffraction structures in the LC layer can be realised by different methods [1; 2].

First experimental observations of molecules orientation changes in a spatially inhomogeneous electrical field under applied light wave were reported in works [3; 4]. These experiments were performed using dye-doped LCs. In [3] it was observed, that in LC doped with laser dyes the joint influence of photoexcited charge carriers and direct current (DC) electric field applied parallel to the director resulted in a reorientation of LC. I. Khoo and S. Slussarenko have found that a similar phenomenon is possible in LC doped with azo-dye without the applied external DC field (diffusion spatial charge formation mechanism [5]). In this case, the field of spatial charge created due to diffusion of photoexcited charge carriers in the inhomogeneous light field was enough for effective reorientation of LC. In work [6], a dynamic grating was recorded for the first time in a cell with a pure nematic when a constant electric field was applied. It should be noted that in the case of applying a constant field, all processes develop in the region of the formation of a double charge layer.

Model

It was shown in [5] that he mechanism of space charge field formation could be due to the Helfrich – Carr effect. Let us imagine that in a nematic LC the orientation was locally changed under the influence of DC electric field (fig. 1).

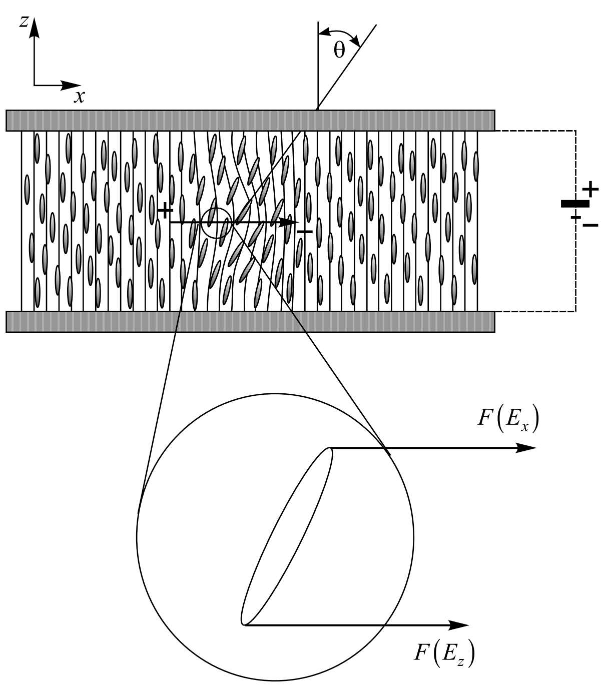


Fig. 1. Transversal field formation

Inhomogeneous light field, for example, could cause this change in the case of sinusoidal grating writing. The orientation disruption results in the local change of the conductivity of LC and the formation of a transversal field component. The magnitude of this component can be defined as

$$E_{x,\,\sigma} = -\frac{\left(\sigma_{\parallel} - \sigma_{\perp}\right)\cos\Theta\sin}{\sigma_{\parallel}\cos^2\Theta + \sigma_{\perp}\sin^2\Theta}E_z. \quad (1)$$

The local change in the dielectric permittivity results in similar input

$$E_{x,\,\varepsilon} = -\frac{\left(\varepsilon_{\parallel} - \sigma\varepsilon_{\perp}\right)\cos\Theta\sin}{\varepsilon_{\parallel}\cos^2\Theta + \varepsilon_{\perp}\sin^2\Theta}E_z, \quad (2)$$

where σ is the conductivity and ε is the permittivity (along and perpendicular to the long molecular axis); E_z is the external DC field; $E_{x,\,\sigma}$, $E_{x,\,\varepsilon}$ are the transversal components of the electric field formed due to change of conductivity and permittivity, respectively; Θ is the director reorientation angle.

The transverse field formation, in turn, results in further LC molecules deflection and, as a result, leads to its further increase.

In [6] similar mechanism was demonstrated experimentally and high-efficiency dynamic holography gratings recording were realised. Here we propose to use the orientational non-linearity as a starting reorientation mechanism [7]. The initial director orientation, caused by this non-linearity can be described as

$$\Theta \approx \frac{\varepsilon_a |E|^2 L\sin(2\alpha)}{32\pi K}, \quad (3)$$

where Θ is the director reorientation angle; E is the light field intensity; α is the angle between light polarisation and director; ε is the dielectric permittivity; K is the Frank constant.

We can see from (3) that in case if the light field is a result of interference of two coherent beams then the director reorientation is modulated a similar way. However, such modulation can also be realised in case not only with light intensity change but also its polarisation. Such modulation is a result of an interference of two beams with perpendicular polarisations.

