Self-starting passive phase conjugate mirror with Ce-doped strontium barium niobate

George A. Rakuljic, Koichi Sayano, and Amnon Yariv
California Institute of Technology, Pasadena, California 91125
Ratnakar R. Neurgaonkar
Rockwell International, Thousand Oaks, California 91360

(Received 15 September 1986; accepted for publication 4 November 1986)

We report the use of Ce-doped $Sr_x Ba_{1-x} Nb_2O_6$, $x = 0.60$ and 0.75, as the holographic four-wave mixing medium in the construction of a self-starting passive phase conjugate mirror using internal reflection. Without correcting for Fresnel reflections, a steady-state phase conjugate reflectivity of 25% was measured with $Sr_{0.75} Ba_{0.25} Nb_2O_6$:Ce. The distortion correcting property of such a mirror was demonstrated using an imaging experiment.

Two-beam coupling in photorefractive crystals has been used to demonstrate passive phase conjugate mirrors (PPCM's) which do not require external pump beams.[1-3] A more recent version of such a device[4-6] introduces an important simplification by using total internal reflection in the photorefractive crystal instead of external mirrors. Such a mirror, however, requires a higher coupling threshold than that of the earlier devices. In this letter we report on the construction of this phase conjugate mirror using cerium-doped strontium barium niobate photorefractive crystals as the holographic four-wave mixing media.

Strontium barium niobate (SBN) belongs to a class of tungsten bronze ferroelectrics that are pulled from a solid solution of alkaline earth niobates. The crystal is transparent and can be grown with a variety of ferroelectric and electro-optic properties depending on the specific cation ratios introduced into the structure. In SBN the unit cell contains ten NbO_6 octahedra with only five alkaline earth cations to fill ten interstitial sites.[7] The structure is thus incompletely filled, which permits the addition of a wide range of dopants into the host crystal. The general formula for SBN is $Sr_x Ba_{1-x} Nb_2O_6$, so SBN:60 and SBN:75 represent $Sr_{0.60} Ba_{0.40} Nb_2O_6$ and $Sr_{0.75} Ba_{0.25} Nb_2O_6$, respectively.

The point group symmetry of SBN is 4 mm, which implies that its electro-optic tensor is nonzero. The dominant electro-optic coefficient is r_{33}, which at room temperature ranges from 100 pm/V in SBN:25 to 1400 pm/V in SBN:75. In order to realize the large values of electro-optic coefficients in SBN crystals, they must, in practice, be poled by first heating them above their Curie points and then allowing them to cool to room temperature with an applied dc electric field of 5–8 kV/cm.

Single crystals of cerium-doped SBN:60 and SBN:75 were grown along the [001] direction by the Czochralski technique. The resulting samples are high optical quality, striation-free cubes 0.5 cm on a side. Cerium doping was chosen since it dramatically enhances the photorefractive properties of SBN.[8-10] In fact, the resultant crystals have been shown to be just as photorefractive as $BaTiO_3$.[9]

The experimental setup for studying phase conjugation with SBN is shown in Fig. 1. Initially the lenses and transparency were removed so that the response of the phase conjugate mirror could be studied with a simple Gaussian beam. The reflectivity of two mirrors, one with Ce-doped SBN:60 and the other with Ce-doped SBN:75, is given in Fig. 2 as a function of time. Not only does the data of Fig. 2 show that phase conjugation using internal reflection is possible with SBN, but also that the steady-state phase conjugate reflectivity measured with Ce-doped SBN:75 is comparable to the 30% reflectivity obtained with $BaTiO_3$.[4] A photograph of the SBN:75 phase conjugate mirror in operation is shown in Fig. 3.

The imaging characteristics of the SBN phase conjugator were also determined with the arrangement shown in Fig. 1, but now with the transparency and lenses in place. The transparency, an Air Force resolution chart, was illuminated by the argon ion laser and focused onto the crystal by the lenses. The phase conjugate reflection was picked off by the beamsplitter and projected onto the screen. Figures 4(a) and 4(b) show the resolution chart and the phase conjugate

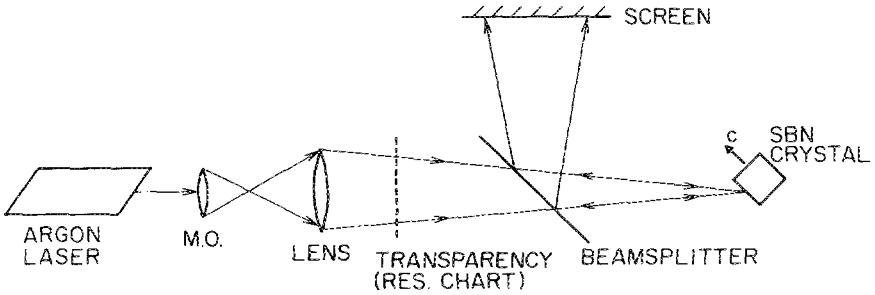

FIG. 1. Experimental setup for studying phase conjugation with SBN.

