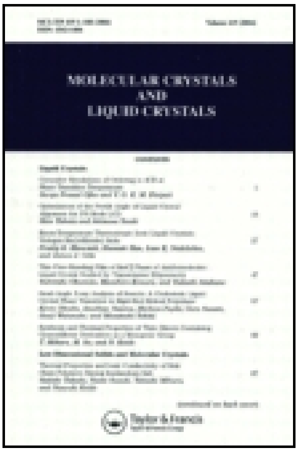

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Some Peculiarities of Transient Processes in Planar Periodic–Planar Polarization Diffraction Gratings

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The transient processes in planar periodic–planar polarization diffraction gratings under influence short bipolar electric pulses are investigated. It is shown that the application of bipolar pulses with certain amplitude and frequency leads to significant increase of diffraction efficiency in non-zero diffraction orders as compared to steady-state diffraction. The dependence of diffraction efficiency of each diffraction order on both the amplitude and frequency of applied pulses is studied. It is shown that the maximum diffraction efficiency of necessary order can be controlled by choosing frequency and amplitude of external pulses. This phenomenon can be used for creation of adaptive polarization diffraction gratings functioning in none-steady state mode.

Keywords Polarization diffraction gratings; liquid crystal; diffraction efficiency

Introduction

Today researchers pay more attention to polarization gratings, which are diffractive optical elements with an anisotropic periodic index profile. Although the polarization gratings are "thin" gratings, the thin-screen approximation predicts high diffraction into the first diffraction orders, making them attractive for optical devices. The unique properties of polarization gratings are polarization selectivity of the diffraction efficiency and the capability of these gratings for converting the polarization states of diffraction beams [1–6].

Known up to now polarization diffraction gratings (PDG) from the structure point of view could be divided in two groups. In the first group the gratings with **planar periodic boundary conditions** are included**:** a periodical structure—polarization patterned grating—is formed on both substrates of liquid crystal (LC) cell. It must be noted that the structure thickness is limited by the necessary conditions providing penetration of grating into the LC layer bulk and the structure stability. More specifically, the cell thickness must not exceed $\alpha\Lambda$ (Λ is grating period), where the coefficient α depends on the type of nematic and orientant, and for most nematics lies between 0.33 and 0.45 [7–10].

The other type of polarization gratings are those with **planar periodic-planar boundary conditions:** on one of the substrates a polarization patterned grating is formed and on the other one uniform planar orientation is provided. This hybrid configuration of the planar and polarization-patterned substrates results in a hybrid structure of alternating regions of planar and twisted alignments. This configuration exhibits a lower refractive index modulation caused by the constraints of the boundary conditions but may be applicable for

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specific device applications (for example in spectropolarimeters based on PDG) if larger refractive index modulations are not necessary.

Usually the control of PDG is based on using the orientation processes in liquid crystals under external steady-state electric field. At the same time from both scientific and practical points of view not less attention could to be paid to functioning of PDG in nonsteady state. Actually under external electric pulses—when transient orientation and relaxation processes take place—some new regularity has been observed, which can cause, for example, increase in diffraction efficiency [11]. Besides functioning in nonsteady mode allows one increase resistance of PDG based devices to such undesirable effects as temperature, charge accumulation, convective streams, which cause uncontrolled structural damages.

This paper is devoted to the study of behaviors of polarization diffraction gratings operating in non-steady state mode.

Problem Statement and Experiment

Usually the control of LC-based photonic elements is realized by application of continuous AC electric field with the 1 kHz frequency. In this case, when the quasi-static control mode of LC cell is realized, the transient processes, taking place in LC, appear during control electric field switching on and off. As a rule, the transient processes are not considered at such operating modes. However, if single bipolar electric pulses whose duration is less than reorientation time of LC molecule and the amplitude provide a Freedericksz transition, are applied to LC, it is possible to observe transient processes in LC during intervals between such control pulses sequence. In this section the results of experimentally study of the transient processes in planar periodic–planar polarization diffraction gratings (PPP PDG) under influence short bipolar electric pulses are presented.

Using the spin coating method a layer of photo-polymerized polymer ROLIC ROP-103 is deposited on two BK7 optical glass substrates, coated with transparent conducting layer (20 nm thick ITO layer with 80 Ohm/sm^2 resistivity). To form the planar orienting boundary conditions one of the substrates has been exposed to linearly polarized *He:Cd* KIMMON laser beam at 325 nm wavelength. The second substrate has been exposed to overlapping orthogonal circularly polarized beams to impart cycloidal orienting boundary conditions (Fig. 1). After the formation of gap 4 μm a cell has been assembled and filled by LC (E-48, Merck).