This work describes the experimental realisation of such grating recording using the described above mechanism. It should be mentioned here that for this polarisation recording the intensity of the light field remains homogeneous and all other possible mechanisms of grating recording are not considered.

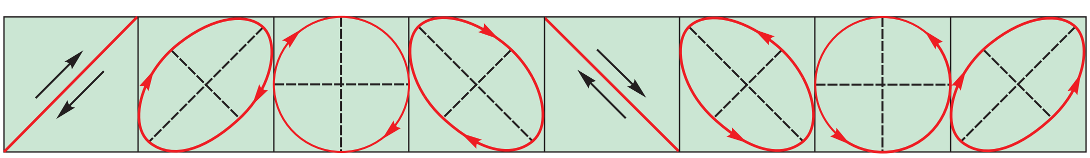
Experiment

The cell used consisted of two glass surfaces covered by conductive ITO layers and nematic LC 5CB (*Merck*, Great Britain), oriented homeotropically. Homeotropic orientation was induced by applying a layer of chlorosilane on a surface of ITO and the consequent heating up to 160 °C. The cell thickness was determined by a 20 μm polymer spacer.

Additionally, the cell was placed into the interference field of two wave YAG : Nd laser beams (λ = 0.53 μm, intensity of beam about 10 mW), laser beams and director of LC were in the beam incidence plane (fig. 2). The second beam was polarised perpendicular to the first one.

The DC electric field in a range from 0 to 6 V has been applied to the cell. The conductance of LC was about 10^{-12} cm/Ohm and has not been changing under the light applied.

Despite the absence of photoexcited charge carriers, light intensity modulation, and absorption at the wavelength of 0.53 μm, we were able to register the self-diffraction, which appeared only under application of the external field of a certain value. These conditions were similar to the ones described in [4]. It is also important to mention that only one writing beam was taking part in process of self-diffraction as for *o*-wave there is no



$\delta = 0$ $\quad 0 < \delta < \frac{\pi}{2}$ $\quad \delta = \frac{\pi}{2}$ $\quad \frac{\pi}{2} < \delta < \pi$ $\quad \delta = \pi$ $\quad \pi < \delta < \frac{3\pi}{2}$ $\quad \delta = \frac{3\pi}{2}$ $\quad \frac{3\pi}{2} < \delta < 2\pi$

Fig. 2. Polarisation of optical field

modulation of $\hat{\varepsilon}$. It could be noted, $\hat{\varepsilon}$ is modulated only for *e*-wave and thus the diffraction is observed only for *e*-wave. The polarisation corresponds to the extraordinary wave in the geometry of the experiment (fig. 3), i. e. has an asymmetrical form.

To analyse the conditions of self-diffraction appearance the intensity of the first non-Bragg order was registered. The self-diffraction was appearing at voltages >2.2 V. This complies well with the results of [5]. The diffraction efficiency (maximum is about 1.5 %) showed a linear dependence on writing beams intensity (fig. 4).

The dependence of diffraction efficiency on spatial frequencies is shown in fig. 5. The maximum diffraction efficiency corresponds to a cell with a period of about 20 μm. The decrease of the diffraction efficiency at high frequencies is due, as in most cases of grating formation in LC cells, to elastic forces of LC that counterforce the grating formation. The decrease at low frequencies is possibly explained by the limited size of the writing beams, on the one hand, and by a reduction of the voltage of the induced space pseudo-charge field, on the other hand.

The fact that orientation non-linearity is not connected to absorption in LC leads to the fact that the described phenomena can be observed not only for the light of He – Cd laser but also for almost any wavelength. We also have observed it using He – Ne laser (0.632 8 μm) and all generation lines of Ar^+ laser.

It is worth mentioning that for long (about 1–2 h) exposure under conditions of self-diffraction, the phenomena of permanent grating formation were observed: if applied electrical field remained the same it was possible to observe diffraction of the probe beam of He – Ne laser in the absence of writing beams. When the applied voltage was switched off the diffraction disappeared, but with repeated application of the voltage to the cell, the diffraction appeared again. It is possible, that long exposition under applied voltage leads to structural changes in the polymer at the cell surfaces. These changes have the character of the modulation, reflecting the interference field. This modulation itself is too weak to cause substantial diffraction, but due to the processes described above the grating amplification under the applied field appears.

