Energy exchange in thick photorefractive crystals of BTO with optical activity at high modulation depth.

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Abstract: The effect of the spatial non-uniformity of the photorefractive grating and the polarization angle of the recording light beams on the gain in thick crystals of BTO with optical activity were obtained.

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1. Introduction

In two-wave mixing (TWM) in a photorefractive material, the energy exchange that occurs along the sample thickness, changes the magnitude and the phase of the interacting beams. These changes can be neglected in the undepleted pump approximation (uniform grating) when the interaction lengths are small (thin crystals) or the beam coupling is very small. Nevertheless, in thick crystals these changes on both the magnitude and the phase of the interacting light beams can not be ignored. In this work we have performed a research intended to study the beam coupling, considering a thick sillenite crystal (BTO) with optical activity in a strong non-linear regime at high modulation depth. We also have included the effect of the polarization angle of the incident light beams on the energy exchange. The spatial non-uniformity of the grating along sample thickness in a self-consistent way is also considered in this treatment.

2. Beam coupling equations

In our approach, first the variation of the overall space charge field as a function of several initial light modulations for the applied field was obtained numerically by solving the set of non-linear material rate differential equations from time 10^{-15} s until stationary state was reached [1,4].

In the second step of our methodology the coupling equations were obtained considering the interaction of two plane monochromatic linearly polarized electromagnetic waves $\vec{R}(z)$ and $\vec{S}(z)$ that propagate in a longitudinal configuration $\tilde{K}_G$ // 001 in an optically active crystal (ρ =100 deg/cm) considering different polarization angles $\phi_P(z)$ of the incident light beams. We use a tensor approach [2-4] where each beam has two components: one along $\hat{u}_E$ perpendicular to the plane of incidence (110) and the other, along $\hat{u}_M$ parallel to the same plane, so that the light waves interacting inside the photorefractive material can be rewritten as $\vec{R}(z) = R_E(z)\hat{u}_E + R_M(z)\hat{u}_M$ and $\vec{S}(z) = S_E(z)\hat{u}_E + S_M(z)\hat{u}_M$.

In our calculations we considered optical activity ρ but absorption is neglected in order to stand out the effect of optical activity in the energy exchange between the recording light beams of the photorefractive grating. The effect of birefringence was taking into account through the coupling constant κ_0 due to the variation of the magnitude of the change in the refractive index induced by the external applied field, E_0 given by:

$$\kappa_0 = \frac{2\pi\Delta n_0}{\lambda\cos\theta} = \frac{\pi n_0^3 r E_0}{\lambda\cos\theta} \qquad (1)$$

where n_0 is the average refraction index in the sample, λ is the wave length of the recording monochromatic beams, θ is the incidence Bragg's angle and r is the electro optic coefficient. Nevertheless, in our approach we take into account in the coupling equations a complex coupling factor $\kappa_1(z)$ obtained from the solution of the material rate equations. This coupling factor allow us to consider variation along sample thickness of the fundamental Fourier component of the space charge field E_I(z), its phase shift ϕ_G(z) with regard to the light interference pattern as well as the phase ψ_m (z) of the light modulation m(z):

$$\kappa_1(z) = \frac{\pi}{\lambda\cos\theta}\frac{n_0^3 r|E_1(z)|}{2}\exp i(\phi(z)+\psi_m(z)) = \frac{\pi\Delta n_1(z)}{\lambda\cos\theta} \quad (2)$$

We also considered that the two interacting light beams were linearly polarized with different polarization angles at the surface of the sample to evaluate its influence on the energy exchange between the recording beams. The polarization angle ϕ_p defined as the inclination angle of the electric field of light waves with respect to the plane of incidence at the surface of the sample, is given by:

$$\phi_p = \tan^{-1}\left[\frac{S_E(z=0)}{S_M(z=0)}\right] \quad (3)$$

Here we consider the variation along sample thickness of the magnitude and phase of the light modulation in a transmission thick sillenite grating (BTO) recorded with a dc applied field of E_0 = 10 kV/cm. An initial light modulation of m_0 = 0.9 in a longitudinal configuration where the grating wave vector K_G is parallel to the direction [001] and the light waves are propagating in the $(\bar{1}10)$ plane was considered. The spatial period Λ of grating recorded was 10μ, and optical activity of BTO was taken equal to ρ = 100 deg/cm. The values of the material parameters to develop the first step of our approach were taken as in Refs. [2,5].

We solved the set of coupling equations [4] in a self consistent way to take into account the variation with depth of the refraction index given by Δn_I(z). We divided the sample in thin layers of thickness Δz in such a way that within each layer $\kappa_1(z)$ is practically constant. In this way, within each layer we have analytical solutions for the coupled equations [3]. When a small change (larger than 0.1%) in this variable occurred, we chose a smaller interval and calculated the new corresponding set of values of constants for the corresponding interval Δz. We started evaluating the initial set of constants for the first layer at the surface of the sample by using $\kappa_1(z=0)$. Next, for the following layers, the values of the complex amplitudes of the beams at the end of each interval were used to evaluate *m* (z) and therefore a new value of κ_1 at z where the following layer starts.

From the complex amplitudes of light waves obtained from the self consistent solutions of the set of coupled equations we calculate the intensities and phases of each wave and the corresponding light modulation *m*(z) as a function of z. The intensities of coupled light beams were obtained as follows:

I_R(z) = $|R(z)|^2$ the intensity of the reference light beam at specific sample thickness z and I_R(z) = $|S(z)|^2$,.We also obtained the gain coefficient G(z) defined as:

$$G(z) = \frac{I_R(z)}{I_R(z=0)} - 1 \quad (4)$$

where I_R(z=0) is the intensity of reference light beam at the surface of the sample.