As a result, the planar periodic–planar diffraction grating with 6.9 μm pitch and 9% diffraction efficiency has been recorded (Fig. 2).

The optical scheme of experiment is given in the Fig. 3.

The linearly polarized beam of *He:Ne* laser at the wavelength 632.8 nm is directed to planar-planar periodic PDG, placed in such a way that the polarization vector of laser beam is parallel to the director of planar oriented LC molecules.

We have studied the peculiarities of dynamic diffraction of laser beam during control of PDG by single bipolar electric pulses. In this case the dynamic diffraction we call the time dependence of energy distribution in diffracted orders during the transient processes, taking place due to influence of bipolar pulses to PPP PDG. The steady-state diffraction efficiency for zero order η_0 is determine as ratio of summarized intensity in non-zero orders to sum of all diffracted beams intensities. Diffraction efficiency for the given non-zero order $\eta_{i\neq0}$ is determined as ratio of light intensity of the given order to sum of all diffracted beams intensities:

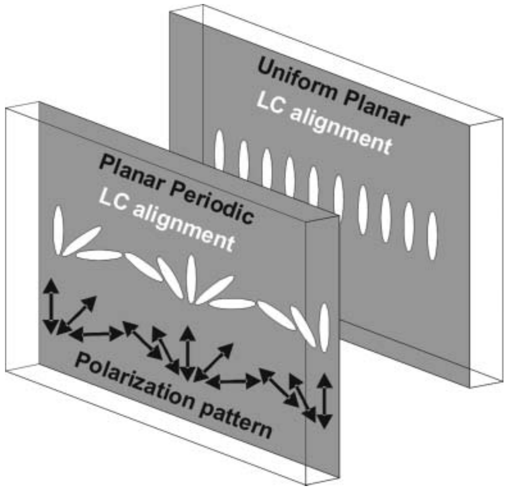

Figure 1. Schematic of the planar periodic-planar liquid crystal polarization diffraction grating.

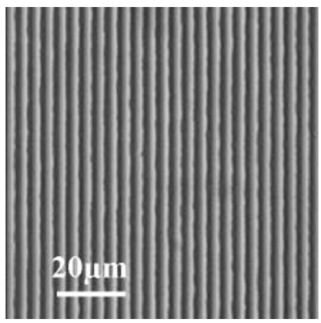

Figure 2. Microscopic image of planar periodic substrate.

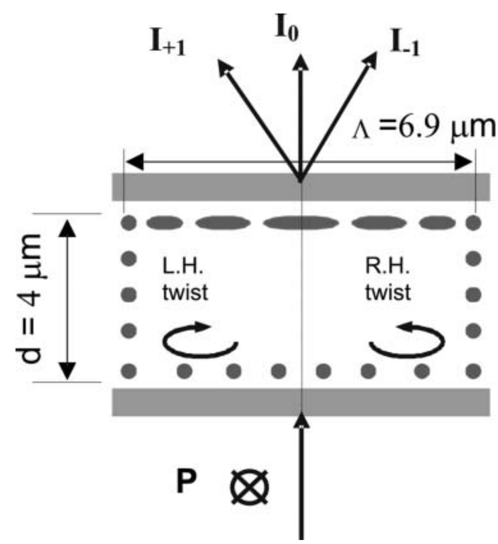

Figure 3. Optical scheme of experiment.

$$\eta_0 = \frac{\sum_i I_i - I_0}{\sum_i I_i}, \tag{1}$$

$$\eta_{i \neq 0} = \frac{I_i}{\sum_i I_i},$$

where I_0 - light intensity in zero diffracted order, I_i- light intensity in i^{th} non-zero order.

Taking into account, that in non-steady state the redistribution of light intensities in different orders changes in time, the maximum dynamic diffraction efficiency is determined as follows:

$$\eta_0^{\max} = 1 - \alpha_0(1 - \eta_0), \quad \text{were } \alpha_0 = \frac{I_0^{\min}}{I_0}.$$
$$\eta_{i \neq 0}^{\max} = \alpha_i \eta_i, \quad \text{were } \alpha_i = \frac{I_i^{\max}}{I_i}. \tag{2}$$

In the expression (2) $I_0^{\min}$- minimum value of light intensity in zero diffracted order in non-steady state, $I_i^{\max}$ - maximum value of light intensity in non-zero order, measured in the time interval between the successions of two consecutive control pulses.

