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Light-induced scattering in SBN:Cr crystal under external electric fields and its suppression*

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In this paper, the enhancement of light-induced scattering in congruent SBN:Cr ($Sr_{0.61}Ba_{0.39}Nb_2O_6$:Cr) crystals in the presence of an externally applied electric field and its suppression are studied. If a coherent image is focalized in SBN:Cr crystal without applying external electric field, the output image will remain clear, because of the weak photorefractive effect in the crystal. When a field is applied properly along the crystal axis, markedly enhanced scattering from the signal beam and the output image dispersion can be observed due to the increase of the photorefractive two-beam coupling gain and the light-induced index change in SBN:Cr crystals. By introducing a coherent or incoherent beam with higher intensity the light-induced scattering can be suppressed through the erasure of scattering gratings. The difference between coherent and incoherent beam is that the former can also amplify the signal beam as the scattered light is removed, whereas the latter can only make the signal beam revert to its initial state. The results obtained under different experimental conditions are consistent with theoretical analysis.

Keywords: light-induced scattering, SBN:Cr crystal, external electric field, photorefractive two-beam coupling

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1. Introduction

The absorption edge of SBN:Cr crystals shifts to the long wave region and there exists a wide absorption band around 650nm due to the Cr doping.[1,2] This indicates that the SBN:Cr crystals should exhibit an eminent photorefractive effect in the red light region. Tomita and Suzuki[1] made comparative measurements of the two-beam coupling gain in SBN:60:Cr crystals at 514.5nm and 632.8nm wavelengths. Recently Woike *et al*[3] investigated the holographic writing and erasing processing and deduced response times for the buildup of holographic gratings from measurements of two-beam coupling gain with low modulation for different concentration of Cr at 632.8nm. We investigated the properties of two-beam coupling[2] and four-wave mixing[4] at 632.8nm wavelength of He–Ne laser. We also proposed a photorefractive edge-enhancement joint-transform correlator with this crystal.[5] In this paper, we present the experimental results of the two-beam coupling and the beam scattering in the presence of an externally applied electric field. It is found that a proper external electric field can lead to a marked increase of beam scattering in the crystals, and by introducing a pump beam (coherent or incoherent) with higher intensity the scattered light can be effectively removed.

Light-induced scattering[6,7] is a well-known photorefractive phenomenon in which a single laser beam is scattered and amplified symmetrically or asymmetrically as it passes through a crystal with high coupling gain. This is a result of the two-beam coupling process where the input beam interacts with its own scattered light, forming a diffraction grating, and coupling additional energy into the scattered light. Light-induced scattering has potential uses in optical communications,[8] optical limiting,[9] motion detection,[10] and optical phase conjugation.[11] But in general, light-induced scattering is one of the major problems in applications like optical data storage and optical image processing. It degrades signal quality in two ways: by adding background noise on top of a

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signal, and by acting as a parasitic loss that can rob a beam of almost all of its energy. Thus suppression of light-induced scattering becomes a main problem in optical image processing. Several ways were proposed and demonstrated to eliminate or suppress the light-induced scattering. Rajenbach *et al*[12] showed that by slowly rotating the photorefractive crystal one could suppress the growth of fanning. Joseph *et al*[13] prevented fanning by using a low intensity pulse to develop the holographic grating, followed by a short pulse with high intensity to provide high amplification. Rabinovich *et al*[14] showed that parasitic loss from beam fanning in two-beam coupling could be suppressed through the use of achromatic gratings. In addition, Wang *et al*[15] discussed the suppression effect of two-beam coupling on the incident beam fanning in the signal.