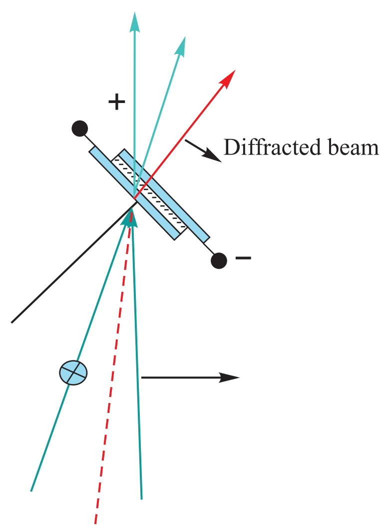


Fig. 3. Configuration of the experiment

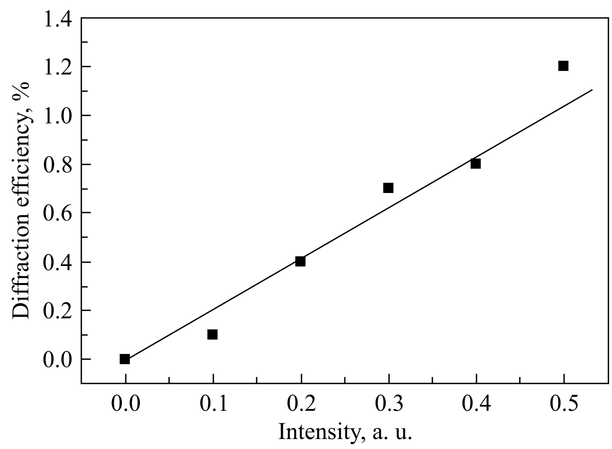


Fig. 4. Linear dependence of diffraction efficiency on the intensity of writing beams

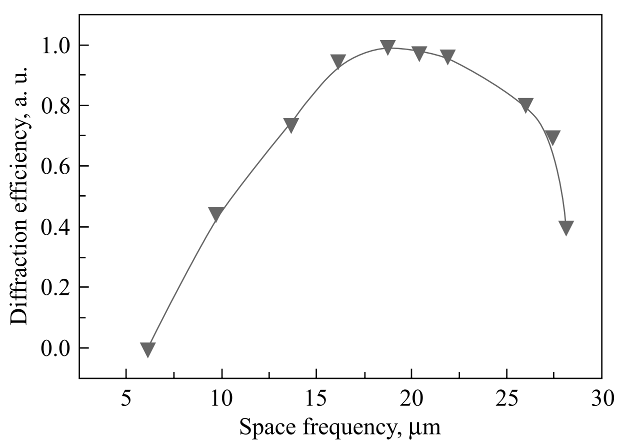


Fig. 5. Dependence of diffraction efficiency on spatial frequencies

Non-locality of the effect

The usual way to check for the signature of photorefractivity, i. e. to find the non-locality of the medium response, is by performing a two-beam coupling experiment. However, in the case of Raman – Nath grating, the presence of higher diffraction orders may confuse and even hide the expected results. Thus, we decided to perform the non-locality check with the method of moving grating.

As it was shown in reference [8], the position of a stationary grating with respect to the interference pattern of the writing beams can be found through a relative displacement analysis. The displacement should be induced by any method along the grating vector and measured in a short time scale with respect to the grating formation time.

We induced a grating displacement corresponding to two spatial periods by phase modulation of one writing beam using a Pockel's cell. We then recorded the light intensity of the zero-order diffracted beams. This intensity behaviour versus time is dependent on the relative initial position of the grating and the writing interference pattern, thus allowing the required test of non-locality. The theoretical details of the method are beyond the scope this article and can be found elsewhere [8; 9].

The schematic of the experiment is shown in fig. 6.

