Research Article

Phase Conjugation Using Four-Wave Mixing in Fast Green FCF Dye-Doped Gelatin Film

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We present optical phase conjugation based on the degenerate four-wave mixing (DFWM) arrangement in gelatin films doped with acid blue 3 dye (FAST GREEN FCF) using He-Ne laser of total power 50 mW. Various parameters which influence the phase-conjugate (PC) signal during the DFWM process were studied (angle of between the forward pump and the probe beam, transition of gelatin film, reflectivity as a function of forward and backward beam). A maximum phase-conjugate beam reflectivity of about 0.02% has been observed in these dye-doped gelatin films. PACS: 42.65.-k, 42.65.Hw.

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1. Introduction

Nonlinear optical phase conjugation by degenerate four-wave mixing (DFWM) is an important technique with applications in many fields of science and technology [1]. When two counter propagating and intense light beams interact with a nonlinear medium, together with a less intense third one, a fourth beam is generated from the medium, which will be the phase conjugation of the third beam. This technique is called four-wave mixing. The main applications of degenerate DFWM techniques are nonlinear spectroscopy, real time holography, and phase conjugation. Phase conjugation by (DFWM) has been demonstrated in numerous nonlinear media [2, 3]. The organic molecules exhibit large polarizabilities because excited π -bond electrons are delocalized and hence easily polarizable [4]. Saturable absorption plays a very important role when dyes are used for the production of phase conjugation light, because $\chi^{(3)}$ is inversely proportional to the saturation intensity [5]. These systems exhibit large third-order susceptibilities. Figure 1 shows the energy level of dyes. These materials can be explained by three-level system [6]. When light is injected, electrons excite from the S_0 level to the S_1 level. The dye molecules will switch over to the triplet state. The number

of electrons at the S_0 level is reduced only by the number of electrons occupying the T_1 level. Therefore, the number of excitable electrons at the S_0 level is dramatically reduced if the intensity of the injected waves is high at a frequency corresponding to the S_0 and S_1 levels energy; the rate of absorption is thus reduced [1]. Thus, absorption becomes a function of intensity. The gratings produced by interference between the probe and pump wave that the period can be determined using the following relation:

$$\Lambda = \frac{2\pi}{\kappa_G} = \frac{\lambda}{2n \sin(\theta/2)}, \quad (1)$$

where λ is the laser wavelength. At small θ angle, the spacing is wider for a transmission grating than for a reflection grating [7, 8]. The theory of DFWM was formulated for a two-level saturable absorber by Abrams and Lind [9] and was modified to describe a three-level absorber by Silberberg and Bar-Joseph [10]. The phase conjugated reflectivity is then given by

$$R = \frac{|k|^2}{|\alpha + w \cot(wL)|^2}, \quad (2)$$

where $w = (|k|^2 - \alpha^2)^{1/2}$, α is saturated absorption coefficient given by

$$\alpha = \alpha_0 \frac{1 + I_1 + I_2}{[1 + 2(I_1 + I_2) + (I_1 - I_2)^2]^{3/2}}, \quad (3)$$

and k is coupling coefficient given by

$$k^* = 2\alpha_0 i \frac{(I_1 I_2)}{[1 + 2(I_1 + I_2) + (I_1 - I_2)^2]^{3/2}}. \quad (4)$$

I_1 and I_2 are two pump beam intensities normalized by the saturation intensity I_s [10].

2. Thermal Grating

Thermal processes can lead to large nonlinear optical effects. Consequently, the illuminated portion temperature of the material increases; the refractive index invariably decreases with increasing temperature [11]. Under steady-state conditions, the heat transport equation reduces to

$$\frac{\Delta(nL)}{nL} = \frac{1}{n} \frac{\partial n}{\partial T} \Delta T + \frac{1}{L} \frac{\partial L}{\partial T} \Delta T, \quad (5)$$

where n is refractive index and L is sample thickness [8, 12].

3. Experimental Configuration

Figure 2 shows the standard experimental degenerate four-wave mixing set-up. A 50 mW He-Ne laser at 632 nm is used to generate PC from Fast Green FCF. The output beam first is divided into two beams by beam splitter BS1 (10 : 90) [13]. The transmitted beam split with another beam-splitter BS2 (50 : 50) to provide the pump beams which are called E_1, E_2 . The beam reflected from BS1 splits by BS3 (50 : 50) to provide the probe beam E_3 . The Fast Green FCF dye film is exposed simultaneously to all the three beams. The path lengths of all waves reaching the sample are matched well with the coherence length of the laser [3], so that they are coherent at the sample. PC travels opposite to the direction of the probe beam. The intensity of phase conjugation wave is measured by a photodetector. The ratio of $E_1 : E_2 : E_3$ is 10: 10: 1. The angle between incident probe beam and forward probe beam is 10° . The experimental setup was mounted on a vibration isolation table [14].

