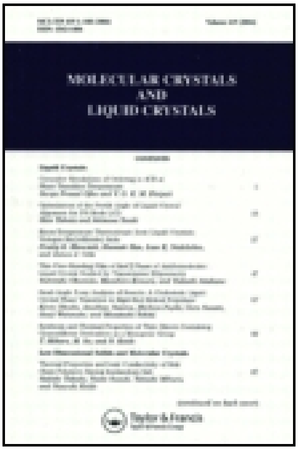

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DIFFRACTION INVESTIGATION OF TRANSIENT PROCESSES OF DOMAIN FORMATION IN LIQUID CRYSTALS

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Abstract A coherent light diffraction method for investigation of domain formation in liquid crystal is proposed. The good agreement between theoretical predictions and the experimental results has been demonstrated.

INTRODUCTION

The diffraction pattern from a liquid crystal illuminated by a laser beam is investigated theoretically and experimentally.

The liquid crystal cell is considered as phase grating with a periodical structure.

It is found that at voltages just above the threshold voltages the shape of the diffraction grating is practically sinusoidal.

The values of the first and second diffraction maxima at a sinusoidal shape of the grating are nearly equal and do not increase simultaneously. On passing from a sinusoidal to rectangular shape the second order diffraction maximum appears with a certain delay and decreases in amplitude with respect to the first diffraction maximum.

Experimental investigations with simultaneous registration of the first and second diffraction maxima are made by means of two photomultipliers and a multichannel analyzer. The results are in qualitative agreement with the theoretical conclusions.

THEORY

The macroscopic nonhomogeneous periodical spatial states of the liquid crystal provoked by different influences have been well known for a long time.[1]

The dynamic of the spatial position of the optical axis vector is a very important characteristic for the liquid crystal optical properties.

It is known that at voltages just above a threshold the Williams domains can be observed in nematic liquid crystals.

The object of the present work is the investigation of the dynamics of Williams domains appearance at several values of the voltage applied across the liquid crystal cell. The periodic domain structure is considered as a phase grating scattering a coherent laser light.

The rectangular coordinate system with axes x,y,z is used so that the liquid crystal layer will be parallel to x,y plane and the z axis will be perpendicular to it. The direction of the domains is parallel to the y axis. Then the director $\underline{N}$ of the liquid crystal will be in the x,z plane and the angle Θ between $\underline{N}$ and x will be periodical function of x with a period T identical to the period of a domain structure.

Let us consider the propagation of light with a wavelength and direction of propagation z through the periodically deformed liquid crystal layer . It is supposed that the electrical vector $\underline{E}$ of the incident light is directed along the x axis.

Because of the anisotropy of the liquid crystal substances the dielectric constant measured longitudinally and transversally to the axes of the liquid crystal molecule are different:

$$\Delta\varepsilon = \varepsilon_{\parallel} - \varepsilon_{\perp}$$

This value is positive or negative depending on the molecular structure of the liquid crystal material. Taking into account all this, we can express the polarization of the liquid crystal molecules with the following dependences:

$$p_{\parallel} = \varepsilon_{\parallel} E_{\parallel}$$

$$p_{\perp} = \varepsilon_{\perp} E_{\perp}$$

Here $E_{\parallel}$=Ecos(Θ) is the component of the electrical vector parallel to liquid crystal axis, $E_{\perp}=E\sin(\Theta)$ is the component of the electrical vector perpendicular to LC axis,p and p are the components of the polarization, longitudinally and transversally to the liquid crystal axes.

The light transmission in a certain direction depends on polarization. Then on the x axis direction we have:

$$p_x^{\parallel} = p_{\parallel}\cos(\Theta) = E\varepsilon_{\parallel}\cos^2(\Theta)$$

$$p_x^{\perp} = p_{\perp}\cos(\Theta) = E\varepsilon_{\perp}\cos^2(\Theta)$$

In general:

$$p_x = p_x^{\parallel} + p_x^{\perp} = E\left(\varepsilon_{\parallel}\cos^2(\Theta) + \varepsilon_{\perp}\sin^2(\Theta)\right)$$

where

$$p_x = \varepsilon_{eff}E$$

$$\varepsilon_{eff} = \varepsilon\cos^2(\Theta) + \varepsilon\sin^2(\Theta)$$

If the relative dielectric constant is introduced for ε_{eff} we will obtain:

$$\Delta\varepsilon_{eff} = \varepsilon_{\parallel}\left(1 - \frac{\Delta\varepsilon}{\varepsilon_{\parallel}}\sin^2(\Theta)\right)$$

