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INVESTIGATION OF PHOTOREFRACTIVE TWO-WAVE COUPLING IN Cr-DOPED STRONTIUM BARIUM NIOBATE CRYSTAL*

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We present here the experimental results of photorefractive two-wave coupling in the congruent strontium barium niobate (SBN:61) crystal doped with 1000ppm Cr. Employing a He–Ne laser (632.8nm), we observed the coupling characteristics under different conditions. The crystal shows excellent photorefractive properties, with a high coupling coefficient nearly 6cm^{-1} as the beam intensity ratio m is less than 100. The saturated coupling coefficient of SBN:61:Cr shows a maximum at a certain external beam crossing angle $2\theta_{\rm peak}$, which varies with different m, showing a nearly linear dependence on m. The saturated coupling response time τ is measured to be less than 0.8 s. The response time decreased with increasing beam crossing angles no matter how large m is. We also observed the behaviour of the probe beam in reversed experimental procedures. We found that the probe beam shows a bistable state in both procedures.

Keywords: photorefractive effect, SBN:Cr crystal, two-wave coupling, bistable state
PACC: 4265, 4270, 7820J, 4280K

I. INTRODUCTION

The photorefractive effect in some oxide crystals has received extensive investigation in the past few decades, in view of the potential applications in optical data storage, optical computing, optical modulating, optical switching, spatial filtering, image processing, optical interconnection, and so on. All of these applications require crystals with high photorefractive sensitivity, fast response and high diffraction efficiency.

Previous work has shown that many materials possess obvious photorefractive properties, such as ferroelectric oxides, non-ferroelectric oxides, semiconductors, quantum-well materials, organic macromolecule polymers and electro-optic ceramics, etc. Among these, the ferroelectric crystals $LiNbO_3$, $BaTiO_3$ and SBN are some of the most interesting materials. Assimilating to $BaTiO_3$, SBN crystals display a large electro-optic coefficient, fast response and small half-wave voltage in fast electro-optic modulating. However, the phase transition near room temperature does not occur in SBN crystals as it does in BaTiO3 crystals.[1] The flexibility of the structure allows SBN crystals to be doped with various kinds and concentrations of impurities as the exciting centres, to efficiently tune the electro-optic and photorefractive properties of SBN crystals. As a result, varieties of SBN crystals, especially SBN crystals doped with transition metals such as Ce, Cr, Rh, etc, have gradually become one type of important material being investigated, as crystals with a large size and good optical quality are readily available.

SBN:Ce is one of the most extensively studied crystals. Several research groups have successively investigated the absorption, two-wave and four-wave mixing, and their applications.[2−6] In contrast, SBN:Cr is relatively less reported.[7−10] Some research of the crystal was carried out only at the wavelength 514.5nm. We have measured the absorption spectrum of SBN:61:Cr crystal, which shows a wide band around 650nm, as shown in Fig.1, due to the Cr doping. The absorption for the He–Ne laser wavelength (632.8nm) is also very intensive. This indicates that the SBN:61:Cr crystals should exhibit an eminent photorefractive effect at 632.8nm. Because two-wave coupling is a substantial mechanism in most photorefractive phenomena, we characterize SBN:61:Cr crystals through two-wave coupling at 632.8nm. In this paper, we report the observed results under different experimental conditions. The coupling coefficient measured reaches a peak value at a certain two-wave crossing angle. The angle corresponding to the peak value varies with a different pump/probe beam intensity ratio m for the SBN:61:Cr (1000ppm) crystal used in our ex-

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periment. The coupling coefficient increases with m. The response time for two-wave coupling to reach the steady state is measured to be less than 0.8 s.

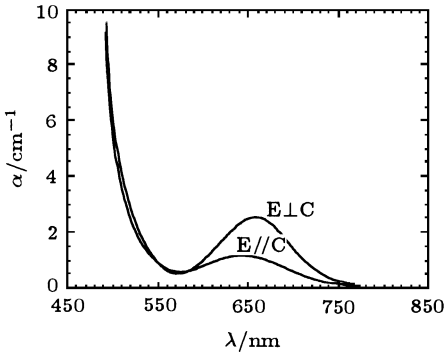


Fig.1. Absorption coefficient of SBN:Cr crystal doped with 1000ppm Cr.

II. TWO-WAVE COUPLING EXPERIMENTS

The experimental set-up for two-wave coupling is shown in Fig.2. A thin polarized beam output from the He–Ne laser is first reflected by mirror M_1, then split into the probe and pump beams by a beam splitter (BS). Both beams symmetrically impinge on the crystal sample with a 2θ angle in air. The bisector is perpendicular to the crystal c-axis in the incidence plane. The two transmission beams are detected by photoelectric cells D_1 and D_2 connected with a PC. As r_{33} is the largest element of the non-zero electro-optic coefficient tensor, the crystal is placed to make the grating wave vector parallel to its c-axis. A $\lambda/2$-zone plate is used to turn the polarization plane from vertical to horizontal. The diameters of the light spots are limited to be the same, approximately 3mm.

