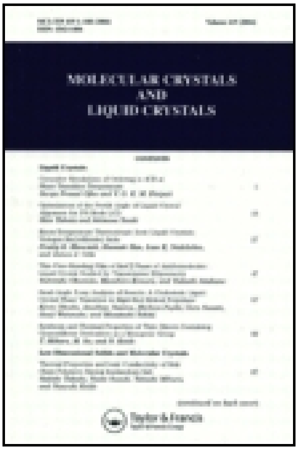

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Light Diffraction in Anisotropic Reflection Gratings

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Light Diffraction in Anisotropic Reflection Gratings

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The Bragg diffraction in thick anisotropic holographic media is studied. Solutions for the wave amplitudes, diffraction efficiencies, and angular mismatch sensitivities are given in reflection geometries for the case of dielectric modulation.

Keywords: anisotropy; volume diffraction gratings

I. INTRODUCTION

The theoretical efforts to understand light diffraction in thick media have been investigated by many researchers [1–3]. For thick gratings, light diffraction in isotropic media has developed in the coupled wave theory of Kogelnik [1]. The same theory for anisotropic thick media has been given by Montemezzani and Zgonik [2]. For anisotropic medium, particularly in Polymer-Dispersed Liquid Crystals (PDLC), the angular selectivity and asymmetric effects for transmission geometry are presented by our group in previously works [3]. Many researchers are investigated the diffraction properties of this type of gratings. Particularly, in our previously works we investigated polarization and thermal effects [4,5]. Authors of the work [2] presented a diffraction of anisotropic gratings for reflection geometries too. Also, the Bragg condition has another form than in theory given by Kogelnik. Experimentally we measure diffraction efficiency depend on incident angle. At such definition of Bragg condition, for comparison of numerical results of theoretical calculations made in [2] with experimental results, bulky recalculations are required that creates inconveniences. Therefore, begins necessary to create theory of the anisotropic hologram, similarly to coupled-wave theory of Kogelnik.

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In this work presented a coupled wave theory valid for anisotropic thick holographic media. We developed the case of reflection holographic grating, the former being characterized by a diffracted beam exiting the medium through the opposite surface as the transmitted beam. The coupled wave equations are solved to give the electric field of diffracted wave and diffraction efficiency. We consider a medium containing a phase plane holographic grating.

II. COUPLE–WAVE ANALYSIS

Let's consider a medium containing a phase grating. We treat the case of thick anisotropic holograms. We assume that the relative-permittivity tensor can be expressed as

$$\vec{\varepsilon} = \vec{\varepsilon}^{0} + \vec{\varepsilon}^{1}\cos(\vec{K}\cdot\vec{r}) \tag{1}$$

where superscripts 0 and 1 denote the constant and modulated parts of dielectric-permittivity, respectively. $|\vec{K}| = 2\pi/\Lambda$ is a grating vector, that we assume parallel to grating surface (or perpendicular to the grating planes).

All electric field in the medium we given by a sum of two waves: incident and diffracted

$$\vec{E} = \vec{E}_i \exp(i\vec{k}_i\vec{r}) + \vec{E}_d \exp(i\vec{k}_d\vec{r}) \tag{2}$$

that has to fulfill the time-independent vector wave equation

$$\vec{\nabla}\times(\vec{\nabla}\times\vec{E}) - k_0^2\vec{\varepsilon}\vec{E} = 0 \tag{3}$$

In Equation (2) $\vec{E}_{i,d}$ are electric field vectors of the transmitted and diffracted waves, $\vec{k}_{i,d}$ are wave vectors for the transmitted and diffracted waves. In Equation (3) $k_0 = \omega/c$ is the free-space wave number. As Kogelnik, the Bragg condition we will give in the following form

$$\vec{k}_i + \vec{K} = \vec{k}_d \tag{4}$$

and the phase detuning from the Bragg condition we will give with the following parameter

$$\Delta = \frac{k_d^2 - k_i^2}{2k_i} \tag{5}$$

We proceed by analyzing the couple wave equations and we insert Equations (1) and (2) into the wave equation (3). After mathematical transformation (see Ref. 3) we can present couple-wave equations in this way

$$\begin{cases} E_i' = -i\chi_i E_d \\ E_d' + i\Delta' E_d = -i\chi_d E_i \end{cases} \tag{6}$$

