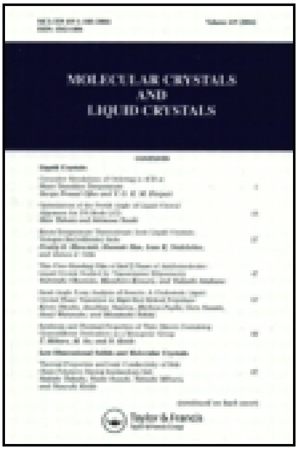

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Shin-Ya Tanaka [a] , Norio Nagayama [a] & Masaaki Yokoyama [a]

[a] Material and Life Science, Graduate School of Engineering, Osaka University, Suita, Osaka, Japan

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CONTROL OF REFLECTIVITY BY BEAM POLARIZATION STATE IN SELF-PUMPED PHASE CONJUGATION MIRROR USING PHOTOREFRACTIVE POLYMER

Shin-ya Tanaka, Norio Nagayama, and Masaaki Yokoyama
Material and Life Science, Graduate School of Engineering, Osaka University, 2-1, Yamadaoka, Suita, Osaka 565-0871, Japan

The photorefractive (PR) properties of two kinds of the double-layered PR polymeric device are presented. As one of the application utilizing the merit of large gain for the multi-layered PR device, the function as a self-pumped phase conjugation mirror (SPPCM) is discussed. Theses devices show a promise for the optical logic device, since they strongly exhibit the incident beam polarization state dependence of the phase conjugation reflectivity.

Keywords: gain factor; multilayer device; photorefractive polymer; self-pumped phase conjugation mirror

INTRODUCTION

Since the first discovery of the polymeric photorefractive (PR) composite [1], organic PR materials have attracted considerable attention as the new class of photonic materials [2–6]. Especially, organic PR polymers have many advantages of easy film-formation in large area and easy processing. So organic PR media must be very useful not only for the hologram recording, but also for the various optical data processing such as light amplification and optical correlation systems [7–9]. Actually, PVK-based low Tg molecular dispersion polymer, incorporating NLO (Non-linear optic compound) and some kinds of plasticizer, have shown very large gain coefficient Γ of over 400 cm^{-1} [10] and high response speed of a few milliseconds [4] due to so-called orientaitonal enhancement effect in addition to the Pockels effect

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Address correspondence to Masaaki Yokoyama, Graduate School of Engineering, Osaka University, 2-1, Yamadaoka, Suita, Osaka 565-0871, Japan. Tel.: +81-6-6879-7932, Fax: +81-6-6879-7934, E-mail: yokoyama@chem.eng.osaka-u.ac.jp

[5]. These values exceed the largest values for inorganic crystals by one order of magnitude or more [11]. However, the actual gain **g** given by $\mathbf{g} = \exp(\Gamma L)$, is limited by a thin film sample (typically, thickness $L = 100\,\mu m$). In order to obtain the overall interaction length, Moerner *et al.* reported that the optical one-pass gain was drastically improved by using of the cascading multi-layer sample [2]. In this study, by utilizing the merit that the multi-layer PR device exhibits of the large optical gain, we demonstrate and confirm that this PR device functions as a self-pumped phase conjugation mirror (SPPCM).

EXPERIMENTAL

Figure 1 shows the optical configuration for SPPCM. The incoming He–Ne laser beam operating at 632.8 nm (p-polarized) and 220 mW/cm^2 is split into two beams (Beam 1 and Beam 2). Beam 1 goes straight in p-polarized state. Beam 2 is able to reach the sample in s-polarized state through a $\lambda/2$ plate if necessary. These two beams are combined with a half mirror and direct on the sample, which is titled at an angle of 60°. Two concave mirrors, which have the focal distance of 5 cm, are placed in 20 cm distance. The PR sample is arranged at the center of two concave mirrors. Regarding the evolution of PR performance, the intensity of incident beam, transmitted beam through the sample, and generated phase conjugation beam are monitored by an oscilloscope with photo diode.

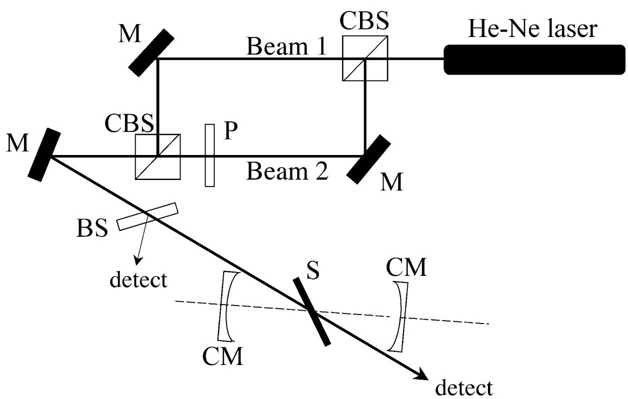

FIGURE 1 Schematic diagram of the fundamentals for the experimental setup. All measurements were carried out in room temperature. He–Ne laser: 632.8 nm. Beam intensity: 220 mW/cm^2. Tilt angle: 60°. P: $\lambda/2$ plate. CBS: cube beam splitter. M: mirror. BS: beam splitter. CM: concave mirror. S: sample.