2. Experimental setup

The basic experimental setup is shown in Fig.1. A thin collimated beam from a He–Ne laser with power of 35mW at 632.8nm wavelength is divided into signal beam and pump beam by beam splitter BS. The signal beam is expanded and collimated by lenses L_1 and L_2, and then spatially modulated by a transparency containing a Chinese word '光' ('light') acting as the input image. A photorefractive crystal sample is placed in the front focal plane of the lens L_3, where the pump beam interferes with the Fourier transform spectrum of the input image. The output image is directly projected on the target of a CCD camera. The intensity ratio of the pump beam to signal beam is selected as 15:1. The crystal sample used in the experiments is a congruent SBN:Cr ($Sr_{0.61}Ba_{0.39}Nb_2O_6$:Cr) crystal (Cr: 1000ppm, size: $6.6\times6.7\times5.5mm^3$). An external electric field is applied along the crystal *c*-axis. To obtain higher two-beam coupling gain, both the polarization and incident plane of the two beams are parallel to the crystal *c*-axis, and the external crossing angle between two beams is chosen to be 16°, near the maximum-gain angle of the crystals according to Ref.[2].

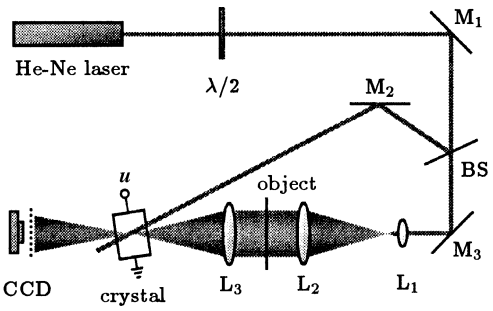


Fig.1. Experimental setup for photorefractive two-wave coupling.

3. Experimental results

Firstly, we observed the enhancement of light-induced scattering in the signal beam and then the suppression of the scattered light by pump beam under the condition of an externally applied electric field and the energy transfer from pump beam to signal beam. The results are illustrated in Fig.2. It is shown that there is almost no scattering in the output image when the pump beam and external field do not exist [Fig.2(a)]. As an electric field of 6kV/cm is applied, a strong scattering appears immediately and the output image is accompanied by obvious dispersion [Fig.2(b)]. Subsequently the scattering slowly weakens to a steady state [Fig.2(c)]. Hereafter the pump beam is switched on, the signal beam is amplified and the scattering fades away slowly [Figs.2(d)–2(e)]. Finally, the dispersion is removed and a steady intensity-enhanced output image is obtained [Fig.2(f)].

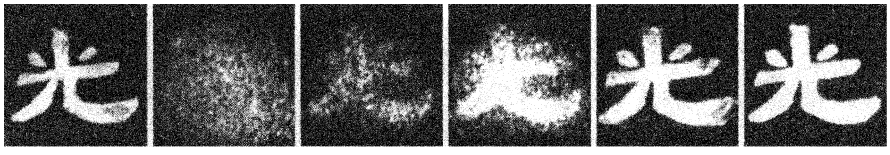


Fig.2. Enhanced beam scattering under applied field and its suppression in SBN:Cr crystal (Cr: 1000ppm, energy transferring from pump beam to signal beam, electric field: 6kV/cm). (a) initial output image without external field and pump beam; (b) image dispersion under external field; (c) steady scattering; (d) pump beam switching on; (e) scattering being suppressed; (f) steady output image after suppressing scattering.

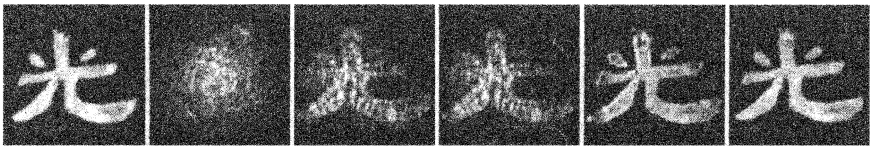


Fig.3. Enhanced beam scattering under applied field and its suppression in SBN:Cr crystal (Cr: 1000ppm, energy transferring from signal beam to pump beam, electric field: 6kV/cm). (a) initial output image without external field and pump beam; (b) image dispersion under external field; (c) steady scattering; (d) pump beam switching on; (e) scattering being suppressed; (f) steady output image after suppressing scattering.