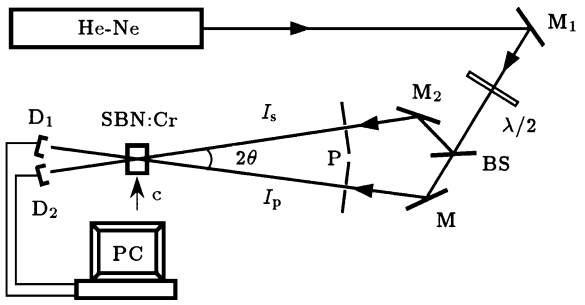


Fig.2. Experimental set-up: M, mirror; $\lambda/2$, half-wave plate; BS, beam splitter; D, detector; P, pinhole.

The crystal sample used is a congruent SBN:61 crystal doped with 1000ppm Cr. T_c is 80°C and the size is $6.5\times7\times5.5\text{mm}^3$. It was grown in the Crystal Growth Laboratory of the Physics Department at the University of Osnabrück using the Czochralski method, and has been polarized at a temperature of 130°C, with an electric field of 1000V/cm.

Firstly, we fixed the intensity ratio $m = I_p(0)/I_s(0)$, and measured the steady-state coupling coefficient Γ versus the external crossing angle 2θ between two incident beams. Γ was obtained by[11]

$$\Gamma = \frac{1}{L}\ln\left(\frac{I_s I_p(0)}{I_p I_s(0)}\right) \tag{1}$$

where I_s and I_p represent the transmitted probe and pump beam intensities after coupling, respectively, and $I_p(0)$ and $I_s(0)$ before coupling.

Figure 3 shows the dependence of the steady-state two-wave coupling coefficient Γ on 2θ. The solid line represents the theoretical prediction of the coupling coefficient, simulated according to the following equation[1]

$$\Gamma = \frac{A\sin\theta}{1+B^{-2}\sin^2\theta}\frac{\cos 2\theta_i}{\cos\theta_i}, \tag{2}$$

where $2\theta_i$ and 2θ are the crossing angles in and out of the crystal, respectively, and A and B are parameters related to the photorefractive material used.

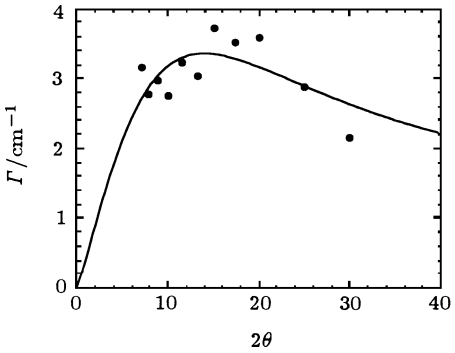


Fig.3. Steady-state coupling coefficient Γ versus beam crossing angle $2\theta(m = 10)$ (the solid line represents simulated results).

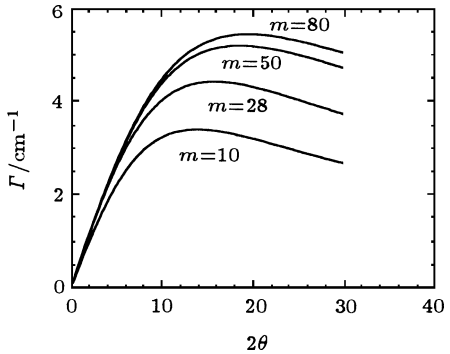


Fig.4. Steady-state coupling coefficient Γ versus beam crossing angle 2θ with different beam ratios m. All the curves are simulated by using Eq.(2).

It is shown from Fig.3 that the steady-state two-wave coupling coefficient Γ increases rapidly with 2θ in the first instance, reaching a peak value, then decreases gradually. That is, an optimal coupling angle exists corresponding to the peak value, which changes with the beam intensity ratio m [$= I_p(0)/I_s(0)$]. Figure 4 describes the dependence of Γ on the beam intensity ratio m. The dependence of the optimal coupling angle on the beam ratio m is presented in Fig.5. It shows that Γ monotonically increases with m, and the optimal coupling angle increases with m (in the range of our experiment) in a nearly linear manner. The maximum Γ for m=80 is near 5.5cm^{-1}, which is larger than the result for SBN:60:Cr and SBN:75:Rh crystals given in Ref.[7], where m=3000 and 1500, respectively.

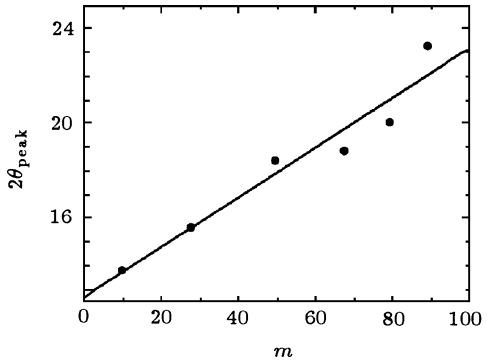


Fig.5. Dependence of the beam crossing angle of optimal coupling on the intensity ratio m.

