Nanocomposites and nanomaterials

Laser beam steering in liquid crystal valves

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Abstract

Experimental studies of nominally pure nematic liquid crystals (NLC) confirm the recording of dynamic holographic gratings not only in cells with a homeotropic orientation, but also with a planar one. An explanation can be found that comes from the photorefractive grating recording mechanism, the features of which are the formation of an unbalanced charge on the surface of the cell substrate under the action of a spatially inhomogeneous light field. The appearance of an internal tangential electric field (along the cell substrates), together with an external electric field applied normal to the cell substrate, adds up to additional elements possible in controlling the vector resultant electric field. In this work, a model of the change in the intensity of laser beams during their self-diffraction and diffraction on a dynamic grating created at the NRC is developed and analyzed. The dynamic phase grating is formed due to the orientation mechanism of birefringence in the NRK during the two-beam interaction of laser beams, which completely spatially and periodically divides the interference pattern of the light field. The results of calculations of the initial intensities of laser beams in the first orders of self-diffraction and diffraction are in good agreement with experimental measurements. with which they explain the dependence of the diffraction efficiency on the magnitude of the external applied voltage, which has a well-defined maximum.

THEORY

DEPENDENCE OF THE DIFFRACTION EFFICIENCY ON THE APPLIED EXTERNAL VOLTAGE

In the previous sections, we obtained the important result that the initial intensities in the first diffraction orders in the NRK cells with the orientational S-effect of birefringence reach their maximum values for certain angles of reorientation of the director. As noted earlier, with a positive electro-optical effect in the NRC, the director takes the direction along the active electric field (for NRC with $\Delta\varepsilon>0$).

$$\begin{cases} E_z(U) = \frac{U}{L} = E(U)\cos[\theta(U)] \\ E_x = \text{const} = E_x^{max} = E^{max}\sin[\theta^{max}] \end{cases} \quad 1)$$

where Ez (U) is the variable value of the external electric field depending on the applied voltage U, which leads to a change in the value of the vector of thetotal field E(U) and the corresponding orientation angle of the director Θ(U). We can determine the magnitude of the constant field Ex=Ex,max if we know the angle Θmax at which the maximum value of the diffraction efficiency is observed. Let θmax be achieved for the total field Emax(U0)=Ez, max(U0)+Ex, max for a certain value of U0. It can be seen from system (9) that it is possible to exclude the value of the field Ez, max(U0) and we will get the formula for Ex,max:

$$E_x^{max} = \frac{U_0}{L}tg(\theta^{max}) \quad 2)$$

If, as in the previous calculations, it is necessary to base the value of θ(U) in the formulas for θ (1) and (2). From system (9) based on calculation (10) we produce:

$$\theta(U) = tg\left[\frac{U_0}{U}\cdot tg(\theta^{max})\right] \quad 3)$$

Recording of dynamic grating in the cell of LC is spatial modulation of angle to inclination of director. Modulation of angle of inclination of director in LC results in spatial modulation of refraction index.

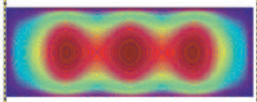


Fig. 1. **Distribution of angle of inclination of director. U=5 V, L=30 μm, Λ=50 μm.**

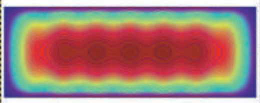
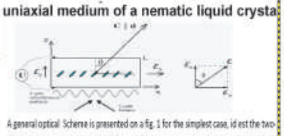


Fig. 2. Mashines of grating in course wish time, or at a small spatial period: λ=20 μm

Fig. 3. **A grating with a maximal modulation-depth**

Scheme of a two dimensional cell of a uniaxial medium of a nematic liquid crysta



A general optical Scheme is presented on a fig. 1 for the simplest case, id est the two-dimensional system and reorientation of director are examined in the volume of cell.

Fig. 4. Scheme of a two-dimensional model of a uniaxial medium of a nematic liquid crystal. is the tilt angle of the LC director relative to the z axis; **d** is the LC director coinciding in direction with the orientation of the long axes of the LC molecules; vector **c** is the optical axis of the LC medium; L is the thickness of the LC cell. The vectors **Ez** and **Ex** is the acting electric field; **k** is the wave-vector of light. **o** and **e** are the directions of extraordinary and ordinary polarization of a light beam.