The time dependence of light intensity for different diffraction orders has been studied, when rectangular bipolar pulses of 2 ms are applied. Pulse frequency has been chosen such to provide medium relaxation after electric perturbation. When a pulse is applied a redistribution of energy from zero order to higher diffraction orders takes place. At the same time under the pulse influence intensity of each diffraction order changes in time.

In Fig. 4 the experimentally obtained dependencies of maximum values of dynamic diffraction efficiencies for zero, the first and the second orders on the control bipolar pulses repetition frequency are presented. At that the light intensity in dynamic was recorded for each diffraction order, and the maximum efficiency was calculated in accordance with formulas (2).

As it is seen from Fig. 4, at the frequency 7.5 Hz the resonant increase of diffraction efficiency in the first order is observed, whereas at the given frequency the efficiency in

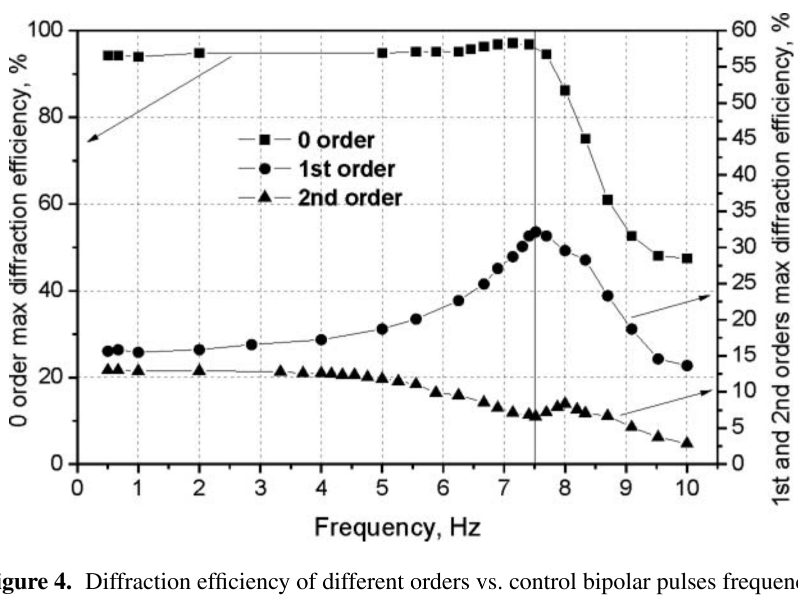

Figure 4. Diffraction efficiency of different orders vs. control bipolar pulses frequency.

the second order has clearly defined local minimum. It means that the energy redistribution in diffraction orders occurs under the influence of control pulse. The given phenomenon can be conditioned by LC molecules reorientation process on the substrates, because of which the periodic structure penetrates into the volume due to molecules binding energy. At frequencies less 7.5 Hz diffraction efficiency in the first order decreases, reaching the value, corresponding to static diffraction mode, whereas at the same frequencies the efficiency in the second order increasing tends to limiting value, corresponding to static diffraction mode. Thus, the energy redistribution from the first order to the second takes place with decreasing in frequency. At frequencies more than 7.5 Hz the diffraction efficiencies in all orders decrease, tending to limiting value, corresponding to quasi-static diffraction mode.

Thus, maximums of diffraction efficiencies for different orders are observed at various pulse repetition frequencies. For more detailed study of transient process, taking place in PPP PDG we have also studied time dependencies of light intensities for different diffraction orders. It should be noted, that time dependencies for each order are recorded for that pulse repetition frequency, at which the maximum diffraction efficiency for the given order is observed. Obviously, in this case it is enough to observe time evolution of intensity for one pulse-repetition interval. The time dependencies of light intensity normalized value for zero, the first and the second orders in dynamic diffraction mode are given in Figs. 5, 6, and 7, respectively.

The dynamic of light intensity in zero order under the influence of bipolar pulse with duration of 2 ms is shown in the Fig. 5, from there it is seen, that at the moment of termination of the control pulse, the transient process begins, conditioned by relaxation of LC molecules. In 13 ms from the pulse application moment the intensity in zero order reaches minimum value, corresponding to maximum value of dynamic diffraction efficiency 94%. In other words, nearly total energy redistribution from zero order to non-zero orders takes place.