where $\chi_{i,d}$ are coupling parameters and can be presented as

$$\chi_{i,d} = \frac{k_0 A}{4 n_{i,d} g_{i,d} \cos\varphi_{i,d}} \tag{7}$$

and Δ' is describe the phase detuning from the Bragg condition

$$\Delta' = -\frac{k_i g_d \Delta}{k_d \cos\varphi_d} \tag{8}$$

In Equation (7), $A = \vec{e}_i \vec{\varepsilon}^{\,1} \vec{e}_d$ is describe the modulation, which are presented for p- and s-polarizations in following way, respectively

$$A = \sin(\varphi_i)\sin(\varphi_d)\varepsilon_{||}^1 - \cos(\varphi_i\cos(\varphi_d)\varepsilon_{\perp}^1 \quad \text{for } p\text{-polarization}, \tag{9}$$

$$A = \varepsilon_{||}^1 \quad \text{for } s\text{-polarization}, \tag{10}$$

where $\varepsilon_{||}^1$ and $\varepsilon_{\perp}^1$ is a parallel and perpendicular components of dielectric permittivity modulation, $\vec{e}_{i,d}$ are the unit vectors along electric field vector of the transmitted and diffracted waves, $n_{i,d}$ are the refractive indexes for the transmitted and diffracted waves, which are presented in following form for p- and s-polarizations

$$n_{i,d}^2 = \frac{\varepsilon_{\perp}^0 \varepsilon_{||}^0}{\varepsilon_{\perp}^0 \cos^2(\theta_{i,d}) + \varepsilon_{||}^0 \sin^2(\theta_{i,d})} \quad \text{for } p\text{-polarization}, \tag{11}$$

$$n_{i,d}^2 = \varepsilon_{\perp}^0 \quad \text{for } s\text{-polarization}, \tag{12}$$

where $\varepsilon_{||}^0$ and $\varepsilon_{\perp}^0$ is a parallel and perpendicular components of dielectric permittivity, $\varphi_{i,d}$ are the angles between the normal to the surface and Poynting vector for the transmitted and diffracted waves, $g_{i,d}$ are the cosines of the angles between the wavevectors and Poynting vectors.

The solution of the equation we will search as follows [3]

$$\begin{aligned} E_i &= E_i^{01}\exp(\gamma_1 y) + E_i^{02}\exp(\gamma_2 y) \\ E_d &= E_d^{01}\exp(\gamma_1 y) + E_d^{02}\exp(\gamma_2 y) \end{aligned} \tag{13}$$

For the reflection geometry the boundary conditions given in the following form [1]

$$\begin{aligned} E_i(0) &= 1 \\ E_d(d) &= 0 \end{aligned} \tag{14}$$

Final solution for diffracted wave for $y = 0$ value, we present by the help of well-known parameters ξ and ν (See Ref. 1)

$$E_d = \frac{\chi_d d}{\xi - i\sqrt{-\xi^2 - \nu^2} \cdot cth\sqrt{-\xi^2 - \nu^2}} \tag{15}$$

where d is a thickness of the diffraction grating, and

$$\xi = \frac{n_i g_d d\Delta}{2n_d \cos(\varphi_d)}, \tag{16}$$

is a parameter that describe phase detuning from Bragg condition,

$$\nu = d\sqrt{\chi_i \chi_d}, \tag{17}$$

is a parameter that describe modulation and couple between incident and diffracted waves. The diffraction efficiency we define as a ratio between output-signal intensity and incident pump intensity [3]

$$\eta = \frac{E_d(0)E_d^*(0)}{E_i(0)E_i^*(0)} \cdot \frac{n_d g_d \cos\varphi_d}{n_i g_i \cos\varphi_i} \tag{18}$$

Substituting Equation (15) into the definition of diffraction efficiency, for diffraction efficiency we will obtain following form

$$\eta = \frac{1}{\left(\frac{\xi}{\nu}\right)^2 - \left(\left(\frac{\xi}{\nu}\right)^2 + 1\right) \cdot cth^2\sqrt{-\xi^2 - \nu^2}} \tag{19}$$

III. CONCLUSION

Now it's a possible compare theoretical dependence of diffraction efficiency and experimental results. Only is required substitute the correct parameters and values in Equation (5), as realized for thick transmission gratings in papers [3–5] for PDLC diffraction gratings. In this study we haven't such experimental results, therefore here are not presented this type of dependences.

So, we are presented a couple-wave theory such as isotropic couple-wave theory that given by Kogelnik. With the help of this model we can obtain diffraction efficiency depending on incident angle, which we measure in experiment.

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