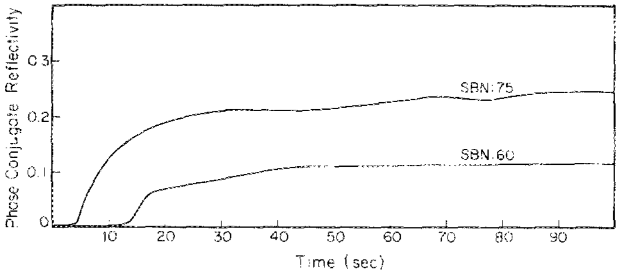

FIG. 2. Phase conjugate reflectivities of the SBN phase conjugators as a function of time. Pump beam power density was approximately 1.5 W/cm^2.

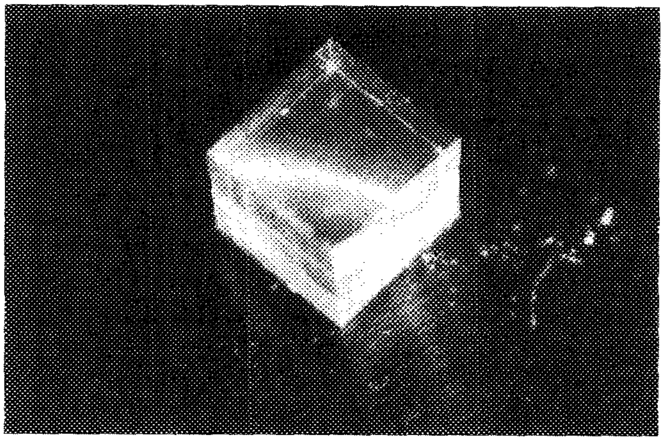

FIG. 3. Photograph of the SBN:75 phase conjugate mirror in operation.

image of the chart. Next, a phase distortion was placed between the transparency and the crystal, which, as shown in Fig. 4(c), rendered the chart indiscernible, and the phase conjugate image was once again viewed as it was projected onto the screen. Since the phase conjugate wave front at the crystal surface is that of the resolution chart after passing through the distortion, but with time reversal, the beam emerging from the distortion is the original undistorted image of the chart. This distortion correcting property of the SBN phase conjugator is shown in Fig. 4(d).

In summary, we have shown that the self-starting passive phase conjugate mirror using internal reflection can be constructed with cerium-doped strontium barium niobate. Phase conjugate reflectivities of 25 and 12%, not corrected for Fresnel reflections, were measured with Ce-doped SBN:75 and SBN:60, respectively. The imaging and distortion correcting properties of the SBN phase conjugator were also demonstrated.

This research was supported by Rockwell International Corporation, the U. S. Air Force Office of Scientific Research, and the U. S. Army Research Office.

