Photorefractive properties of ion-implanted waveguides in $BaTiO_3$

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Abstract

Optical confinement within a planar waveguide structure in $BaTiO_3$ produces significant decreases in the response times of two-wave mixing, self-pumped and mutually-pumped phase conjugation.

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Summary

Photorefractive materials have been used to demonstrate a wide range of potential applications in optical phase conjugation, image amplification and optical processing schemes. Materials such as $BaTiO_3$ and SBN display high optical non-linearities, allowing the construction of phase conjugate mirrors with reflectivities in excess of 100, and high fidelity self-aligning phase conjugate mirror configurations. The commercial implementation of these schemes may however be limited by the long response times of currently available materials. It has been shown that it is possible to decrease the response time by use at elevated temperature[1], material manipulation[2], and increased intensity. Here we describe the decrease in response times of photorefractive processes, such as two-beam coupling, self-pumped and mutually-pumped phase conjugation, resulting from the optical confinement of the interacting beams within a planar waveguide structure in $BaTiO_3$.

The waveguide under investigation was fabricated via the technique of ion-implantation, using 1.5 MeV H^+ ions at a dose of 10^{16} ions/cm^2. These implant parameters produced a 15μm deep waveguide, with losses of 14 dB/cm. Initial studies of the waveguide were carried out using a standard two-beam coupling arrangement. The beams, derived from an Ar+ ion laser operating at 488nm, were launched using 4X microscope objectives, producing a beam waist of $\approx$ 4μm at the crystal face. These measurements revealed that the two-beam coupling gain direction was reversed in the waveguide as compared to that in the bulk crystal[3]. The gain direction reversal may be a result of an inversion of the crystal's c axis in the waveguide region, or, more likely, a change in the dominant photocarrier (from holes to electrons) brought about by the implantation process.

The two beam coupling response time was measured as a function of total input power in both the waveguide and the bulk crystal. Comparison of these data sets, as is shown in figure 1, reveals that, at a given input power, the response time has been reduced by 2 orders of magnitude in the waveguide as compared to the bulk. The reduction in response time is attributed to a combination of the optical confinement in the waveguide, which resulted in a 3 order of magnitude increase in the intensity over that in the bulk, and the possible modification of the charge transport properties brought about by the implantation process.

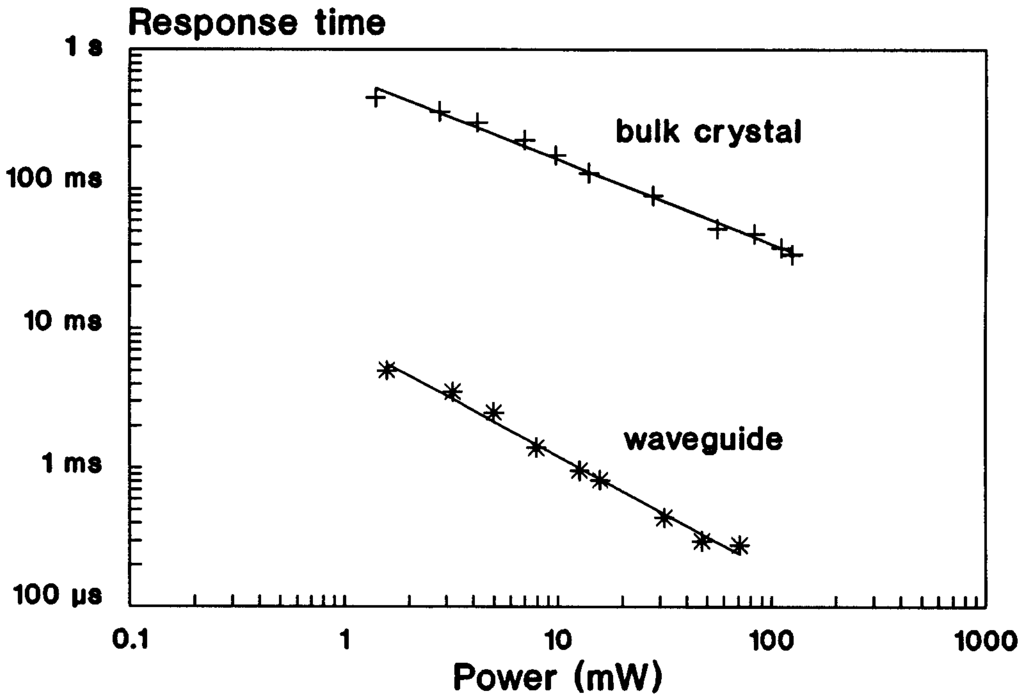

Figure 1: Two beam coupling response time versus incident power for waveguide (*) and bulk (+) crystal regions.