Taking into account that:

$$n = (\varepsilon\mu)^{1/2}$$

where n is the refraction index and μ is the magnetic permittivity of vacuum, and supposing that $\Delta\varepsilon/\varepsilon_{\parallel}$ is small enough, we obtain for Δn_{eff} an analogous value to $\Delta\varepsilon_{eff}$:

$$\Delta n_{eff} = n_{\parallel}\left(1 - \frac{1\Delta\varepsilon}{2\varepsilon_{\parallel}}\sin^2(\Theta)\right)$$

The phase delay of the light wave transmitted through the liquid crystal layer with a thickness d can be expressed in this way:

$$\Delta\phi = 2\pi n_{eff}\frac{d}{\lambda} = 2\pi\frac{d}{\lambda}n_{\parallel}\left(1 - \frac{1\Delta\varepsilon}{2\varepsilon_{\parallel}}\sin^2(\Theta)\right)$$

Taking into account that Θ is a periodic function of x and substituting $\Theta=\sin(kx)$ in the equation for $\Delta\phi$, we obtain the final expression for $\Delta\phi$:

$$\Delta\phi = \frac{2\pi}{\lambda}n_{\parallel}d\left(1 - \frac{1\Delta\varepsilon}{2\varepsilon_{\parallel}}\sin^2(\sin(kx))\right)$$

where the amplitude of α varies from 0 to $\pi/2$.
The refractive index spatial distribution dependence on the value α is shown in Fig. 1. Curve 1 illustrates the refractive index changes at α = 0.1, curve 2 at $\alpha = \pi/4$ and

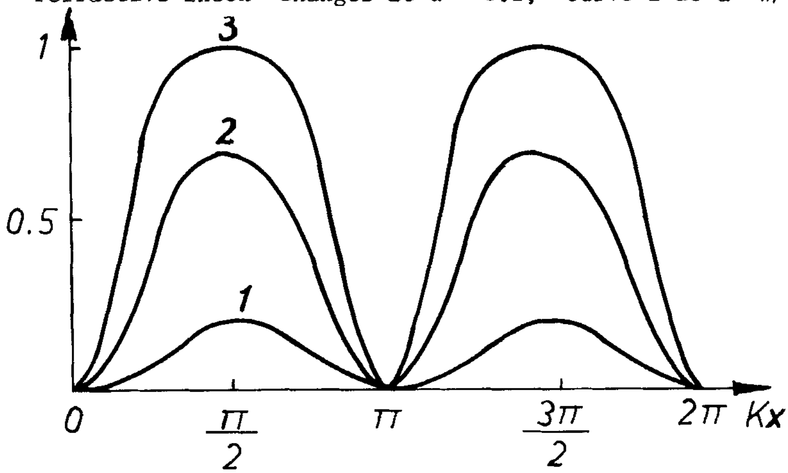

FIGURE 1. The refractive index spatial distribution dependence of the value ; curve 1: α = 0,1, curve 2; $\alpha = \pi/4$, curve $\alpha = \pi/2$.

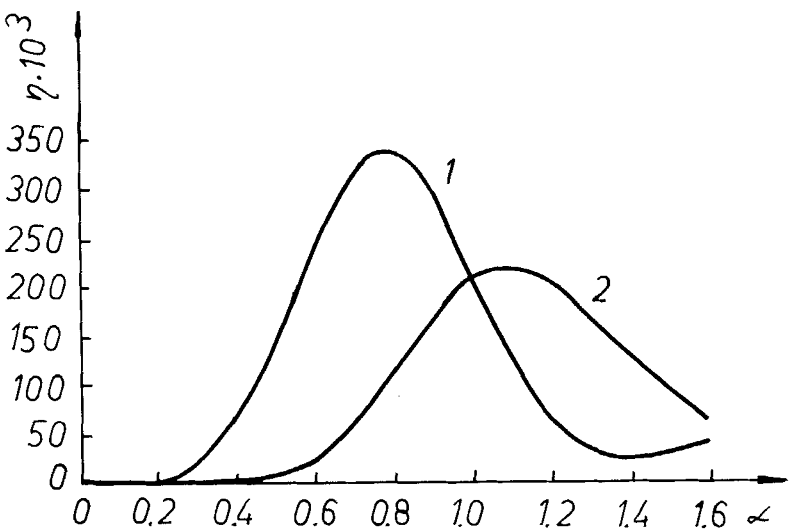

FIGURE 2. Diffraction efficiency in the first and second order dependence on α.

