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OBSERVATION OF PHOTOREFRACTIVE EFFECT OF $KNbO_3$ CRYSTAL AT μW ILLUMINATION*

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The photorefractive effects of the as-grown and proton-implanted $KNbO_3$ crystals were studied by two-wave mixing at 62.2 μW/cm^2 illumination. At this pump power level, the as-grown crystal showed little photorefractive effect, while the proton-implanted crystal showed an obvious effect. Furthermore, there seemed to exist two photorefractive gratings with response times of 22.54 and 1596.30s, at 62.2μW/cm^2 pump power level, in the proton-implanted sample. This phenomenon has been attributed to the influence of proton-implantation.

Keywords: ion-implantation, photorefractive effect, ferroelectric crystals
PACC: 6180J, 7820W, 4270G

I. INTRODUCTION

Photorefractive (PR) crystals have many potential applications in optical information processing and phase conjugation.[1] PR effect originates from the redistribution of photoinduced charge among the deep traps.[1,2] Two-beam coupling is one of the interesting nonlinear optical phenomena occurring in PR media and also a useful tool to observe the PR effect and to determine the PR response time of PR materials. $KNbO_3$ crystal is one of the most interesting materials for nonlinear optics applications owing to its large electro-optic coefficients, and its large nonlinear optical susceptibilities. It is also one of the materials with the fastest PR response among ferroelctric oxides, but its PR response speed still needs improving for its applications in real-time information storage and phase conjugator.[2] The technique of ion implantation has been found to be well suited for speeding up the PR response of $KNbO_3$ crystal.[3,4] But in all the reports, the PR response time was measured at rather high intensity of laser illumination. To our knowledge, PR properties of $KNbO_3$ crystal have not been observed at μW illumination. In this report, we present our experimental result of the PR effect in proton-implanted $KNbO_3$ crystal at rather low intensity illumination of 62.2μW/cm^2 level. The experimental results show that there are two PR gratings with different response times of 22.54 and 1596.30s. Besides, no PR signal was detected in the as-grown sample at this low illumination level.

II. EXPERIMENT

The $KNbO_3$ crystals used in this experiment were prepared at Research Institute of Synthetic Crystals, with dimensions of 10mm×8mm×2mm. The concentration of the dopant Fe is 10 ppm, i.e., 10 parts in 10^6. Proton-implantation was undertaken on a 2×1.7 MV parallel accelerator in Technical Physics Department, Peking University, with an energy of 3.0 MeV to a dose of 1×10^{16} cm^{-2}. The direction of ion incidence is 7° with the normal of the sample to avoid the channel effect. The PR response properties of the crystals were measured in Photonics Laboratory, Department of Physics, Peking University. Two-wave-couple method was used in this experiment, and erasure process was taken to measure the PR response time of the samples. Two mutually coherent p-polarized He-Ne laser beams A and B with the same intensity and a wavelength at 632.80 nm were incident upon the crystals, see Fig.1. The angle between the two beams is 2θ=20° in air and the laser spot is 1.0 mm in diameter. After the beam-coupling behavior reached stable, we blocked the writing beam A and kept beam B as the

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readout and also the erasure beam. In Fig.2 is shown the diffraction beam intensity I_R for proton-implanted sample. It decayed slowly to zero due to the erasure effect. Also the PR response time (I_R-t) curve was measured for the as-grown samples. Contrary to the case in Fig.2, I_R keeps as a constant of zero.

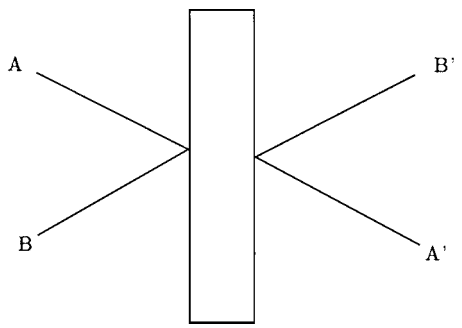


Fig.1. Scheme of photorefractive two-wave mixing.

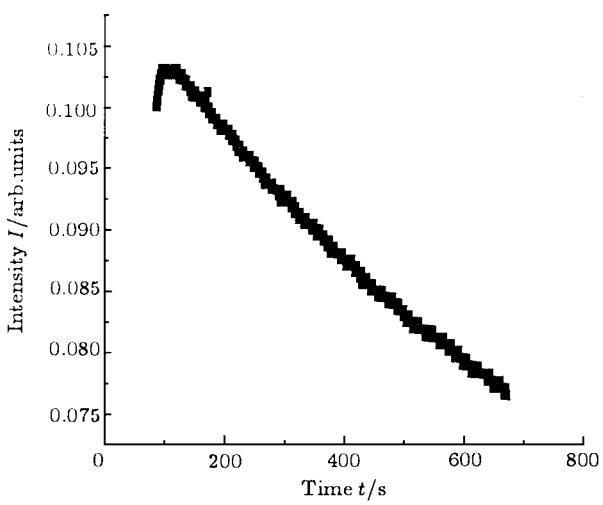


Fig.2. Decay curve of photorefractive diffraction intensity (Erasure light intensity I=62.2 μW/cm^2).

