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Holographic formation of chirped multilayer inhomogeneous PPM-LC diffraction structures

This work presents theoretical research of the holographic formation of chirped multilayer inhomogeneous PPM-LC diffraction structures, in which it was found that the lattice profiles can have two-dimensional inhomogeneity and also differ from layer to layer, which is due to both changes in the structure period and the influence of material absorption.

INTRODUCTION

The diffraction characteristics of multilayer inhomogeneous holographic diffraction structures (MIHDS) formed in photopolymerizing compositions with nematic liquid crystals (PPM-LC) [1] have several distinctive features. They have not only high diffraction efficiency, but also a unique angular selectivity, which is a set of local maxima [2].

At the same time, the level of local maxima of angular selectivity in such structures is inhomogeneous, which negatively affects their possible applicability as optical spectral filters, where it is necessary to observe the equality of the channel transmission level [3, 4].

To solve this problem, the use of chirped multilayer inhomogeneous holographic PPM-LC diffraction structures is proposed [9]. The selectivity of such structures has a broadening and a higher level for the lateral zones compared to conventional holographic diffraction structures (HDS) [1, 5]. The process of formation of chirped HDS is carried out with the help of light beams having amplitude-phase inhomogeneity. As a result, the period of the formed structure and the harmonic amplitude of the refractive index at each point of the diffraction layer may differ, which causes changes in the level of angular selectivity for diffracted radiation.

Thus, the purpose of this work is to study the holographic formation of chirped MIHDS in the PPM-LC.

THEORETICAL MODEL OF THE FORMATION OF CHIRPED MIHDS WITH PPM-LC

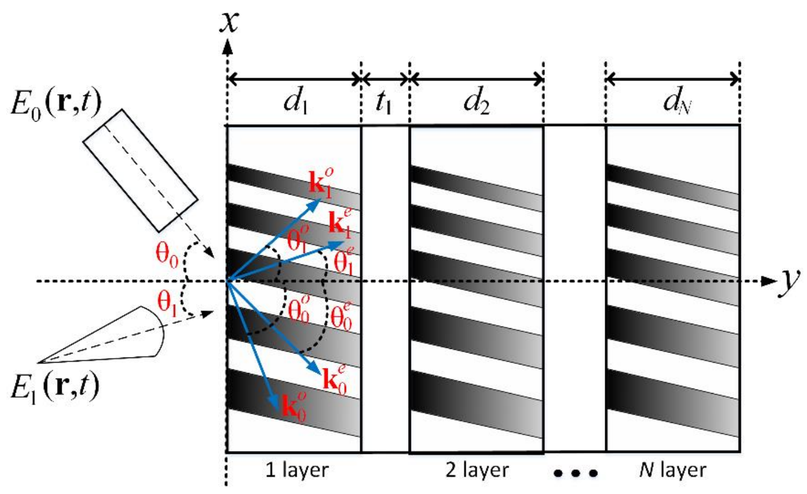

Fig. 1. *Schematic of formation of MIHDS with PPM-LC*

The intensity of the interference pattern :

$$I^{n,m}(t,\vec{r}) = \sum_{m=o,e} I_{sum}^{n,m}(t,\vec{r}) \cdot \left[1 + m^{n,m}(t,\vec{r}) \cdot \cos(\varphi(\vec{r}))\right]$$