3. Results and discussion

In figure 1 we show a comparison of the evolution of the beam intensities along sample thickness as they propagate and exchange energy inside the BTO crystal for an initial polarization angle $\phi_P=\pi/2$, for the uniform grating approximation ○ $I_R(z)$ and ● $I_S(z)$ and for the non uniform grating approximation □ $I_R(z)$ and ◆ $I_S(z)$. Figure 2 also shows the beam intensities along sample thickness for several initial polarization angles for the non-uniform grating approximation □ $I_R(z)$ and ■ $I_S(z)$ $\phi_P=\pi/16$, and ▲ $I_S(z)$ *and* Δ $I_R(z)$ $\phi_P=3\pi/16$. In figure 3 we show the gain G(z) of the BTO grating along sample thickness obtained with the same conditions as in figure 1 and figure 2, ◆ $\phi_P=\pi/2$, ▲ $\phi_P=3\pi/16$; ■ $\phi_P=\pi/16$ for the non-uniform grating and ○ $\phi_P=\pi/2$ for the uniform grating approximation.

From our calculations we can see two remarkable results, first from figure 1 it is clear that for a uniform grating in the sample of BTO, both coupled light beams exchange its energy with the other one periodically along sample thickness, describing a continuous cycle in which the energy is transferred from one of them to the other. Instead for the non-uniform grating calculations, one of light beams always gives its energy to the other one monotonically in a continuous way, without the light beams exchange each one its initial role. The corresponding gain associated to figure 1, described in figure 3, shows an oscillatory behavior for ϕ_P=π/2 like the intensities of light beams for the uniform approximation. However, in the non uniform grating approximation the gain increases and tends to saturate showing also a not marked oscillatory behavior for ϕ_P=π/2. However, this behavior is not showed by the light beam intensities when the polarization angle ϕ_P at the surface of the BTO crystal is different from π/2 radians. Instead of

that the intensities of light beams show again an oscillatory behavior which tends to disappear when ϕ_P is small. The corresponding gain for ϕ_P different from $\pi/2$ radians shows a behavior similar to that described by the intensities of light beams.
The other one remarkable result is the great influence of the polarization angle at the surface of the crystal

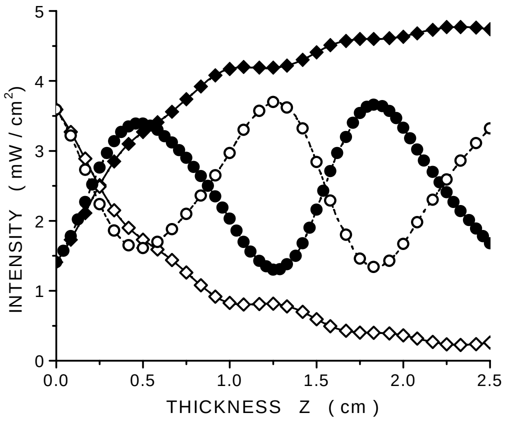

Fig. 1 Variation of the intensity beams along sample thickness for the uniform grating approximation ♦ $I_S(z)$ and ◊ $I_R(z)$ $\phi_P=\pi/2$, and for non uniform grating ● $I_S(z)$ and ○ $I_R(z)$ $\phi_P=\pi/2$.

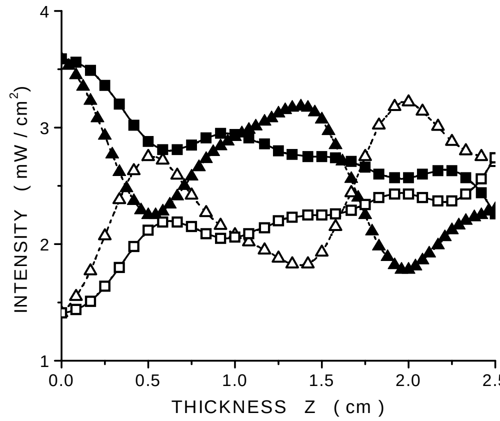

Fig. 2 Variation of the intensity beams along sample thickness for the non uniform grating approximation ■ $I_S(z)$ and □ $I_R(z)$ $\phi_P=\pi/16$, ▲ $I_S(z)$ and Δ $I_R(z)$ $\phi_P=3\pi/16$.

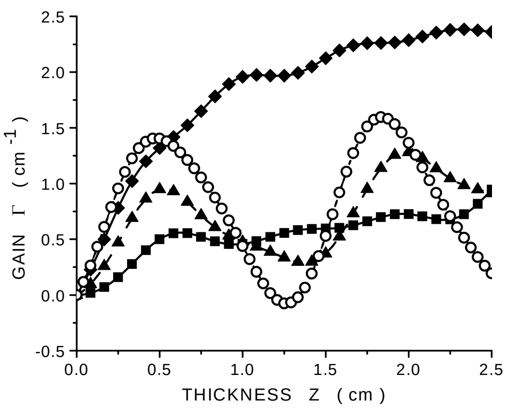

Fig. 3 Variation of the gain coefficient along sample thickness, for the uniform grating approximation ○ $\phi_P=\pi/2$, and for the non uniform grating approximation ■ $\phi_P=\pi/16$, ▲ $\phi_P=3\pi/16$ and ♦ $\phi_P=\pi/2$.

4. Conclusions and Acknowledgment

In conclusion, the vector approach employed in this work to describe the propagation and the energy exchange between the two light waves in the material (BTO) predicts a strong influence of the polarization angle of the incident beams on the gain and on the energy exchange of coupled beams along sample thickness. Specifically we have observed an oscillatory behavior in the gain and in the intensities of light beams along sample thickness in the uniform grating approximation for $\phi_P=\pi/2$. In the case of non-uniform grating approximation we have observed also a damped oscillatory behavior for ϕ_P different to $\pi/2$.
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