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CHARACTERIZATION OF DIFFRACTION GRATING IN PHOTOREFRACTIVE SOL-GEL GLASS

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The photorefractivity of a sol-gel glass was investigated using two-beam-coupling (TBC), degenerate-four-wave-mixing (DFWM), and phase shifting methods. The sol-gel glass was prepared by introducing the following photorefractive elements in the polyethyleneglycol matrix: TNF, SG-Cz, and SG-MN were used as charge generator, charge transporter, and electrooptic material, respectively. TBC gain of $90\,cm^{-1}$ *and diffraction efficiency of 46% were obtained at* $107\,V/\mu m$ *field. Also we measured the grating build-up and relaxation characteristics. The holographic phase shift was measured to be 51° at* $107\,V/\mu m$ *field. In order to compare this photorefractive sol-gel glass with inorganic photorefractive crystal, we measured the photorefractive properties of* $Fe:LiNbO_3$*. As a result, we obtained the TBC gain of* $50\,cm^{-1}$*, the diffraction efficiency of 47%, and the phase shift of 90° for* $Fe:LiNbO_3$ *sample.*

Keywords: degenerate four wave mixing; holographic phase shift; photorefractivity; sol-gel glass; two beam coupling

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INTRODUCTION

Photorefractive materials have been extensively investigated for the applications in optical data storage since Ashkin found that laser beam had caused a reversible refractive index change in an inorganic photorefractive crystal [1]. Photorefractive crystals ($LiNbO_3$, $BaTiO_3$, and $Bi_{12}SiO_{20}$ etc.) show long time stability and erasable characteristic [2,3]. However, it is difficult to grow and modify their structures to fit various applications. Organic material was a good candidate for this purpose. Photorefractive polymer can show the photorefractive effect configurations were the same as the DFWM set up. For measuring the phase shift, the phase of one writing beam in the TBC set up was translated by PZT attached mirror instead of moving the sample mechanically. Translation speed of mirror, 4 μm/s, was responsible for 8.9 μm/s of sample moving speed in our experimental condition. It was too fast to erase the grating inside the polymer. And two transmitted intensity were measured during translating the mirror and stored at computer for the calculating the phase shift between the intensity modulation and the refractive index modulation.

The used photorefractive polymer was prepared by introducing the photorefractive elements in the sol-gel matrix as follows: TNF, SG-Cz, SG-MN, and PEG were used as charge generator, charge transporter, electro-optic material, and plasticizer respectively. Polyethyleneglycol ($M_n \sim 600$) was employed as a plasticiser for sol-gel matrix. The polymer is sandwiched by ITO coated glass pair to apply the electric field to the polymer. The chemical structures of the functional compounds that were employed to prepare the photorefractive composite were illustrated in Figure 2. The other chemical aspects of the polymer can be found in the references [11,12].

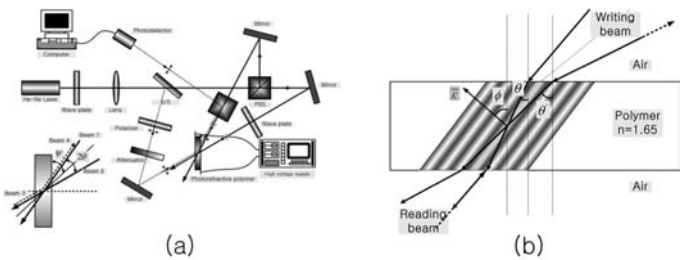

FIGURE 1 (a) Set up for DFWM and TBC Experiments. (b) Schematic configuration of beams and grating inside the sample.

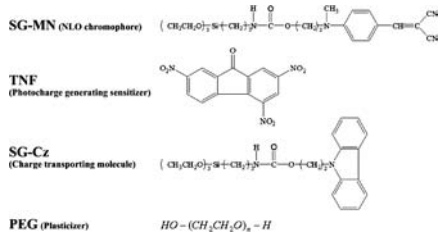

FIGURE 2 Molecular structures of the photorefractive elements.

RESULTS AND DISSCUSSIONS

The diffraction efficiency is proportional to $sin^2(C \cdot \Delta n)$ from the Kogelnik's coupled wave theory [13] and the refractive index modulation in the photorefractive materials depends approximately on the square of the applied external field [14]. Thus the diffraction efficiency can be expressed as follows:

$$\eta = K \cdot sin^2(A \cdot E_{app}^2), \tag{1}$$

where K is an appropriate constant which is less than unity and it reflect the absorption losses, Fresnel losses, and any deviation from the Bragg condition and A is a constant that determined by the sample.