curve 3 at $\alpha = \pi/2$. It is evident from the figure that when α increases the refractive index spatial distribution has a trapezoidal rather than a sinusoidal shape.

We have calculated the diffraction efficiency of the liquid crystal phase grating. As a first approximation we assume that: $\theta = \alpha \sin(kx)$.

The diffraction efficiency is described by[2]:

$$S_e(d) = \frac{1}{T} \int_0^T \tau(x,d) \exp(-ilkx)\, dx$$

where S_e is the complex amplitude of the first diffraction plane wave, $k=2\pi/T$ and $\tau=\exp(i\Delta\phi)$.

A program is written, that enables one to compute the diffraction efficiency. Fig. 2 illustrate the results obtained for values of the diffraction efficiency in the first and second order depending on α. For numerical calculations we assume $d = 10$ µm, $T = 20$ µm, $\lambda = 0{,}633$ µm, $n = 1{,}5$.

EXPERIMENT

The experimental block scheme is shown in Fig. 3.

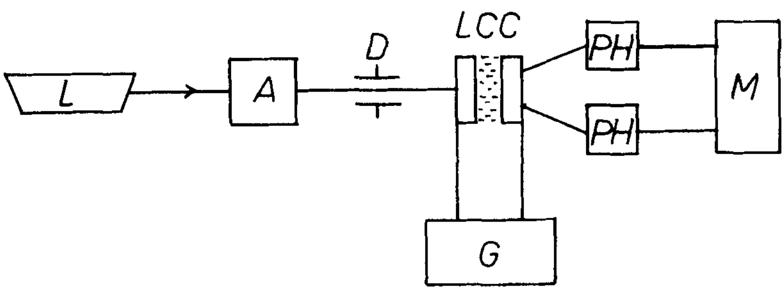

FIGURE 3. The experimental block scheme.

L - laser
A - attenuator
D - diaphragm for obtaining a narrow light beam
LCC - liquid crystal cell of MBBA with 10 µm thickness
G - low frequency voltage supply.
PH - photomultipliers for registration of the first and second diffraction maxima.
M - multichannel analyzer.

The liquid crystal cell contains a MBBA layer with 10 m thickness and a planar configuration.

The voltage on the liquid crystal cell is just above the threshold one for obtaining a phase grating and registration of a first and second diffraction maxima when the Williams domains have been created. The method of photon counting is used here and it assures a good sensitivity and accuracy. The registration of the pulses is accomplished by two photomultipliers for the first and second diffraction maxima, respectively. The photomultipliers work at low temperature (about -20°C) for assuring good efficiency of the regime and low noise.

The results were registrated by means of a multichannel amplitude analyzer (4096 channels). In Fig. 3, 4 and 5 the curves at different exciting voltages are shown: in Fig. 3 at voltage just above the thresold (7.4 volts), in Fig.4 at 7.9 volts and in Fig. 5 at voltage much above the threshold (8.4 volts).

