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Waveguide mutually pumped phase conjugators

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The operation of the bridge mutually pumped phase conjugator is reported in a planar waveguide structure in photorefractive $BaTiO_3$. The waveguide was fabricated by the technique of ion implantation, using 1.5-MeV H^+ ions at a dose of 10^{16} ions/cm^2. An order of magnitude decrease in response time is observed in the waveguide as compared with typical values obtained in bulk crystals, probably as a result of a combination of the optical confinement within the waveguide and possible modification of the charge-transport properties induced by the implantation process.

Key words: Photorefractive, optical phase conjugation, mutually pumped phase conjugation, waveguide, ion implantation.

In recent years self-aligning phase conjugator configurations have been extensively researched in photorefractive materials such as $BaTiO_3$ and SBN. Many potential applications may be imagined for devices that are able to produce a phase conjugate (PC) output from a single beam incident upon a crystal as in the case of the self-pumped phase conjugator,[1] or that produce two simultaneous PC outputs via the interaction of two mutually incoherent beams within the crystal, as in the case of the mutually pumped phase conjugator (MPPC).[2,3,4] The scope for their implementation may however be limited by the long response time of currently available materials. Recently we have demonstrated significant decreases in response times of photorefractive effects by increasing the intensity of the interacting beams by confinement in a planar waveguide structure. A two-order-of-magnitude decrease in response time was reported for both two-beam coupling[5] and self-pumped phase conjugation.[6]

A schematic of the bridge MPPC[7,8] is shown in Fig. 1. The input beams are incident upon adjacent faces of the crystal, and both undergo beam fanning, Beam 1 toward the $+c$ face and Beam 2 toward the face upon which Beam 1 is incident. The overlapping fanning gratings collapse into the characteristic bridge coupling channel, accompanied by the simultaneous growth of two PC outputs, with Beam 1 providing the light for the PC of Beam 2 and vice versa. The self-aligning interconnection properties of the MPPC geometries have led to the demonstration of potential applications in laser phase locking,[9] optical communication systems,[10] and beam steering,[11] all of which would be enhanced by the decrease in response time offered by confinement within a waveguide geometry.

The waveguide under investigation here was fabricated via H^+ ion implantation. The 1.5-MeV H^+ ions, at a dose of 10^{16} ions/cm^2, were directed toward a polished face of a single crystal of $BaTiO_3$, perpendicular to the plane containing the crystal c axis. The ions initially lose energy within the crystal via electronic interactions with lattice ions. Once the ions' energy has been sufficiently reduced they undergo nuclear collisions, displacing atoms and distorting the lattice, creating a well-defined damage layer of reduced refractive index. The waveguide is then formed between the polished surface of the crystal and the damage region. The refractive profiles for n_e and n_o, determined from dark-mode measurements obtained by prism coupling, indicate that the waveguide is ≈ 15 µm deep and is capable of supporting ≈ 20 modes.[5] Waveguide losses, measured by end launching, were estimated at 14 dB/cm, corrected for Fresnel reflections and assuming a launch efficiency of 80%.

Previous two-beam coupling experiments with this crystal have revealed that the ion implantation process caused the gain direction to be reversed in the waveguide as compared with the bulk,[5] which may be a result of the repoling of the waveguide region, or,

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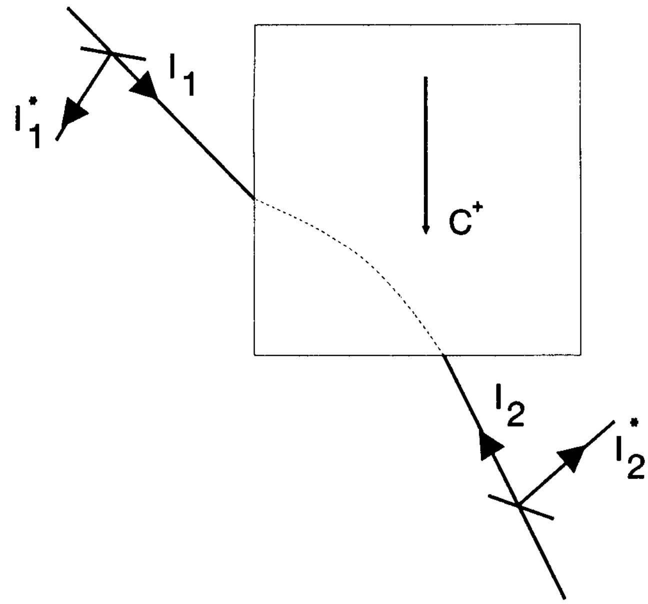

Fig. 1. Schematic diagram of the bridge MPPC.

more likely, the change in the dominant photocarrier. Figure 2 shows a schematic of the crystal, with the orientation of the input beams to perform bridge MPPC within the waveguide indicated.