The diffraction efficiency for considering the loss from the material and tilted incident angle configuration can be expressed by [13]

$$\eta_{normalized} = e^{-D_0(1+C)} \times \frac{sin^2\sqrt{v^2 - \xi^2}}{\left(1 - \frac{\xi^2}{v^2}\right)}, \tag{2}$$

where

$$v = \frac{\pi \Delta n d}{\lambda\sqrt{c_R c_S}} \hat{e}_R \cdot \hat{e}_S, \quad \xi = \frac{\alpha d}{4}\left(\frac{1}{c_R} - \frac{1}{c_S}\right), \quad D_0 = \frac{\alpha d}{c_R}, \quad C = \frac{c_R}{c_S}, \tag{3}$$

λ is the wavelength of the beam, α is the optical absorption coefficient of the polymer, d is the sample thickness, C_R and C_S are $\cos\theta$ and $-\cos(\theta + 2\phi)$, respectively, which are called to obliquity factor coming from geometry, and $\hat{e}_R$ and $\hat{e}_S$ are the polarization vectors of the incident and probe beams, respectively. The experimental geometry for this case was shown in Figure 1(b).

The steady-state diffraction efficiency was measured by the degenerate four-wave mixing experiment. External applied electric field was adjusted from 0 to 107 V/μm. The diffraction efficiencies with various applied

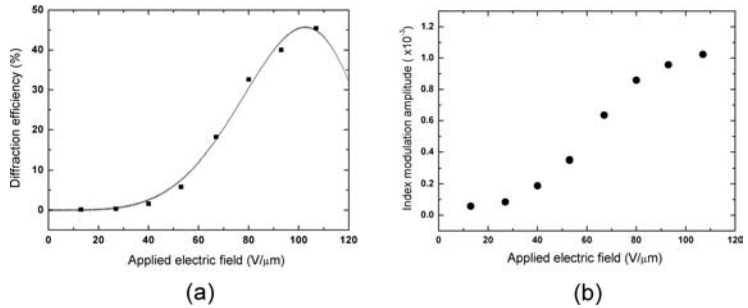

FIGURE 3 (a) Diffraction efficiencies and (b) Refractive index modulation amplitudes as a function of external applied field. (In Fig. 3(a), the solid line is the theoretical curve by Eq. (1).)

electric field were depicted in Figure 3(a). The diffraction efficiencies were fitted by using Eq. (1), and it was represented by solid line in the figure. Measured diffraction efficiencies were matched well to theoretical expectation. We got the maximum diffraction efficiency of 45.4% at external electric field of 107 V/μm. Refractive index modulation amplitudes, Δn, were calculated from the Eq. (2). and depicted in Figure 3(b). We used absorption coefficient of $65.9\,\mathrm{cm}^{-1}$ at 632.8 nm. Index modulation amplitude increased with increasing external field and nearly saturated around 100 V/μm. The results at higher external field than 107 V/μm could not be obtained because the sample was destroyed at high electric field. We got the maximum index modulation amplitude of 1.02×10^{-3} at external field of 107 V/μm.

TBC geometry was similar to the DFWM experiment, but the writing beams were TM-polarized. TBC gain coefficient is calculated by: [15]

$$\Gamma = \frac{1}{L}\ln\left(\frac{\gamma_0\beta}{\beta + 1 - \gamma_0}\right), \tag{4}$$

where L is the effective interaction length, which is represented as $d\cos\theta$, d is the sample thickness, β is beam ratio, which is unity for our case, and γ_0 is beam coupling ratio, which is represented by I/I_0. TBC gain coefficients as a function of the applied electric field by using transmitted intensity and Eq. (4). (Fig. 4(a)) TBC gain was very small at low external field but increased linearly with the external field over 40 V/μm. The maximum gain coefficient was 45.5% at external applied field of 107 V/μm.