Similar experimental results are also observed in the same crystal in the presence of an externally applied field after reversing the energy transferring direction, namely from signal beam to pump beam. As is shown in Fig.3, a weakened but steady, clear image is attained. Moreover, similar image scattering also appears in the case of applying the external field before switching on the signal beam.

4. Discussions

To understand this interesting phenomenon, we measured the photorefractive two-beam coupling gain in SBN:Cr crystal under application of an external electric field. The dependence of intensity gain Γ on applied field E_0 experimentally measured is shown in Fig.4. Γ is defined by [16]

$$\Gamma = \frac{1}{L} \ln \frac{I_{\mathrm{P}0} I_{\mathrm{S}}(L)}{I_{\mathrm{S}0} I_{\mathrm{P}}(L)},$$

where $I_{\mathrm{s,p}0}$ and $I_{\mathrm{s,p}}(L)$ are the signal beam and the pump beam intensities at the input and output plane of the crystal, respectively, and L is the coupling length along the beam direction in the crystal. It is seen that the gain increases steadily with positive external electric field. When a negative field is applied, the gain increases firstly to a peak and then decreases sharply. The sign change of Γ denotes the reverse of the energy transfer direction in the two-beam coupling due to the spontaneous polarization reversal.

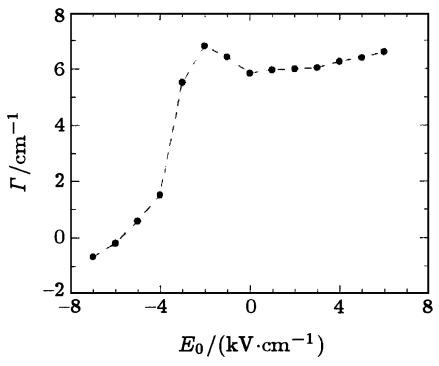


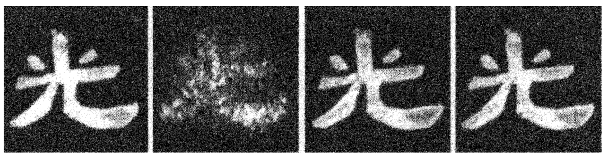
Fig.4. Photorefractive two-wave coupling gain as a function of applied field in SBN:Cr crystal.

It is evident that an external electric field can properly increase the two-beam coupling gain, but the increment of the two-beam coupling gain can contribute little to the beam scattering enhancement here. The reasonable explanation is that introducing an external electric field not only improves the two-beam coupling gain, but also amplifies the light-induced index change in the irradiated zone of the crystal. This is also confirmed by the experimental measurement for light-induced index change in SBN:Cr crystal under application of the external field.[17]

As mentioned above, the signal beam in the crystal sample is the spatial spectrum of the input image. When there is only the signal beam in the crystal and no externally applied electric field, the spatial spectrum of the input image will cause relatively weak light-induced index change and light-induced scattering in the crystal, so the output image is clear. With an applied external electric field of 6kV/cm, the migration of the light-induced charges will be expedited. The interaction between the external field and the original internal space-charge field results in the redistribution of the original space charges, and thereby the redistribution of index change in crystal. During this time, the index distribution is very unstable, so the image is dispersed. When the external electric field and the internal space charge field tend to balance, the refractive index grating gradually reaches the steady state. In addition, the index modulation and then the diffraction efficiency are increased due to the external field. Therefore the strengthened scattering becomes stable. Switching on the pump beam with higher power may erase the scattering gratings and simultaneously write-in a deeper modulation holographic grating with the signal beam in the crystal. So the dispersion is removed and the enhanced image is superposed by its original output image and real-time holographic reconstruction image. Similarly, the suppression of scattered light in Fig.3 is also achieved

through the erasure of scattering gratings by the pump beam.

