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Fast switching of light propagation in a photorefractive crystal via Pockels effect

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Abstract

We experimentally demonstrate fast switching of light propagation and phase conjugate generation in a $BaTiO_3$:Ce crystal with a high efficiency. The switching mechanism is based on the phase mismatch in photorefractive beam coupling between an incident beam and a fanning beam. The phase mismatch is induced by an externally applied electric field via Pockels effect. In our experiment, we obatin a voltage-generator-determined switching time of the order of 10 μs. The required voltage to reduce the output phase conjugate power by more than 90% is about only 100 V for our 3.8 mm-thick crystal.

Keywords: Photorefractive effect; Optical switching; Phase conjugation; Pockels effect; Phase mismatch

Intensive research has been going on in the field of fast and efficient optical switching. The most popular development is the optical switch based on Pockels effect using a $LiNbO_3$ crystal [1]. This type of optical switch can achieve very high speed due to the fast Pockels effect. Another type of switches is the one using absorption by carriers in semiconductor optical modulator, which seems promising in waveguide optics [2]. A switch using the Kerr-nonlinear photonic crystals has also been proposed to achieve efficient optical switch [3].

Photorefractive crystal is an important nonlinear-optical medium. Since the photorefractive effect is capable of efficient beam coupling even at a very low level of powers and has various promising applications in optical phase-conjugate-wave generation, optical processing, optical interconnection and switching, etc., it has attracted a lot of interest of reserchers in the past decades [4,5]. However, a crucial disadvantage of the photorefractive effect is its rather slow temporal response, which is usually larger than the order of

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seconds. The slow response time greatly limits its applications, particularly in fast optical switching. Recently, we have proposed and experimentally demonstrated that this problem of slow speed of switching can be overcome by applying an electric field to control the efficiency of photorefractive four-wave mixing [6,7].

In this paper, we experimentally study the fast switching of a single beam propagation through a cerium-doped $BaTiO_3$ photorefractive crystal as well as the consequent phase conjugate generation. The switching is achieved by applying an external voltage. The system is rather simple and is very easy to align in practice. The high efficiency of switching with very weak input power and with the applied voltage smaller than 100 V makes it rather promising in practical applications.

The experimental set-up is schematically shown in Fig. 1. An extraordinary beam of wavelength $\lambda = 514.5$ nm is incident upon the $BaTiO_3$:Ce crystal with an angle of θ_0 outside the crystal, where the angle is defined positive for a clockwise rotation from the surface normal. The doped cerium can enhance the photorefractive effect of $BaTiO_3$, maybe, due to the increased density of acceptor impurity. The dimension of the crystal is 6.1 mm × 4.0 mm × 3.8 mm ($L = 3.8$ mm), with c-axis along the 6.1 mm edge. To apply an electric field to the crystal, a pair of Indium-Tin-Oxide (ITO) transparent electrodes are coated onto the input surface and its opposite surface of the crystal.

At first, we consider the case when there is no external electric field. Owing to the strong photorefractive effect the fanning beam is amplified at the expense of the incident beam power and consequently the counterpropagating phase conjugate beam is generated [8,9]. In Fig. 2 we show a typical temporal evolution of the power of the transmitted beam at $x = L$ and the output phase conjugate power at $x = 0$ for incident angle $\theta_0 = 30°$, where the input beam is turned on at $t = 0$ and the input power at $x = 0$ is $I_0 = 9.1$ mW. The steady-state output phase conjugate power is $I_{pc} = 1.24$ mW and the steady-state power of the transmitted beam is $I_t = 3.8$ μW. (Note that, owing to the poor transparency of the electrodes, the phase conjugate power inside the crystal is in fact larger than that measured here.) It is seen that, due to the slow speed of the photorefractive grating formation, the transmitted power (or the phase conjugate power) takes more than 40 seconds to reach its steady state.

After the power reaches the steady state, we apply an electric field E_x to the crystal along x-axis, as shown in Fig. 1. Under the field the refractive indices for the incident and the fanning beams change, due to the Pockels effect, as follows [6,7]

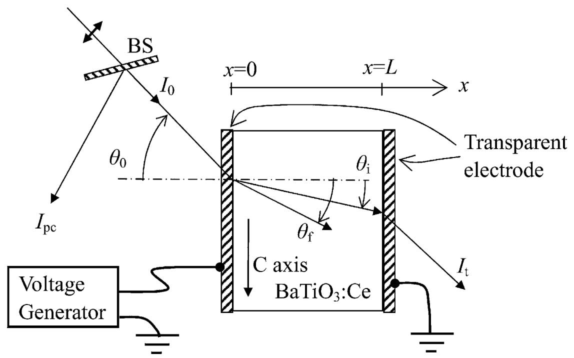

Fig. 1. Schematic diagram of the experimental set up. BS represents a beam splitter, I_0 is the input power, I_t is the power of the transmitted beam, and I_{pc} is the output power of the phase conjugate beam. θ_0 is the incident angle outside the crystal, θ_i and θ_f are propagation angle of the incident beam and fanning beam relative to the x-axis, respectively, inside the crystal.

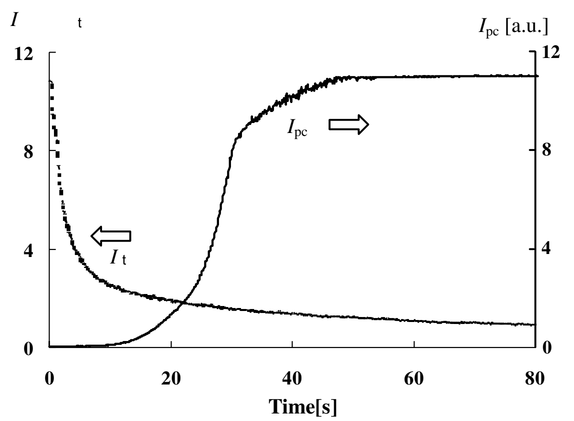

Fig. 2. Temporal evolution of the transmitted power I_t and of the output phase conjugate power I_{pc} under no applied electric field. The input power I_0 is turned on at $t = 0$.