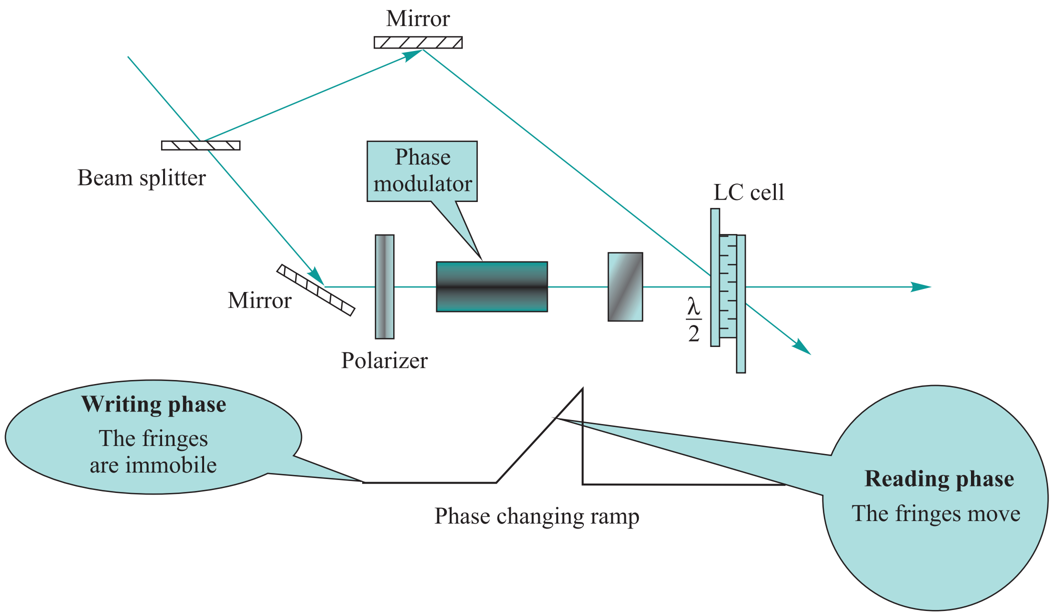


Fig. 6. Experimental set-up for moving grating measurement

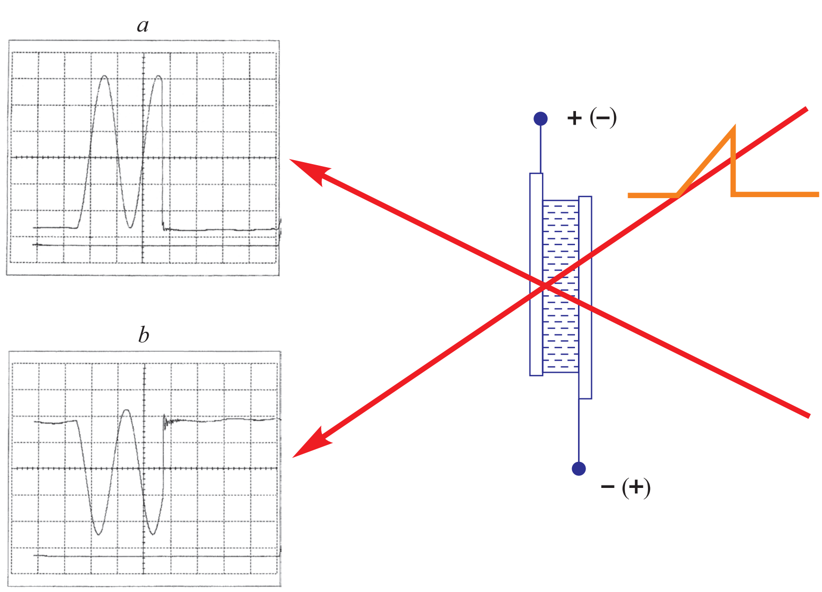


Fig. 7. Temporal behaviour of the writing beam in the moving grating experiment

Our results are shown in fig. 7 and demonstrate that in a steady state the phase shift between the grating and writing interference pattern is exactly $\frac{\pi}{2}$ (see fig. 7). Moreover, the sign of the phase shift depends on the voltage polarity.

The figure shows the intensities of the zero-order diffraction. Oscillograms (see fig. 7) correspond to different polarities of the voltage applied to the bounding surfaces of the cell. It can be seen that, in one case, the intensity increases to a certain value (the initial shift of the grating relative to the interference field $\left(-\frac{\pi}{2}\right)$) and, with an increase in the shift, again returns to the original intensity. When changing the polarity, we have the opposite picture – a drop in intensity (the initial shift of the grating relative to the field $\left(+\frac{\pi}{2}\right)$).

Conclusions

The experiments described above suggest that the main mechanism responsible for the effects is the amplification of the light-induced distortion of the LC anisotropy. The diffraction efficiency (DE) dependence on the spatial period, shows a non-monotonic behaviour. The maximum DE is correlated with the cell thickness. The DE decrease at smaller periods is due, as in most cases of grating formation in LC cells, to the action of elastic forces that counteract the grating formation. The DE decrease at higher periods can be explained, on one hand, by the limited number of fringes in the illuminated spot and, on the other hand, by the reduction of the induced electric field. This is because a larger grating pitch induces a smaller local distortion, hence a smaller local anisotropy change, which in turn produces a lower transverse electric field.

The non-locality of the effect needs to be discussed, too. Equations (1), (2) give no evidence of this attribute. The well-studied orientation non-linearity is local, too. It can be assumed that the non-locality in our case is associated with a misadjustment of the interference field (tilted by 45 degrees) and formed perpendicular to the cell surface grating. This mismatch is the result of the fact that the grating is formed near the bounding surface, where, due to the formation of a double charge layer, the applied field is localised. Finally, we notice that the light field in all experiments presented here has only the role to induce an initial director distortion that gives rise to the photorefractive effect. Furthermore, in one case, where a memory effect maintains the previously generated pre-distortion, there is no need for an inducing light field.

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