Ⅲ. RESULTS AND DISCUSSION

In two-beam coupling experiments, two beams with intensities I_1 and I_2 are incident on the sample and produce a spatially periodic irradiance pattern. If the resultant refractive index grating is not in phase with the irradiance grating, then the energy is transferred from one beam to the other. The direction of the energy transfer is determined by the crystal orientation and the dominant photocarrier, but not by the relative power of the beams. Considering a configuration of an experiment where the c-axis of the crystal is orientated in such a way that the signal beam I_2 is amplified at the expense of the pump beam I_1, then the transmission of the signal beam is given by[5]

$$\frac{I_2(L)}{I_2(0)} = \frac{[I_2(0)+I_1(0)]\exp[(\Gamma-\alpha)L]}{I_1(0)+I_2(0)\exp(\Gamma L)}, \qquad (1)$$

where Γ is the gain coefficient, α is the absorption coefficient, and L is the interaction length, $I_1(0)$, $I_2(0)$, $I_1(L)$, $I_2(L)$ are the initial and final intensities of the two beams, respectively.

In the transport band theory, the steady-state two-beam coupling gain γ is defined as[1,2]

$$\gamma = \frac{I_2(L)^{\text{with pump beam}}}{I_2(L)^{\text{without pump beam}}} = \frac{I_2(L)}{I_2(0)}. \qquad (2)$$

In our experiment, beams 1 and 2 have equal intensity. If we neglect the absorption inside the crystal, then according to Eq. (1) we have

$$\Gamma = \frac{1}{L}\ln\frac{\gamma}{2-\gamma}. \qquad (3)$$

The PR sensitivity S, defined as the index change per incident energy density, is given by[3,6]

$$S = \frac{\Delta n}{I\tau_0} = \frac{\Gamma\lambda}{4\pi I\tau_0}, \qquad (4)$$

where λ is the wavelength of the light, I the intensity, and τ_0 the build-up time for writing the PR space charge grating.

From the recorded data, we got a Γ value of 0.4 cm^{-1} and τ_0 of 22.54 s. The high gain Γ and the fast response time τ_0 of the sample lead to a PR sensitivity S of 0.0144 cm^2/kJ.

The phenomenon that the PR effect of proton-implanted $KNbO_3$:Fe crystal has been observed under μW illumination may be elucidated by the fact that, after H^+-implantation, the PR response time has been shortened, and therefore the sensitivity of the crystal has been enlarged more. So at this low illumination, the PR effect can be shown obviously. Another possible explanation lies in the fact that after H^+-implantation, charge carrier density N_A has been increased much, which leads to E_{sc} being also increased at large scale. (E_{sc} is the space charge field of PR grating, its value is equal to the square root of I_R.) It can be seen in detail as follows.

As the charge carrier density has been augmented by many times after proton-implantation (see below), the amplitude of the space charge field has also been increased much. From the band transport theory, we can get the following equation under a steady condition:[1,2]

$$E_{sc} = -m\frac{E_s(E_0+iE_d)}{(E_d+E_s)-iE_0}, \qquad (5)$$

where m is the ratio of two laser beam intensities, E_0, E_s, E_d are the applied external field, saturated field and diffusion field, respectively.

For the simple diffusion case, E_0=0, and in our experiment, m=1, then the amplitude of space charge field is[1,2]

$$E_{sc} = \frac{E_d}{1 + K^2 l_s^2} \sin Kz = \frac{\frac{k_B T}{q} K}{1 + K^2 \frac{\varepsilon k_B T}{q^2 N_A}} \sin Kz. \quad (6)$$

As the dopant (Fe) concentration is only 10 ppm, about $1.56\times10^{17}\,cm^{-3}$, the implanted proton has a higher concentration up to $2.03\times10^{20}\,cm^{-3}$ in the ion-end region, according to the TRIM (transport of ions in matter, a Monte Carlo code) calculation. That is to say, after proton-implantation, the charge carrier density N_A is enhanced about 2–3 orders in magnitude, so we can expect the observation of PR effect at a rather low illumination level.

As no obvious PR effect was detected in the unimplanted crystals, the remarkable PR effect in the implanted crystals can be reasonably considered as the contribution of the proton-implantation. Also for this reason, although the beam spot is about 1mm and the implanted region is only about 50 μm, observable PR effect can be attributed to be influence of proton-implantation.

IV. CONCLUSION

The PR effect of proton-implanted $KNbO_3$ crystal has been observed at 62.20 $\mu W/cm^2$ level illumination. This phenomenon is attributed to the influence of proton-implantation. Further investigation is under way.

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