The PR polymer used in this study was consisted of 35 wt% 7-DCST as an NLO, 1 wt% C_{60}, charge generation sensitizer, 16 wt% EtCz and 16 wt% BisCzPro, plasticizer, and 32 wt% PVK. These compounds were dissolved in chlorobenzene before being cast on indium tin oxide (ITO) electrodes. Cast samples were dried *in vacuo* for overnight and heated up to about 120°C to make a sandwiched sample cell with two ITO substrates with 100 μm polyimide spacers. Thus, these two samples made in this procedure were stacked using the refractive index matching oil. This sample denotes sample A as shown in Figure 2A. On the other hands, the sample, made by the similar procedure using a double-sided ITO substrate, denotes sample B.

Figure 2B shows the magnified illustration of the sample and two concave mirrors. When the single incident beam I_1 is thrown on the sample, the scattered beam occurs in various directions because of grains and material imperfection. These weak beams that are scattered in the direction for large gain will be amplified due to two beam coupling with I_1,

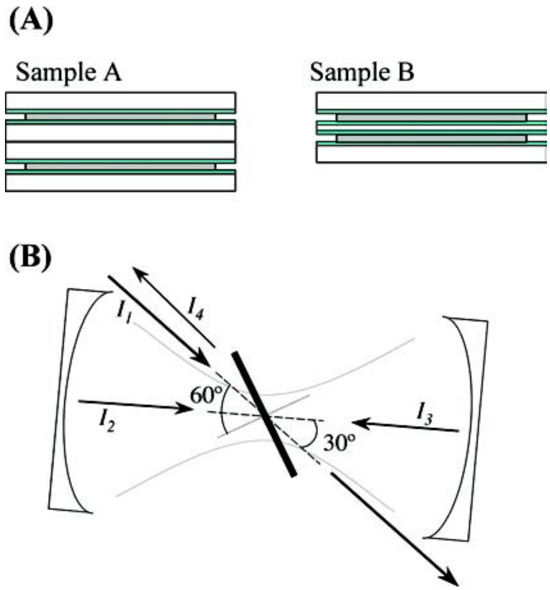

FIGURE 2 (A) Illustration of two kinds of multi-layered PR sample structure. Shaded portion denotes the PR polymer. Sample A has a stacking structure of usual single PR cell with index matching oil. Sample B is constructed with the thin double-sided ITO substrate. (B) Magnified image of the two concave mirror and sample. A single pumping beam I_1 is incident on the sample at an angle 60°. Two concave mirrors are placed between 20 cm and the resonator beams I_2, I_3 are set up at an incident angle of 30°.

and hence the resonated beams I_2 and I_3 are generated if the total optical gain can be made to exceed the total optical loss caused by scattering and absorption of beam. Thus, the coupling of I_1 and resonated beams I_2, I_3 generate the phase conjugation (PC) beam I_4 based on four wave mixing.

RESULTS AND DISCUSSION

Firstly the results of gain factor measured by usual two beam coupling method are compared between the samples A and B, respectively, in Figure 3. Apparently, sample B showed much higher signal gain than sample A. The glass thickness of the double-sided ITO substrate constructing sample B is about 200 μm, while, in sample A, the glass part of ITO substrate is of almost 1 mm. Since these glass parts are specifically unnecessary for the emergence process of PR effect, two incident beams can not interfere sufficiently for each layer of sample A, because of occurring light scattering at the interface of glasses. In other words, this result indicates that the thinner is the thickness of the double-sided ITO, the more high performance can be obtained.

Next, the function of SPPCM was examined using the sample B thus obtained with high gain. Figure 4 shows the beam polarization state dependence of phase conjugation (PC) reflectivity $\mathbf{R}$, defined by $I_4 = \mathbf{R}I_1$ in the double-layered sample. When I_1 was input at p-polarized state and the external field was applied over 50 V/μm, the PC reflectivity increased

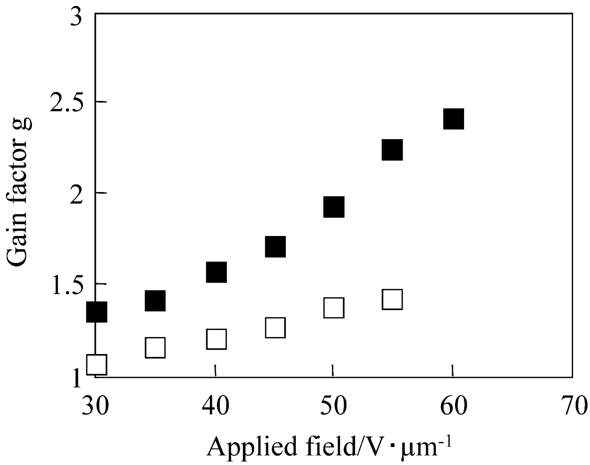

FIGURE 3 External applied field dependence of the signal gain by two beam coupling method. Two beams are input at p-polarized state. Key: sample A (open square) and sample B (closed square).