To verify that the removal of the scattering is caused by the erasure of the noise grating by a higher power pump beam rather than by other mechanisms, incoherent beams (beams with perpendicular polarization or coming from another He–Ne laser) with equal intensity as the coherent ones were employed to repeat the same procedure as in former experiments. Figure 5 shows the experiment results. We can see that removal of the scattered light is successfully achieved with incoherent pump beams too. Meanwhile, the coupling effects between the signal and erasure beams are nonexistent because of their incoherence. So the erasing of space charge field due to incoherent beams is the only effective course.



(a) (b) (c) (d)

Fig.5. Beam scattering suppression in SBN:Cr crystal (Cr: 1000ppm, electric field: 6kV/cm) using incoherent pump beam: (a) initial output image; (b) scattering image; (c) scattering suppression using perpendicularly polarized beam and (d) using incoherent beam.

As shown above, light-induced scattering in photorefractive materials can be suppressed by introducing a coherent or incoherent beam with higher intensity. The difference between coherent and incoherent beams is that the coupling effects between the coherent pump beam and the signal beam amplify the latter as the scattered light is removed, whereas incoherent beams make the signal beam revert to its original state. Similar results are also obtained in another SBN:Cr crystal (Cr: 250ppm).

5. Conclusions

A properly applied externally electric field can improve the photorefractive properties of some materials. Unfortunately, it generally leads to a marked increase in beam scattering and degrades signal quality because it tends to enhance the coupling gain. We propose a new method for suppressing light-induced scattering through the erasure of scattering gratings by a higher power pump beam (coherent or incoherent). Experimental results and theoretic analysis show that the method is effective. Another reason why the experimental results reported here are significant is that by applying the external electric field, it is convenient to study the evolution and suppression of beam scattering, which is much fainter with no applied field. In addition, because it is based on the internal mechanism of the interaction of light and crystals, the method we proposed here can be used to investigate in depth the mechanism of beam scattering and the effects of external electric field on photorefractive properties of the materials, more than just to remove the scattering of the signal beam.

Acknowledgments

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References

[1] Tomita Y and Suzuki A 1994 *Appl. Phys.* A **59** 579
[2] Zhao J L, Wang B, Wu J J, Yang D X, Kapphan S and Pankrath R 2001 *Chin. Phys.* **10** 739
[3] Woike T, Dörfler U, Tsankov L, Wolf G, Wöhlecke M, Gtanzow T, Pankrath R, Imlau M and Kleemann W 2001 *Appl. Phys.* B **72** 661
[4] Yang D S, Zhao J L, Li Z W, Xu Q T and Zhang P 2002 *Acta Photon. Sin.* **31** 1161 (in Chinese)
[5] Zhao J L, Xu Q T, Zhou W M, Yang D S, Kapphan S and Pankrath R 2002 *Opt. Commun.* **212** 287
[6] Feinberg J 1982 *J. Opt. Soc. Am.* **72** 46
[7] Clark III W W, Wood G L, Miller M J, Sharp E J, Salamo G J, Monson B and Neurgaonkar R R 1990 *Appl. Opt.* **29** 1249
[8] Ewbank M D 1988 *Opt. Lett.* **13** 47
[9] Cronin-Golomb M and Yariv A 1985 *J. Appl. Phys.* **57** 4906
[10] Ford J, Fainman Y and Lee S 1988 *Opt. Lett.* **13** 856
[11] Feinberg J 1982 *Opt. Lett.* **7** 486
[12] Rajbenbach H, Delboulbe A and Huignard J P 1989 *Opt. Lett.* **14** 1275
[13] Joseph J, Pillai P K C and Singh K 1990 *Opt. Commun.* **80** 84
[14] Rabinovich W S, Feldman B J and Gilbreath G C 1991 *Opt. Lett.* **16** 1147
[15] Wang L J, Guo S J and Wang J Y 1996 *Acta Opt. Sin.* **16** 1082 (in Chinese)
[16] Liu S M, Guo R and Ling Z F 1993 *Photorefractive Nonlinear Optics* (Beijing: Standard Press of China) p10 (in Chinese)
[17] Zhao J L, Li B L, Yang D X, Zhang P and Li Z W 2003 *Acta Photon. Sin.* **32** 1486 (in Chinese)