where $\varphi(\mathbf{r}) = \varphi_0 + \nabla\varphi \cdot \mathbf{r} + 0.5\varphi \cdot \mathbf{r}^2$, $|\nabla\varphi| = \varphi' = K_1$ is the average value of the vector modulus $\mathbf{K}_1$, $0.5\varphi = \varphi''$ is the shift of the modulus of the lattice vector $\mathbf{K}_1$ from the average value; $m^{n,m}(t,\mathbf{r}) = 2\sqrt{I_0^{n,m}(t,\mathbf{r}) \cdot I_1^{n,m}(t,\mathbf{r})} \cdot (\mathbf{e}_0 \cdot \mathbf{e}_1) / \left(I_0^{n,m}(t,\mathbf{r}) + I_1^{n,m}(t,\mathbf{r})\right)$ is the local contrast of the interference pattern; $I^{j,n,m}(\mathbf{r}) = \left|E_j^{n,m}(\mathbf{r})\right|^2$; $I_{sum}^{n,m}(t,\mathbf{r}) = \left[I_0^{n,m}(t,\mathbf{r}) + I_1^{n,m}(t,\mathbf{r})\right]$; $I_0^{n,m}(t,\mathbf{r}) = I^{0,n,m}(t,\mathbf{r}) \cdot e^{-\alpha^{n,m}(t,\mathbf{r}) \cdot y / \cos\left(\theta_0^m\right)}$; $I_1^{n,m}(t,\mathbf{r}) = I^{1,n,m}(t,\mathbf{r}) \cdot e^{-\alpha^{n}(t,\mathbf{r}) \cdot y / \cos\left(\theta_1^m\right)}$; $j = 0,1$; $m = o,e$; $\mathbf{K}_1^{n,m} = \mathbf{k}_0^{n,m} - \mathbf{k}_1^{n,m}$ is the lattice vector; $\mathbf{r}$ is the radius vector; $\mathbf{k}_j^{n,m}$ are the wave vectors of the beams; $n = 1,2 \ldots N$ is the layer number; $\alpha^{n,m}(t,\mathbf{r}) = \alpha_2^n + \alpha_1^n \exp\left[-\left(I_0^{n,m}(t,\mathbf{r}) / \cos\left(\theta_0\right) + I_1^{n,m}(t,\mathbf{r}) / \cos\left(\theta_1\right)\right) \cdot y \cdot t / T_a\right]$ – is the PIA coefficient; $\alpha_1^n = \alpha_0 K_0^n$ and α_2 are the absorption components for the dye and the substrate; α_0 is the value of the absorption component of the dye molecule; ϕ is the value of the quantum yield for the dye; $T_a = 1 / \left(\phi\alpha_0 \max\left[I_0^{n,m}(t,\mathbf{r})\right]\right)$.

Solution for the amplitude of the first harmonic of the refractive index:

$$n_1^{n,m}(t,y,x) = n_{1p}^{n,m}(t,y,x) + n_{1LC}^{n,m}(t,y,x)$$

where:

$$n_{1p}^{n,m}(t,y,x) = \delta n_p \frac{2^k}{b^{n,m}(t,y,x)} \int_0^t I_{0n}^{n,m}(\tau,y,x)\left[p^{n,m}(t,y,x) k m^{n,m}(t,y,x) - f^{n,m}(t,y,x)(1 + 1.5 L^{n,m}(\tau,y,x))\right] d\tau$$

and $n_{1LC}^{n,m}(t,y,x) = \delta n_{LC} \frac{D_{LC}}{D_m} \int_0^t f^{n,m}(\tau,y,x) \cdot b_m^{n,m}(\tau,y,x) d\tau$ are the amplitude profiles of polymer and LC gratings; δn_{LC} and δn_p are the coefficients of change in the refractive index of the LC and polymer; D_{LC} and D_m are the diffusion coefficients of the LC and the monomer; $b^{n,m}(t,y,x) = \frac{T_p^{n,m}(t,y,x)}{T_m^{n,m}(t,y,x)}\left(1 + \frac{\varphi'' \cdot x}{\varphi'}\right)^2$; $T_m^{n,m}(t,y,x) = \left[D_m \cdot \left|\varphi'\right|^2\right]^{-1}$ is the diffusion time, $T_p^{n,m}(t,y,x) = 1 / \left(K_g K_b^{-k} \left(\alpha_0 \beta \left\langle K^n \right\rangle I^{n,m}(t,y,x) \tau_0\right)^k\right)$ is the polymerization time; $\left\langle K^n \right\rangle$ is the concentration of the dye; K_g and K_b determine the values of the growth and breakage coefficients of the polymer chain; the parameter β characterizes the reaction of photoinitiation; the parameter τ_0 sets the lifetime in an excited state; $p^{n,m}(t,y,x) = \exp\left[\frac{-2^k}{b^{n,m}(t,y,x)}\left(1 + L^{n,m}(t,y,x)\right)t\right]$; $L^{n,m}(t,y,x) = k(k-1)\frac{\left[m^{n,m}(t,y,x)\right]^2}{4}$; k is a parameter of the degree of nonlinearity of the process; $b_m^{n,m}(t,y,x) = \left(1 + \varphi'' \cdot x / \varphi'\right)^2 \exp\left[-s\left(1 - p^{n,m}(t,y,x)\right)\right]$; s is a parameter of the rate of change of diffusion; $I_{0n}^{n,m}(t,y,x) = I_{sum}^{n,m}(t,y,x) / \max\left[I_{sum}^{n,m}(t,y,x)\right]$ is the normalized intensity of beams in the n-th layer; $f^{n,m}(t,y,x) = \frac{2^k}{b^{n,m}(t,y,x)} k \int_0^t p^{n,m}(\tau,y,x) m^{n,m}(\tau,y,x) I_{0n}^{n,m}(\tau,y,x) \cdot \exp\left[-1 \cdot \int_\tau^t b_m^{n,m}(T,y,x) + \frac{2^k}{b^{n,m}(T,y,x)} I_{0n}^{n,m}(T,y,x) \cdot \left(1 + 1.5 L^{n,m}(T,y,x)\right) dT\right] d\tau$.