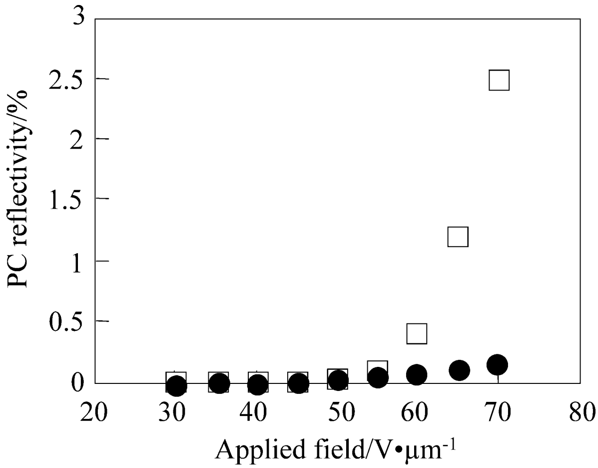

FIGURE 4 Comparison of self-pumped phase conjugation reflectivity of incident on p-polarized (open squares) and s-polarized wave (closed circles) versus external applied field. In the case of p-polarized beam incidence, no phase conjugation was observed below the threshold of $\sim$50 V/µm. On another front, for incident s-polarized wave, PC beam was hardly obtained.

steadily, reaching about 2.5% at 70 V/µm. No generation of the PC light below 50 V/µm seems to be caused by not generating the resonate beams I_2, I_3 effectively in low external applied field. Thus, we have succeeded in observing self-pumped phase conjugation by utilizing high refractivity of a double-layered PR polymer device. On the other hands, interestingly, I_1 beam with s-polarized state, hardly generated the PC beam. This result is consistent with the case of two beam coupling measurement in the PR polymer system with a single cell, where the gain coefficient for the incidence of s-polarized beam is smaller than for the incidence of p-polarized beam and the direction of energy transfer is opposite for the two cases [5]. Thus, this result indicates that the resonate beams I_2, I_3 is not developed sufficiently at the first step of the PC beam generation, when the incident beam is s-polarized state.

Based on a large polarization state dependence of incident beam in the SPPCM experiments, finally, we attempted to irradiate s-polarized beam superimposed on p-polarized incident beam. Figure 5 shows the transient response of the PC beam upon irradiating s-polarized beam after p-polarized beam incidence. It is observed that the well-defined PC beam appeared by p-polarized beam incidence on the sample attenuates gradually upon irradiating the s-polarized beam, that is, the s-polarized wave can prevent the appearance of PC beam. This is probably resulted from that

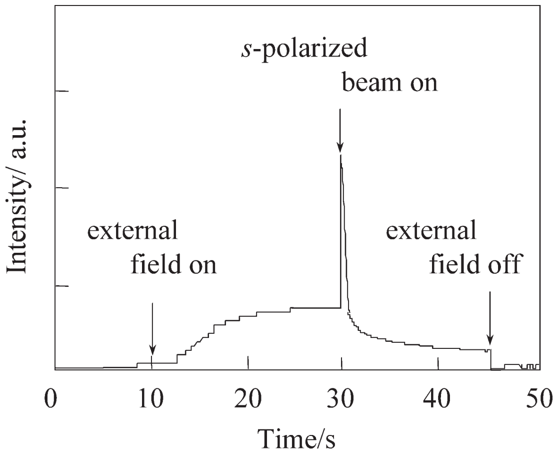

FIGURE 5 Transient response of PC beam intensity for external applied field = 70 V/μm and intensity of $I_1 = 60\,\mathrm{mW/cm^2}$. The voltage was applied in the condition that only the *p*-polarized light was irradiated. After 20 seconds, *s*-polarized beam was irradiated on the sample in the same optical pass of p-polarized beam.

The *s*-polarized beam abates the contrast of holographic grating in the PR polymer formed by *p*-polarized light.

CONCLUSION

In this work, we succeeded in constructing a well-functioned multi-layered cascade PR cell of organic photorefractive polymer by using a thin double-sided ITO. The device showed large optical gain enough to examine the generation of the phase conjugation beam in a self-pumped phase conjugation mirror composed of two concave mirrors and the PR polymer. It was also found that the phase conjugation reflectivity of this device was strongly dependent on the polarization state of the incident beam. When the *p*- and *s*-polarized beams irradiated concurrently to the sample on the same optical pass, the generation of the PC wave was suppressed effectively. This result suggests the potential application to the optical logic device using organic PR polymer.

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