TECHNICAL NOTE

Improvement of response time with an additional bias beam in a $BaTiO_3$ self-pumped phase-conjugate mirror

Takamasa Suzuki and Takuso Sato

Improvement of the response time of the $BaTiO_3$ self-pumped phase-conjugate mirror is demonstrated with a simple configuration. It is based on beam amplification in the crystal driven by an additional bias beam.

The photorefractive crystal $BaTiO_3$ is commonly used as a self-pumped phase-conjugate mirror[1,2] (SPPCM) for its large beam-coupling coefficient. The disadvantage of the SPPCM is its slow response time, which depends mainly on the total intensity of the incident beams.[3] The time response[4] or frequency response[5] in SPPCM's have been described, but there are few reports[6] on improving response time. In this note we report how to improve the response time of $BaTiO_3$ SPPCM with limited finite laser power. The response time τ described here denotes the time required for the generation of a phase-conjugate wave (PCW).

The insets of Fig. 1 show the configuration of the conventional SPPCM and a SPPCM with an additional bias beam. The conventional one is shown in Fig. 1(a). A part of object beam I_{11} is bent in the direction of the c axis and acts as pump beams a and b in regions 1 and 2, respectively. The beams are reflected at the corner cube of the crystal and play the role of other pump beams b' and a' at each region. Thus the PCW is generated by internal degenerate four-wave mixing. The energy of the pump beam is supplied from only the object beam. The mechanism has been described in detail in Ref. 3. Response time τ of the phase-conjugate mirror, based on the geometry of degenerate four-wave mixing, is evaluated as[3]

$$\tau = K/I_T, \qquad (1)$$

where K is a constant, and I_T is the total intensity of the incident beam in milliwatts per millimeter squared. To improve the response time, we introduce an additional bias beam, as shown in Fig. 1(b). In this configuration, we use the beam amplification[7] that is based on two-beam coupling,[8] and the process of the generation of PCW is explained as follows. First, bias beam I_{21} acts as the pump beam, and object beam I_{11} is amplified by the energy transfer from I_{21}. Next, self-pumping is generated by the amplified object beam I_{11} in the same way, as explained in Fig. 1(a). Since the energy of the pump beam is supplied not only from the object beam but also from the bias beam, τ is reduced according to Eq. (1). The theory of two-beam coupling has also been explained[7,8]; we do not describe it in detail here.

In practical systems, the intensity of the object beam is limited mainly by the laser power that is used and by amplitude transmittance T of the object. When a plane wave with intensity I_{in} passes through the object, intensity I_A of the object beam is given by

$$I_A = TI_{\text{in}}. \qquad (2)$$

On the other hand, if the beam is divided into two by the beam splitter (BS), which has reflection coefficient R, the total intensity I_B at the crystal is given by

$$I_B = [R + (1 - R)T]I_{\text{in}}, \qquad (3)$$

where RI_{in} and $(1 - R)TI_{\text{in}}$ are the intensity that is reflected by the BS and the intensity that is passed through the BS and object, respectively. In our configuration, RI_{in} is used as the bias beam. Thus, by the use of the BS, the total intensity of the incident

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T. Suzuki is with the Faculty of Engineering, Niigata University, 8050 Ikarashi 2 Niigata-shi 950-21, Japan. T. Sato is with the Tokyo Institute of Technology Graduate School at Nagatsuta, 4259 Nagatsuta, Midoriku, Yokohama 227, Japan.

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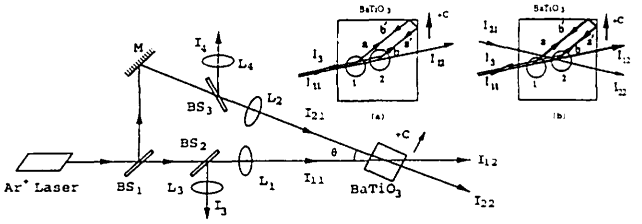

Fig. 1. Experimental setup. The crystal size is 5 mm × 5 mm × 5 mm. The angle θ is fixed at 20° and the incident angle of I_{21} is 90° with respect to the c axis. I_{12} and I_{22} are the transmitted beams. L's, lenses; BS's, beam splitters; M, mirror. The insets represent the configurations of (a) the conventional SPPCM, (b) the SPPCM with the bias beam.

beam is increased by

$$I_B - I_A = R(1 - T)I_{\text{in}}. \qquad (4)$$

So this method is effective when T is small.