4. Dye-Film Preparation

The gelatin, supplied by Sigma Chemicals, is Type-A porcine skin with approximately 300 bloom. To produce dye doped gelatin film, 1 gram of gelatin is added to a 10 ml solution of the dye and heated to about 5°C while stirring about 15 min to achieve a homogeneous solution. The solution was dispensed on the glass slide and agitated briefly to achieve an even delivery. Films were then allowed to be cooled. The thickness of films was about $40 \mu\text{m}$ [8].

FIGURE 1: Three-level model for organic dyes.

FIGURE 2: Experimental set-up for Observation of PC Wave.

FIGURE 3: Molecular structure of acid blue 3.

5. Material

The organic dye Fast Green FCF (acid blue 3) belongs to the triphenylmethane groups. These groups are green, blue, or violet in colour [15]. The chemical structure and formula of this dye are shown in Figure 3. The UV-VIS absorption spectrum of Fast Green FCF dye exhibits the absorbance peak at 630 nm as shown in Figure 4. But the absorption peak is broad enough to allow us to work with 632 nm wavelength of He-Ne laser [13].

6. Results and Discussion

The PC signal measurements are taken by varying the parameters which influence the PC signal during the DFWM process. Figure 5 shows the PC signal versus the time for different dye concentration of the gelatin films. PC intensity rises linearly to a maximum and then starts decreasing. The phase grating formed is transient.

To get maximum reflectivities, it is necessary that there be a perfect overlap of the probe and the pump beams in the nonlinear medium. Figure 6 shows the PC reflectivities as a function of recording angle between the forward pump

FIGURE 4: UV-VIS absorption spectrum of acid blue 3 dye in water.

FIGURE 5: PC signal versus time for different concentration.

FIGURE 6: PC Reflectivity as function of angle between the probe beam and forward pump beam in acid blue 3.

FIGURE 7: Dependence of PC reflectivity on backward pump power.

FIGURE 8: Dependence of PC reflectivity on forward pump power.

and probe beam. It seems from the figure that, as the angle between the probe beam and the forward pump beam increases, the PC reflectivity first increases and then decreases.

This may be because as the angle increases, the probe beam becomes elliptical and only a fraction of its area falls within the interaction region. Because of two-wave coupling, the maximum PC reflectivity is achieved when the angle is 8 degrees. We intend to study the effect of the backward pump beam power on the PC reflectivity by keeping the power of the forward pump and probe beams constant and varying the backward pump beam.

Figure 7 shows that higher backward powers are necessary to achieve higher reflectivity. The purpose is to study the dependence of the PC reflectivity on forward pump beam power by keeping the power of backward pump and probe beam constant and varying the forward pump power.

Figure 8 shows the variation of reflectivity for different power of forward pump beam. The PC reflectivity increases linearly with the power of forward pump beam. There are

FIGURE 9: Transmission as a function of pump power in acid blue 3.

two main processes which must be considered in the discussion of origin of OPC in gelatin films: (1) the formation of thermal grating and (2) photochemical bleaching.

The gelatin film illuminates with 632 nm radiation of variable intensity. The transmittance of the sample is measured simultaneously by using photodetector. If the effect observed in our experiments is of purely thermal nature, no bleaching will be observed. The results obtained for the sample are shown in Figure 9. It is clearly demonstrated that the transmission of sample increases. The experiment described above indicates that the photochemical nature of processes is mainly responsible for OPC in the sample under study.

7. Conclusion

In conclusion, we have observed low-intensity optical phase conjugation with acid blue 3 dye doped in gelatin films using 632 nm He-Ne wavelength. Though this dye gives good reflectivities, it suffers from low-damage threshold which may restrict its use for various applications. The effects of dye intensity backward, forward pump and interbeam angle between probe and forward pump beam on phase conjugation reflectivity are also studied. PC signal first increases and then decreases. PC reflectivity is increased by increasing the intensity of the backward and forward pump beam. The maximum PC reflectivity is achieved when the angle between probe and forward pump beam is 8 degrees. The gelatin film illuminates with radiation of variable intensity and transmittance of the sample is measured. A maximum phase-conjugate beam reflectivity of about 0.02% has been observed. Since the fast green FCF dye doped gelatin film is used at 632.8 nm, it may be suitable for low power semiconductor laser in the red wavelength region.

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