Figure 6 describes the dependence of steady-state coupling response time τ on the beam crossing angle 2θ with different m. Here τ is defined as the time required for the probe beam intensity to increase from its initial value to $(1-e^{-1})$ of its steady-state value, after the pump beam is switched on. In our experiment, the measured response time τ of SBN:61:Cr is very short, less than 0.8 s, much shorter than that of SBN:Ce.[1] It is shown that τ decreases with increasing 2θ, nearly reaching 0.2 s. This can be explained as follows. According to the band transport mechanism, the formation of the photorefractive grating consists of four stages: photo-induced charge exciting, charge transporting from the bright zone into the dark zone, the induced charge being re-trapped, and electro-optic effect inducing refractive index change. The photo-induced charge transport would be the basic limitation of the response time, as long as the incident intensity is strong enough. As the crossing angle becomes larger, the period of grating formation decreases. This means that the charge will travel a shorter distance to the dark zone, so that the response time decreases.

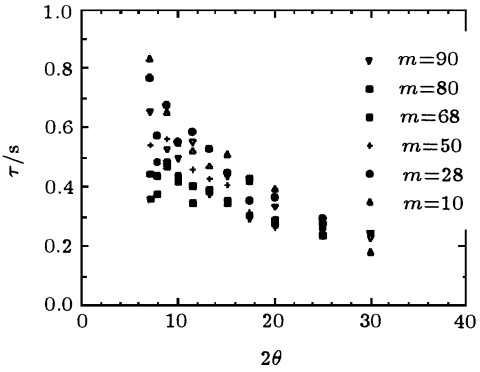


Fig.6. Steady-state coupling response time τ versus beam crossing angle 2θ.

Ⅲ. DISCUSSION

In our experiments, we first blocked off the pump beam and only kept on the probe beam, then switched on the pump beam and observed the change of the probe beam intensity. Thereafter, we blocked off the probe beam and only kept on the pump beam, then switched on the probe beam and observed its decay. Under both conditions, we observed that the probe beam intensity increased in a monotonic non-exponential mode. After coupling reached the steady state, the pump beam was switched off, and the probe beam intensity decreased quickly to its initial value before coupling. If the probe beam was switched off, the detected intensity in the probe beam direction behind the crystal decreased gradually until it reached zero. All the observations are shown in Fig.7. In our experiments, we have not observed the transient procedure behaviour of the probe beam, which occurred in the KNSBN crystal.[12]

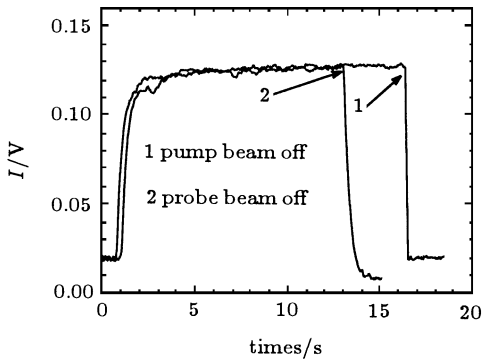


Fig.7. Evolution of the probe beam intensity in different processes in two-wave coupling.

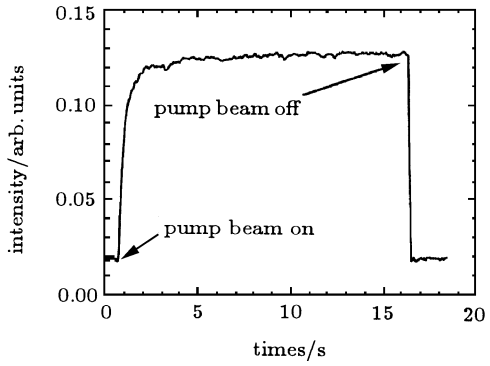


Fig.8. Bistable state characteristics of the evolution of the probe beam intensity.

It is also shown in Fig.8 that the probe beam intensity evolution demonstrates a bistable state. That is, when the probe beam with a certain intensity is put into the SBN:61:Cr crystal, its output can show two steady states, which can be converted through the switching on and off of the pump beam. In the two-wave coupling experiment, when the probe beam is sent onto the crystal, there is a stable output intensity. Now, switching on the pump beam to couple with the probe beam, the output of the probe beam changes to another stable value rapidly. Then switching off the pump beam again, the output of the probe beam decreases to the initial stable value.

IV. CONCLUSION

In this paper, we have reported on the experimental measurements of two-wave coupling in the SBN:61 crystal doped with 1000ppm Cr. The steady-state coupling coefficient is characterized as a function of the parameters involved in the experiment. The coefficient has a peak value at a beam crossing angle $2\theta_{\rm peak}$. The coefficient is also a function of the intensity ratio m of the two coupling beams. The response time for steady-state coupling is less than 0.8 s. For every value of m, the response time is measured to decrease with an increasing 2θ angle. This can be explained by the formation mechanism of the photorefractive index grating. The measured maximum Γ of the sample is smaller than that of the SBN:60:Ce crystal, but the response time is much shorter than that of the latter crystal.[8] Our results are also larger than that of Ref.[13] for the KNSBN crystal. The evolution of the probe beam shows a bistable state in the coupling. This bistable state character could be used in bistable apparatus applications, such as optical switching, optical storage, optical amplification, optical computing, and so on.

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