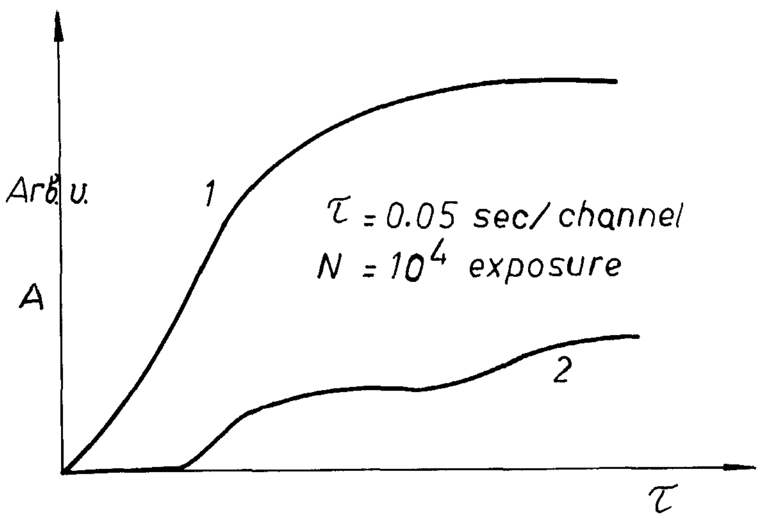

FIGURE 4. The curves of first and second order at voltage just above the tresold (7,4 volts). N = 0.88A.

DISCUSSION

From the theory of the electrohydrodynamical instabilities in liquid crystals, it is well known that the amplitude of the induced structural instabilities increases from 0 to a certain maximal value when the control voltage is applied.[3]

It is clear that small amplitudes of deformations (small values of α) exist at the low voltages nearly the threshold ones as well as in the beginning of the transient process. At exciting voltages much above the threshold α increases rapidly and obtains a large stationary values: Fig. 2.

From the curves shown in Fig.4 it follows that there is a certain delay in the appearance of the second maximum with respect to the first one. This delay decreases with increas-

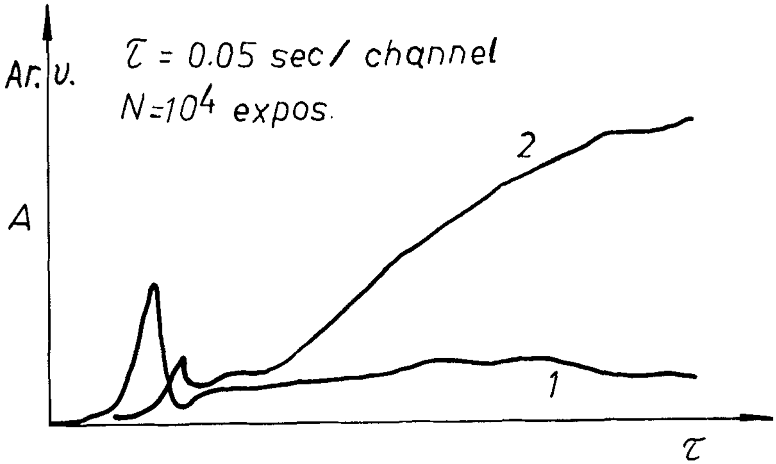

FIGURE 5. The curves of first and second order at 7,9 volts applied on LC cell.

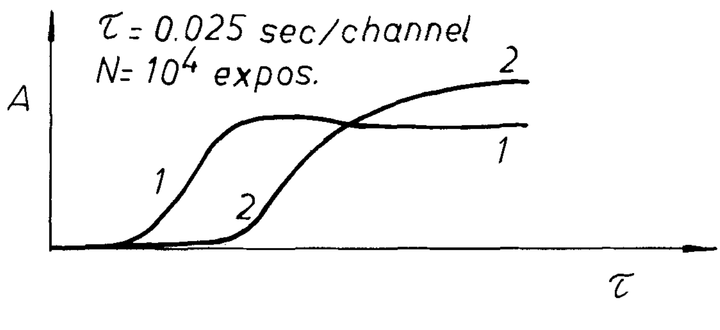

FIGURE 6. The curves of first and second order at voltage much above the threshold (8,4 volts).

ing of the driving voltages.

The ratio between the amplitudes of the first and the second diffraction maxima has a more large value and decreases at a more deformed liquid crystal structure (larger α).

At the voltage just above the threshold (7,4 volts) the saturation is obtained at relatively low values of the first and second orders without passing through a maximum (Fig.5).

The slope in the increase of the first and second diffraction order depends on α. On Fig. 6 (driving voltage 7.9 volts) the first order signal reaches its maximum value and starts to decrease when the second order one still increases. In point A those values are equal and after that the second diffraction order remains larger than the first diffraction order.

At higher voltage (8,4 volts) the transient process runs in a similar way but for a shorter time.

The good agreement between the experimental results and the theoretical predictions verifies the efficiency of the diffraction methods for the domain formation investigations.

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