NUMERICAL CALCULATION

$\lambda = 1310$ nm; $d_n = 15$ μm is the thickness of one layer of PPM-LC; $w_0 = 0.5$ mm is the width of the beam; $\theta_1 = -\theta_0 = 15$ degrees; $k = 0.5$; $s = 1$; $T_a = 1.2$ s^{-1}; $\alpha_2 = 10^{-4}$ Nep/μm; $\alpha_1 = 0.128$ Nep/μm; $\delta n_p = 0.009$; $C_n = \delta n_{LC} / \delta n_p = 0.2$; $D_m = 10^{-15}$m^2/s; $\varphi'' = 6.8 \cdot 10^8$.

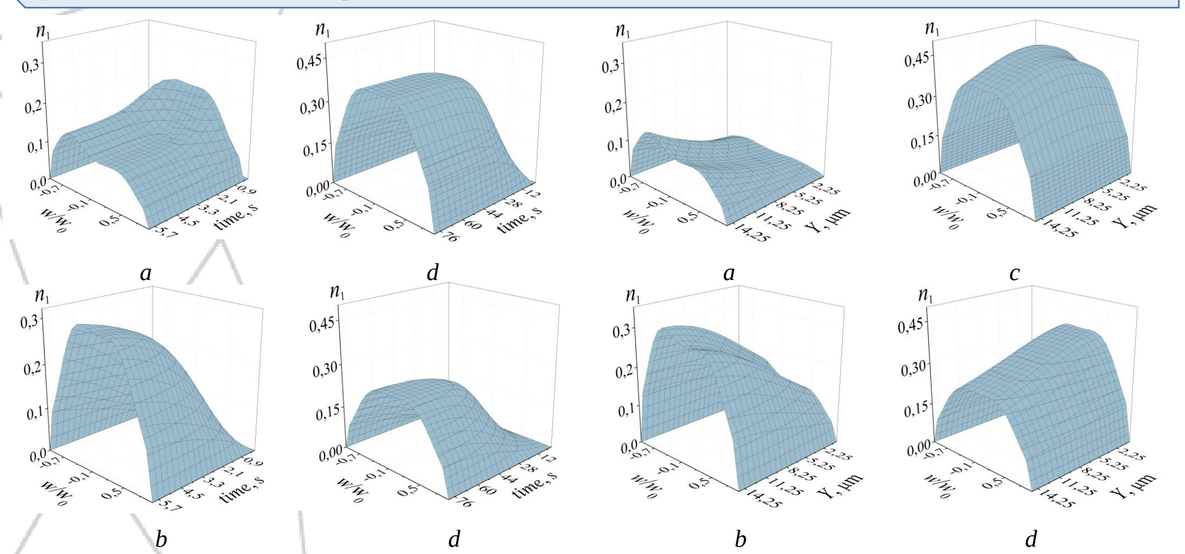

Fig. 2. *Kinetics of the formation of the amplitude of the first harmonic of the refractive index in (a, b) nonlinear and (c, d) linear recording mode for (a, c) 1st and (b, d) 2-nd layer of a two-layer HDS*

Fig. 3. *Spatial profiles of lattices for (a, c) the 1st and (b, d) the 2-nd layer of a two-layer HDS, formed under (a, b) nonlinear and (c, d) linear recording modes*

CONCLUSIONS

The paper presents a theoretical model describing the process of holographic formation of chirped multilayer inhomogeneous diffraction structures in photopolymerizing compositions containing nematic liquid crystals.

As a result of the study of the process of holographic formation according to the presented theoretical model, it was found that in nonlinear and linear recording modes, the lattice profiles have two-dimensional inhomogeneity and may differ from layer to layer. This phenomenon is caused both by the influence of material absorption and by a change in the period of the holographic diffraction structure due to recording by light beams having amplitude-phase inhomogeneity. In the nonlinear recording mode, the degree of difference in the profile of the lattices along the transverse coordinate is noticeably higher, which indicates a greater influence of the change in the period of the holographic diffraction structure on the process of its formation.

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The work was done as part of the Priority 2030 Strategic Academic Leadership Program