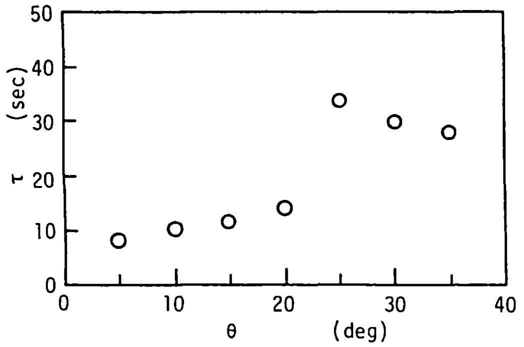

Fig. 2. Response time of the ordinary SPPCM as a function of θ. The power of the incident beam was 160 mW/cm².

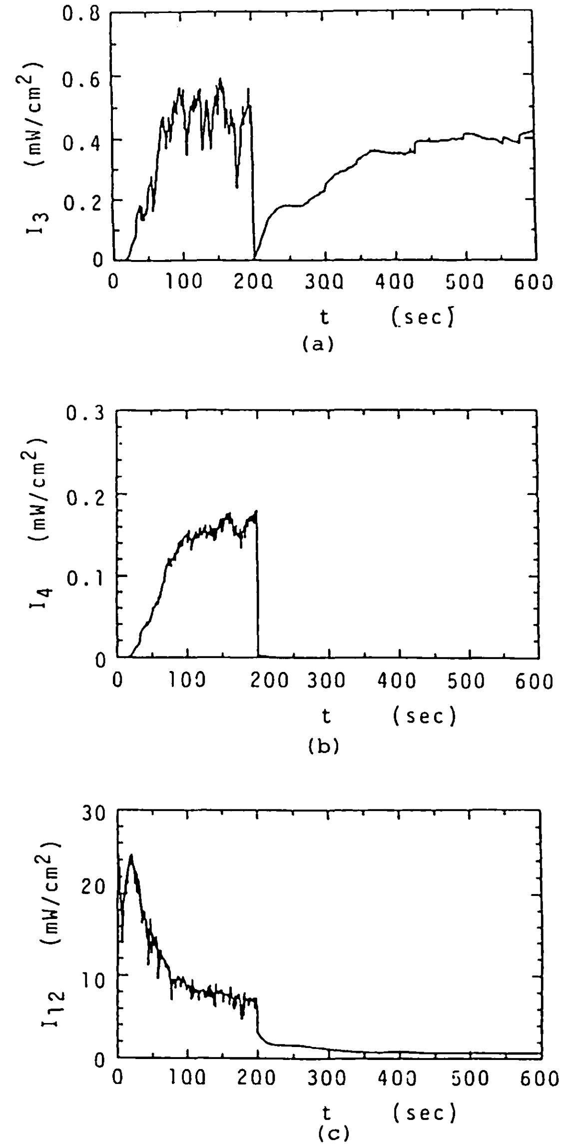

Fig. 3. Typical revolutions of PCW's I_3 and I_4, and transmitted beam I_{12} at θ = 20°. The intensities of I_{11} and I_{21} were 10 and 100 mW/cm², respectively: (a) I_3, the phase-conjugated object beam; (b) I_4, the phase-conjugated bias beam; (c) I_{12}, the transmitted object beam. The bias beam was intercepted by a shutter at t = 200 s.

The experimental setup is shown in Fig. 1. An argon-ion laser beam (λ = 514.5 nm) is divided into object beam I_{11} and bias beam I_{21}, each of which are 2 mm in diameter. The incident angle of I_{21} was 90° with respect to the c axis. The PCW's are I_3 and I_4, respectively. We measured the response time of ordinary SPPCM for various incident angles (θ's) without a bias beam. The power of the incident beam was 160 mW/cm². The measured results are shown in Fig. 2. The response times were ~ 10 s for θ ≤ 20°, and we carried out the following experiments at θ ≤ 20°. Figure 3 shows the typical evolutions of PCW's I_3, and I_4 and the transmitted beam I_{12} at θ = 20°. Both PCW's arose simultaneously at t ~ 20 s. The intensities of I_{11} and I_{21} were 10 and 100 mW/cm², respectively. I_{21} was cut off with a shutter at t = 200 s. The evolution of I_3 is shown in Fig. 3(a). It fluctuated temporally under the influence of I_{21} until I_{21} was cut off with a shutter. When I_{21} was cut off, I_3 dropped to nearly 0, but arose again immediately because the desired phase grating has been seeded before t reached t = 200 s. Since BaTiO$_3$ acts as a conventional SPPCM after the interception of the bias beam, the fluctuations in I_3 are not observed. The evolution of I_4 is shown in Fig. 3(b). Since the incident angle was not appropriate for the generation of a PCW, the steady-state output level was smaller than I_3, although the intensity of I_{21} was ten times as large as I_{11}. Figure 3(c) shows the evolution of I_{12}. It fell quickly when I_{21} was cut off because the energy transferred from I_{21} was removed. This drop shows that I_{11} had been amplified by the beam coupling. Response time τ and the steady-state intensity of I_3 plotted for I_{11} are shown in Fig. 4. They were measured for θ = 10° and 20°. Response time τ is denoted as the time required for first observing I_3. The intensity of the bias beam I_{21} was 50 mW/cm², which was different from that in Fig. 3. Figure 4(a) shows the response time of I_3. When I_{21} was not introduced, τ increased with the decrease of I_{11}; also, I_3 could not be obtained at I_{11} = 1 mW/cm². When I_{21} was introduced, however, τ was mainly dependent