A SCHEMA OF TWO-BEAM INTERACTION IN LC

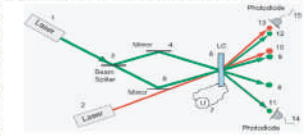


Fig 5. Optical scheme of two-wave mixing in LC cell
"Green" laser (second harmonic Nd:YAG) - for dynamic grating and self-diffraction of laser beams.
"Red" laser (He-Ne) - for testing - diffraction on a given grating.

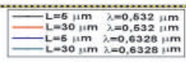


Fig. 6. The maximum value of the change in the phase shift d(L, q) depending on the orientation angle of the director q and on the thickness L of the NRC cell with homeotropic orientation. The orientation angle of the director q is in the range from 0 to p/2 radians relative to the z axis. The thickness L of the liquid crystal cell varies in the range of values from 5 to 30 mm. The maximum value of the phase shift d(L, q) is calculated in radians.

SELF-DIFFRACTION

The following formula was obtained for the initia l intensity in the first order of self-diffraction [1]:

$$I_{\{-1\}} = I_{\{+1\}} = TI_0\left[J_1^2(\delta) + J_2^2(\delta)\right]$$

Fig. 7. Normalized intensity (diffraction efficiency) of self-diffraction in the first diffraction order depending on the angle of rotation of the director θ in the NRC cell 5CB. The graphs were calculated for light wavelengths λ=0.532 μm and λ=0.6328 μm and NRC cells with a thickness of 5 and 30 μm.

TEST BEAM

The following formula was obtained for the initial intensity in the first-order diffraction of the test beam of light [1]:

$$I_{\{-1\}} = I_{\{+1\}} = TI_0\,J_1^2(\delta)$$

Fig. 8. Normalized intensity (diffraction efficiency) of self-diffraction in the first diffraction order depending on the angle of rotation of the director θ in the NRC cell 5CB with planar orientation. The graphs were calculated for light wavelengths λ=0.532 μm and λ=0.6328 μm and NRC cells with a thickness of 5 and 30 μm.

Fig. 9. Diffraction efficiencies in the first diffraction order depending on the value of the external applied voltage for the test beam. Black curves for 5 μm, red curves for 30 μm. NRC Cell E7 "without absorption": , Leff=L.

A) RECORDING A DYNAMIC GRATINGS: IN HOMEOTROPICAL ORIENTED LC CELLS. NRC CELL WITH HOMEOTROPIC ORIENTATION.

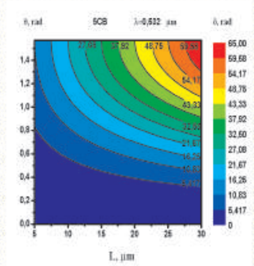
At the output of the cell, the difference between the onsets of phases δ, for ordinary and unusual laser beams is equal to [1]:

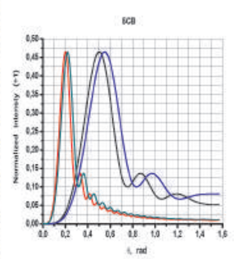
$$\delta = (2\pi/\lambda)(n_e(\theta) - n_0)L \quad 4)$$

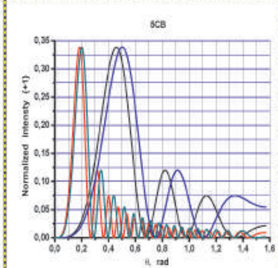
where λ is the wavelength of light, $n_e(\theta)$ is the unusual refractive index of light, which depends on the reorientation angle of the director θ relative to the z axis; n0 is the usual refractive index of light.