At the control pulses repetition frequencies 7.5 Hz for the first order (Fig. 6) the relaxation process is conducted by appearance of intensity maximum, at that the diffraction

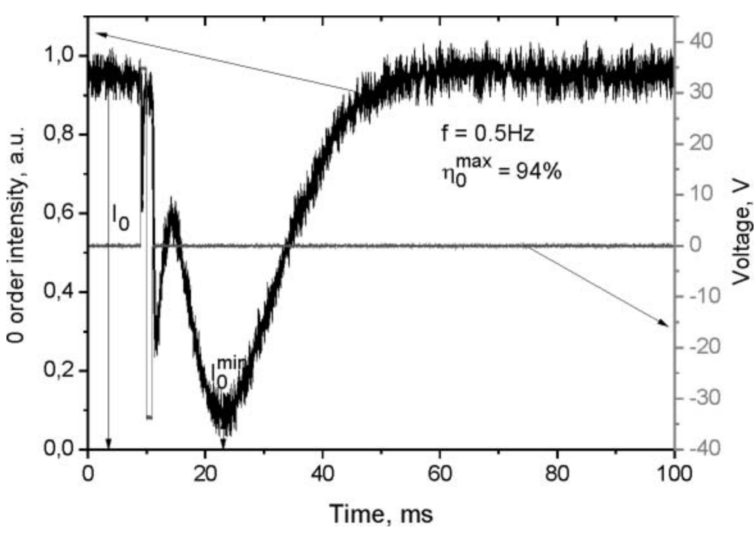

Figure 5. Time dependences of zero diffraction order intensity.

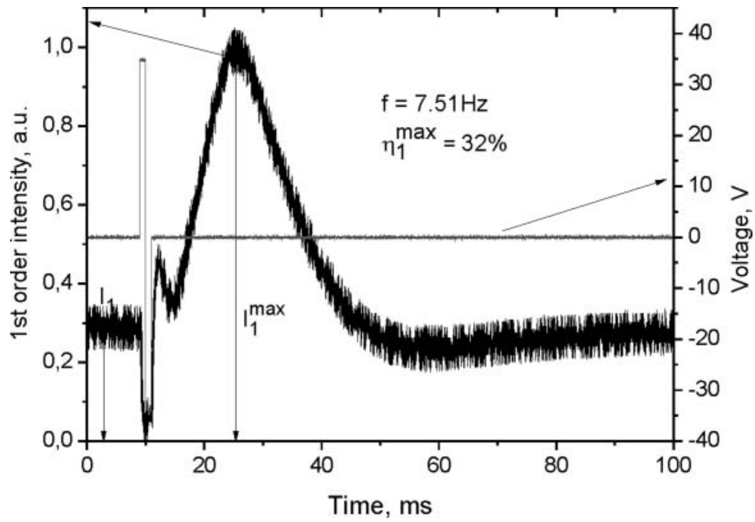

Figure 6. Time dependences of first diffraction order intensity.

efficiency increases to 32% from 9%, taking place before the moment of pulse impact (static mode).

At pulse repetition frequency 0.5 Hz analogous behavior is observed for the second order (Fig. 7), dynamic diffraction efficiency increases to 13% from static diffraction efficiency 0.5%.

The investigation of dynamic diffraction efficiency for different orders vs. amplitude of control bipolar pulses is also carried out. The pulse repetition frequency for each order corresponded to the frequency, at which the maximum of dynamic diffraction efficiency

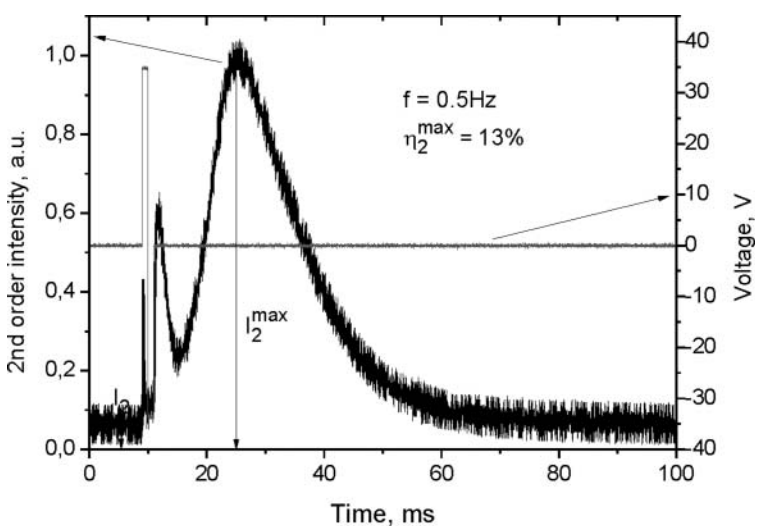

Figure 7. Time dependences of second diffraction orders intensity.