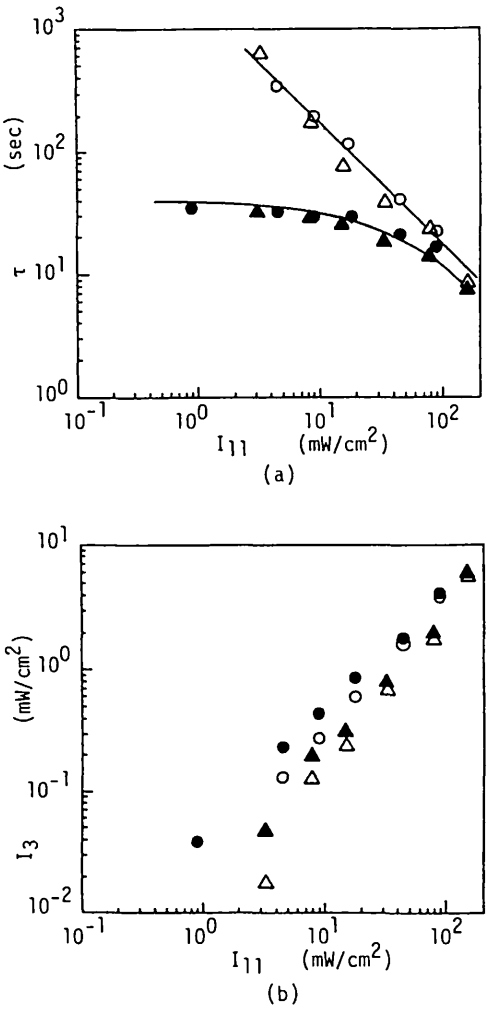

Fig. 4. (a) Response time and (b) steady-state intensities of phase-conjugated object beam I_3 measured for various intensities of the incident object beam I_{11}. ▲, $\theta = 10°$ and ●, $\theta = 20°$ with bias beam; △, $\theta = 10°$ and ○, $\theta = 20°$ without bias beam, at which the intensity of bias beam was fixed to 50 mW/cm^2. The solid curves are theoretical fits based on Eq. (1).

on I_{21} with the decrease of I_{11}. Moreover, I_3 could be obtained even if I_{11} were 1 mW/cm^2. The solid curves are calculated with Eq. (1), where $K = 20$ and $I_T = I_{11} + I_{21}$. The dependence on θ was almost the same between $\theta = 10°$ and 20°. So τ is inversely proportional to the total intensity of the incident beams and can be improved by the bias beam I_{21}.

The steady-state intensity of I_3 is shown in Fig. 4(b). It is reduced with the decrease of I_{11}, whether I_{21} was introduced or not. But the intensity of I_3 obtained with I_{21} was slightly larger than that without I_{21} because a part of I_{21} is transferred to I_{11} by the beam coupling. I_3 is not amplified much, although the object beam is amplified by the beam coupling, as shown in Fig. 3(c). It is thought that I_3 is distributed by the phase hologram that contributes to the two-beam coupling. The configuration in our experiment is not a complete SPPCM when I_{12} is not shuttered. But the behavior is the same as a conventional SPPCM except for the fluctuation of I_3. If one wishes to have a conventional SPPCM, it is necessary only to shut off I_{21}. An yet τ is improved. For example, when I_{11} = 10 mW/cm^2, I_3 rises at $t \sim 200$ s without I_{21}, while it rises completely at $t = 100$ s with I_{21} = 100 mW/cm^2, as shown in Fig. 4(a). If I_{21} is shuttered at $t = 100$ s, I_3 will rise promptly. So τ becomes half of that in a conventional SPPCM.

In conclusion, we have demonstrated improvement of the response time of SPPCM by introducing a bias beam. This method can be carried out easily and is useful for obtaining a PCW in a short time from objects that have poor transparency.

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