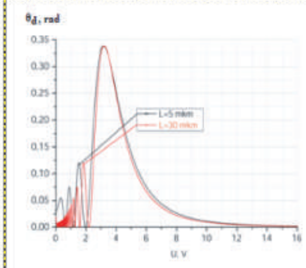
The dependence of the refractive index for an unusual wave on the angle of rotation of the director θ is described by the formula (see [1]):

$$n_e(\theta) = \frac{n_0 n_e}{\sqrt{n_e^2\cos^2\theta + n_0^2\sin^2\theta}} \quad 5)$$









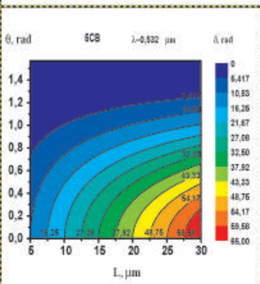
B) RECORDING A DYNAMIC GRATINGS: IN PLANAR ORIENTED LC CELLS. NRC CELL WITH PLANAR ORIENTATION.

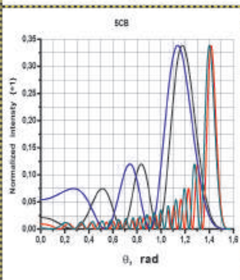
Consider the variable depth of modulation of the dynamic gratings in the NRC cell with the initial planar orientation of the molecule. In this case, the initial angle of the director Θ= π/2, and the angleΘ, changes in the opposite direction, that is, from π/2 to 0 (π/2..0). Thus, the "background" will have a maximum value of δ:

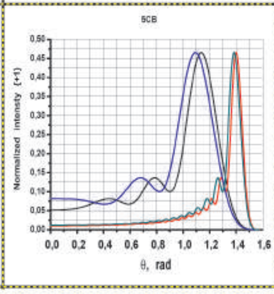
$$\delta_{max}(L,\theta=\pi/2) = (2\pi/\lambda)(n_e - n_o)L \quad 6)$$

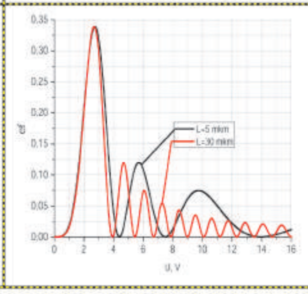
where $n_e = n_\parallel$, $n_o = n_\perp$, and the lattice amplitude it self will decrease. Then it is the difference between the "background" and δ(Θ) that will determine the modulation depth of the dynamic grating:

$$\delta_{plane} = \delta_{max}(L,\pi/2) - \delta(L,\theta) \quad 7)$$









CONCLUSIONS

The paper developed a model for calculating the intensity of laser beams in higher diffraction orders during the two-beam interaction of laser waves in the cells of nematic liquid crystals. Both the intensity in the self-diffraction mode for recording laser beams and for the test laser beam when it is diffracted on a dynamic grating are calculated. The modulation depth of the phase dynamic grating is calculated in the assumed mechanism of the change in the orientation of the NRC director under the action of the electric field, which leads to a change in the amount of optical birefringence in the NRC cell.

Within the framework of the developed model, such experimental results can be explained using the photorefractive mechanism of recording dynamic gratings. Its feature is the generation of an unbalanced charge and the formation of an internal electric field of a space charge under the action of a light interference pattern. Thus, the resulting electric field, which leads to reorientation of the director, consists of an external electric field due to the voltage applied to the cell, and an internalelectric field of the space charge, which arises under the action of light. If we consider the internal field to be independent of the applied voltage U, then a change in the value of U will lead to a change in the value of the vector of the external field and a rotation of the resulting total vector of the electric field. As a result, there is a reorientation of the NRC director, which is aligned along the vector of the total electric field acting in the cell.

In accordance with our model, it was found that the diffraction efficiency reaches a maximum for a certain angle of rotation of the director. Moreover, this rotation angle is small relative to the initial orientation of the molecules. These dependencies also allow us to explain the existence of the optimal voltage value U0 to achieve the maximum diffraction efficiency The obtained results are fundamental for the design and development of practical elements, such as light modulators and sensors, based on NRC.

References

1. Bugayhuuk, V. Mystetskyi, Kinetics of dynamic refractive index gratings in nematic liquid crystals in spatially inhomogeneous electric fields, Mol. Cryst. Liq. Cryst., 747, No. 1, pp. 64-71, (2022).