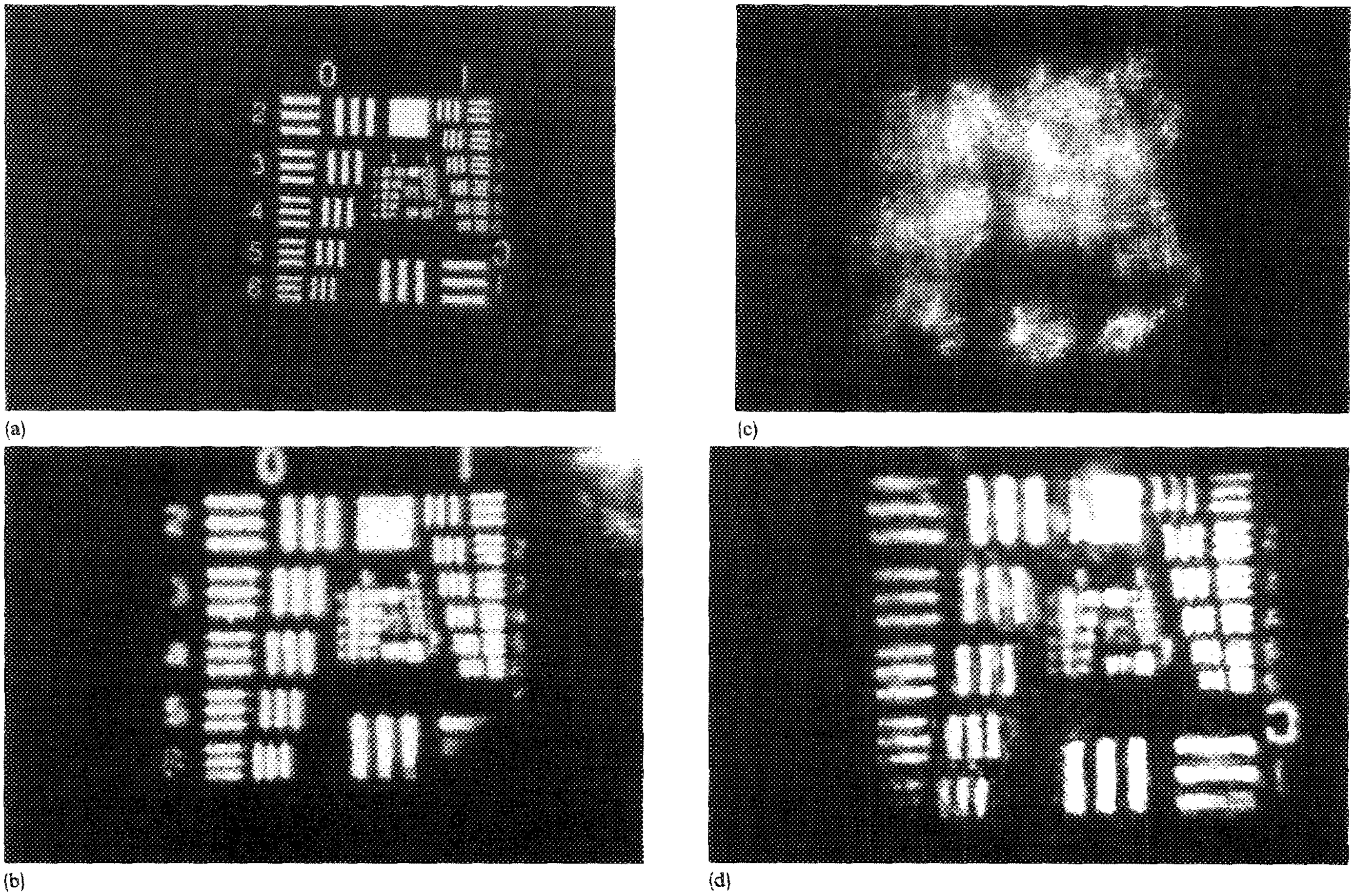

FIG. 4. (a) Air Force resolution chart. (b) Phase conjugate image of the resolution chart. (c) Image of the resolution chart with distortion. (d) Phase conjugate image of the resolution chart with distortion.

[1] J. O. White, M. Cronin-Golomb, B. Fischer, and A. Yariv, Appl. Phys. Lett. **40**, 450 (1982).
[2] M. Cronin-Golomb, B. Fischer, J. O. White, and A. Yariv, Appl. Phys. Lett. **41**, 689 (1982).
[3] M. Cronin-Golomb, B. Fischer, J. O. White, and A. Yariv, Appl. Phys. Lett. **42**, 919 (1983).
[4] J. Feinberg, Opt. Lett. **7**, 486 (1982).
[5] K. R. MacDonald and J. Feinberg, J. Opt. Soc. Am. **73**, 548 (1983).
[6] J. Feinberg, Opt. Lett. **8**, 480 (1983).
[7] P. B. Jamieson, S. C. Abrahams, and J. L. Bernstein, J. Chem. Phys. **48**, 5048 (1968).
[8] K. Megumi, H. Kozuka, M. Kobayashi, and Y. Furuhata, Appl. Phys. Lett. **30**, 631 (1977).
[9] G. A. Rakuljic, A. Yariv, and R. R. Neurgaonkar, Proc. SPIE **613**, 110 (1986).
[10] G. A. Rakuljic, A. Yariv, and R. Neurgaonkar, Opt. Eng. **25**, 1212 (1986).