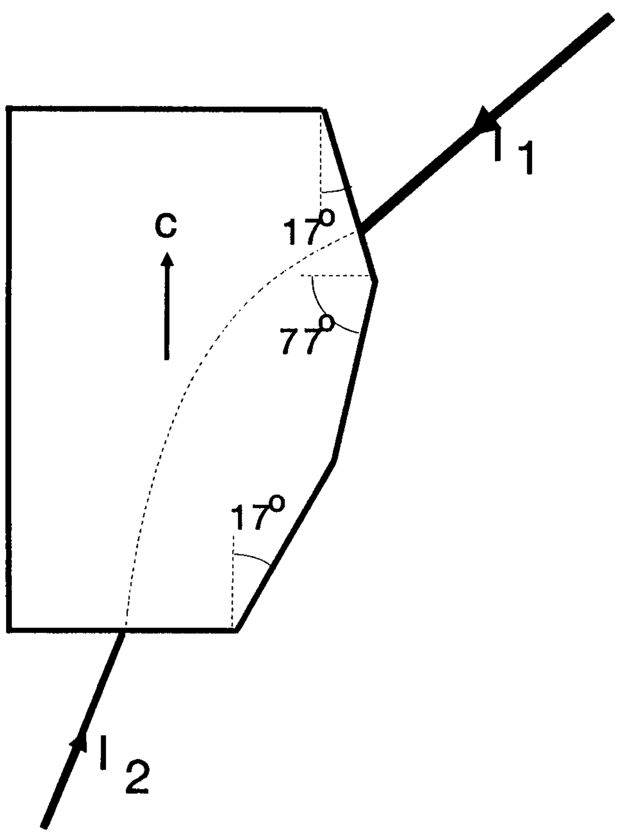

Fig. 2. Schematic diagram of the implanted $BaTiO_3$. The direction of the c axis indicated is that in the bulk crystal. The input beams indicate the configuration used to obtain bridge MPPC in the waveguide.

The two input beams were derived from the output of an argon-ion laser operating multilongitudinal mode at 488 nm. The path difference at the crystal was arranged to be in excess of the coherence length of the laser (≈ 5 cm) to ensure their mutual incoherence. The input beams were launched using cylindrical optics of a focal length of 25 mm, producing a 1.5 mm $\times$ 7 μm line focus at the crystal face.

The graph in Fig. 3 shows the dependence of the phase conjugate reflectivities on the input beam power ratio within the waveguide. The form of this graph agrees with previously reported experimental and theoretical work on MPPC geometries.[12] The reflectivity in this geometry was limited to 8%, a result of the high losses of this current waveguide.

Direct comparison of the performance of the waveguide and bulk was not possible, because the crystal geometry did not allow bridge conjugation to occur in the bulk. However, at 60 mW incident power the response time [time required to reach $1 - \exp(-1)$ of the maximum output] in the waveguide (corresponding to an intensity of ≈ 300 W/cm^2) was measured at 100 ms, whereas typical values measured in other bulk crystals at this input power (corresponding to intensities of ≈ 2 w/cm^2) were of the order of 2 s, giving approximately an order of magnitude decrease in response time in the waveguide as compared with the bulk. Correcting for waveguide losses, launch efficiency, and Fresnel reflections results in an estimated intensity of ≈ 50 W/cm^2 at the center of the coupling channel and indicates that the reduction in response time in the waveguide probably results from a combination of the increased intensity produced by the optical confinement within the waveguide and the possible modification of the charge-transport properties induced by the implantation process. It is anticipated that by reducing the waveguide losses the PC reflectivity could be increased and the response times could be significantly decreased.

The bird-wing phase conjugator (BWPC) has also been investigated in the waveguide. However, competition between the bird-wing phase conjugator ge-

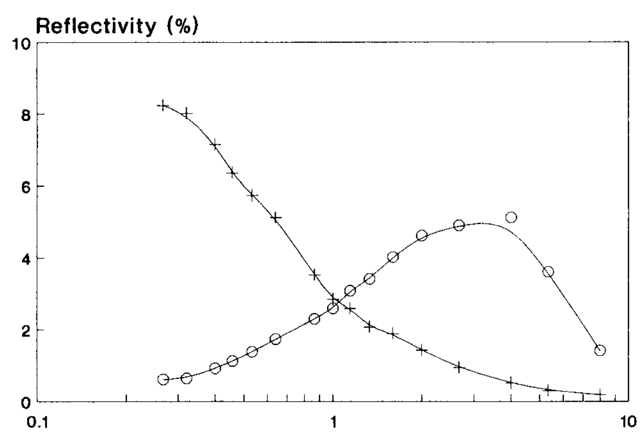

Fig. 3. Dependence of the PC reflectivities of beam 1 (○) and beam 2 (+) on the input beam power ratio, I_2/I_1.

ometry and self-pumped phase conjugation[13] resulted in the bird-wing phase conjugator operating over a severely limited dynamic range of input beam ratio, with reflectivities of the order of only 1%.

In summary, the operation of the bridge mutually pumped phase conjugator has been reported in a planar waveguide structure in $BaTiO_3$. An order-of-magnitude decrease in response time has been measured in the waveguide as compared with typical values obtained in bulk crystals. Current research efforts are being directed toward the reduction of waveguide losses via annealing and optimization of implant parameters, and toward optimization of the launch efficiencies for the various MPPC geometries via appropriate crystal cuts.

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