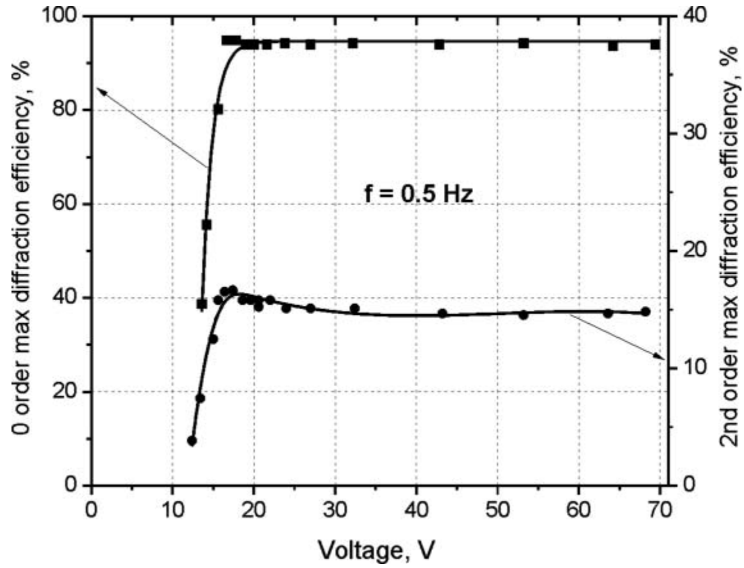

Figure 8. Maximum diffraction efficiency of zero and second orders vs. amplitude of control bipolar pulses.

is provided. In this case the pulses duration was 2 ms too. This dependence has clearly defined threshold character for observed diffraction orders. However, if the efficiency for zero and the second orders at above-threshold amplitude does not depend on amplitude of control pulses (Fig. 8), for the first order monotonic increase of diffraction efficiency as pulse amplitude increase is observed (Fig. 9).

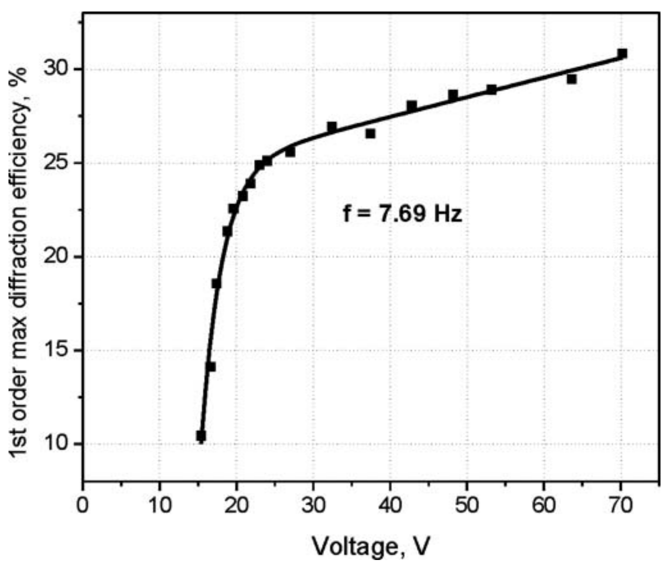

Figure 9. Maximum diffraction efficiency of first order vs. amplitude of control bipolar pulses.

Figure 10. Registered diffraction pattern in planar periodic-planar PDG in the different functioning modes: a - dynamic diffraction 2 ms, 35 V, 7.5Hz bipolar pulse is applied; b - static diffraction, no voltage; c - 1 kHz; 25 V AC voltage is applied.

Conclusion

The preliminary investigations of transient processes in planar–planar periodic diffraction gratings show that the application of bipolar pulses with certain amplitude and frequency leads to significant increase of diffraction efficiency in non-zero diffraction orders (Fig. 10a) as compared to steady-state diffraction (Fig. 10b). It is important to note, that at conventional control, the application of continuous AC electric field with the frequency 1 kHz leads to disappearance of steady diffraction (Fig. 10c).

Thus, our investigations show that the maximum diffraction efficiency of necessary order in transient processes can be controlled by choosing frequency and amplitude of external pulses, applied to planar-planar periodic polarization diffraction gratings. This phenomenon particularly can be used for development and creation of adaptive polarization diffraction gratings. The usage of such gratings is very perspective from viewpoint of investigation of polarization state of sample in pulse mode. At that high sensitivity and noise immunity, exception of temperature fluctuations and insensibility to convection effects are provided.

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