In the TBC experiment, the intensity modulation pattern was quickly translated by moving the mirror and the intensity of two transmitted beams

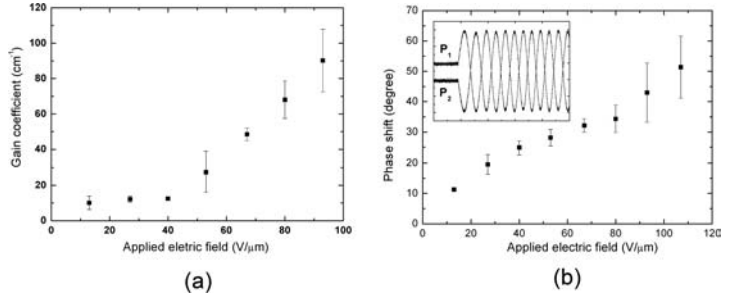

FIGURE 4 (a) TBC gain coefficients, and (b) the phase shift as a function of external applied field.

were monitored. The phase of the index grating is obtained from the difference of two transmitted beams as follows: [7]

$$P^{(-)} = P_1 - P_2 = 2P\cos(\phi_P + 2\pi\xi\cos\theta/\Lambda), \tag{5}$$

where P, ϕ_p, ξ, and Λ are diffraction amplitude, the phase shift of the index, the displacement of the interference pattern and the grating spacing, respectively. The transmitted intensity was subtracted each other and fitted by Eq. (5). The phase shift as a function of the applied electric field was shown in Figure 4(b). The phase shift was increased with similar mechanism to inorganic photorefractive crystals except applying the electric field externally to align the chromophore showing electro optic effect. Photo-induced index modulation and the intensity modulation has the phase shift of about $\pi/2$ between them intrinsically in the inorganic crystal because the local space charge field generated by trapping of photo induced charge has phase shift of $\pi/2$ with intensity modulation [4,5]. However, in the photorefractive polymer, it is not anymore. The asymmetric energy transfer in the two-beam coupling is caused by the phase shift. The phase shift depends on external field in the organic photorefractive materials. It is valuable to measure the phase shift in the photorefractive polymer because the gain is very sensitive to the phase shift. Some methods were proposed; phase shifting method [6,7], ac-phase modulation technique [8], grating moving technique [9,10].

In this report, we investigated the photorefractivity a sol-gel glass as a function of external applied field. Diffraction efficiency with degenergate four wave mixing (DFWM), and gain coefficient from the two beam coupling (TBC) experiment were measured. The phase shift between intensity modulation and the index modulation was measured by phase shifting technique. We compared the photorefractivity with the results at Fe-doped $LiNbO_3$.

EXPERIMENTAL

DFWM method is depicted in Figure 1(a). He-Ne laser at the wavelength of 632.8 nm was divided to two beams that have same intensity and same TE polarization state, and interfered on the sample with the angle 26°. In this case, the interference fringes have the spatial period, Λ, of 1.4 μm. The intensity of the each writing beam was 970 mW/cm^2. Another beam was branched from the original beam for probing beam. The probing beam is counter-propagated to one of the writing beams and the intensity of the probing beam is weakened by approximately 1% of writing beams in order to avoid erasing of grating by itself. The polarization state of the probing beam became TM through half wave plate. By locating the sample in the Rayleigh range, we could assume that the two writing beams were the plane waves inside the polymer. In order to make a nonzero projection of the external field in the direction of the grating vector, photorefractive polymer sample were slanted so that the surface normal make 47° to the bisector of writing beams. For the TBC experiment, the weak probing beam was excluded from the set up for the DFWM experiment. TM polarized beams were used for this experiment. The other geometrical with the applied field. The maximum phase shift was 51° at external applied field of 107 V/μm.

In order to compare the results with that of inorganic crystal, the same experiment as above were conducted with iron-doped $LiNbO_3$ crystal. We obtained the TBC gain of 32cm^{-1}, and the diffraction efficiency of 47%. And the phase shift was 90° for Fe:$LiNbO_3$ crystal as expected.

CONCLUSION

1) The photorefractivity of a sol-gel glass was investigated using two-beam-coupling, degenerate-four-wave-mixing, and phase shifting methods. TBC gain of 90 cm^{-1} and the diffraction efficiency of 46% were obtained at 107 V/μm field. The holographic phase shift was measured to be 51° at 107 V/μm field.
2) In order to compare this photorefractive sol-gel glass with inorganic crystal, we measured the photorefractive properties of Fe:$LiNbO_3$. As a result, we obtained the TBC gain of 50 cm^{-1}, the diffraction efficiency of 47%, and the phase shift of 90° for Fe:$LiNbO_3$ sample.

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