It was recently shown that using a cylindrical lens to focus the input beam in a Self-Pumped Phase Conjugator, SPPC, configuration, produced an order of magnitude decrease in response time[4]. Figure 2 shows a comparison of the dependence of the SPPC response time upon the input power, for three cases: a) using a cylindrical lens, f=22mm, to launch into the waveguide, b) using a cylindrical lens in the bulk, and c) unfocussed beam in the bulk. At the higher input powers the graphs reveal that the use of a cylindrical lens to launch into the waveguide produces a further order of magnitude decrease in the response time, since now a high intensity is maintained over the entire crystal length, and is not limited by the depth of focus of the cylindrical lens. The bulk crystal showed a threshold of ≈ 10mW, below which SPPC did not occur. In the waveguide this threshold was significantly reduced to below a 1mW. The change in gradient of the response time curve for case (a) correlates with a decrease in the phase conjugate (PC) reflectivity as SPPC approaches threshold. The maximum PC reflectivity observed from the waveguide was ≈ 20%, which, given the 14 dB loss of the waveguide, implies that stimulated photorefractive scattering is in operation here. The fidelity of the PC output was limited by the non-uniform launch efficiency across the input beam, since SPPC would only occur for angles of incidence > 0°.

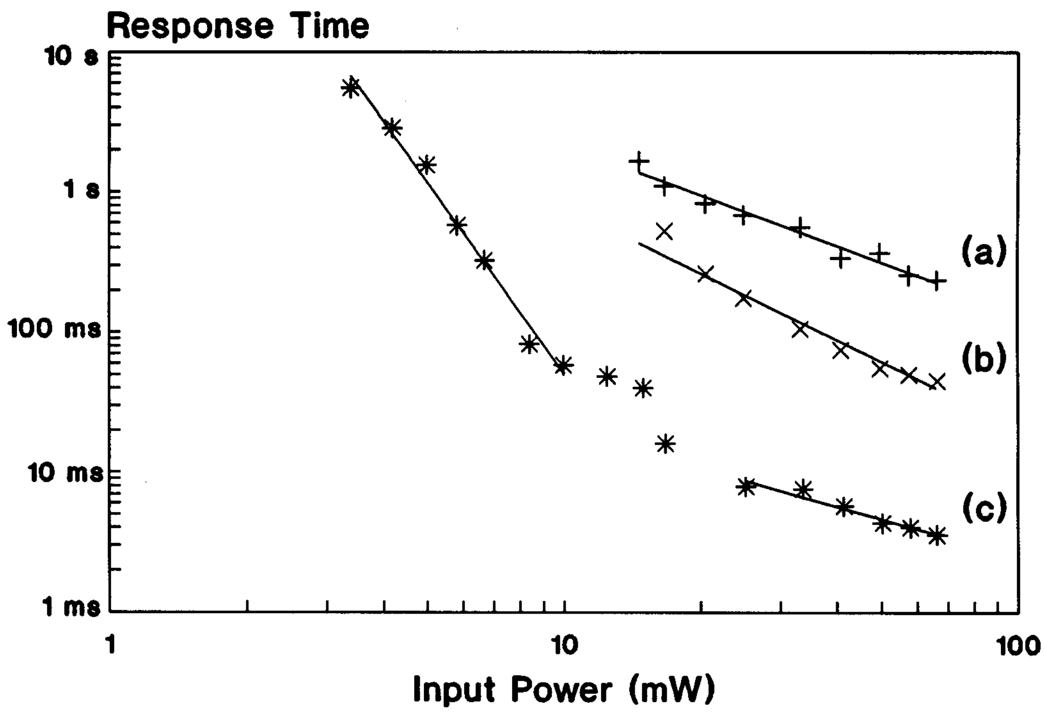

Figure 2: Response time as a function of input power for (a) an unfocussed beam in the bulk, (+), (b) a line focus in the bulk, (x), (c) a line focus in the waveguide (*). Estimated irradiances at the crystal face using 30mW incident power are 1W/cm for (a), and 300 W/cm^2 for (b) and (c).

The operation of the Bridge and Bird-Wing Mutually Pumped Phase Conjugator configurations have also been investigated in the waveguide. Figure 3 shows the dependence of the PC reflectivity of the Bridge conjugator upon input beam ratio. The maximum reflectivity, 8%, was limited by the losses of the waveguide. An order of magnitude decrease in the response time was observed in the waveguide as compared to typical values obtained in bulk crystals, giving a response time of ≈ 100 ms in the waveguide at 60mW incident, as compared to ≈ 1 s in the bulk. Competition between SPPC and the Bird-Wing Phase Conjugator severely limited the dynamic range of operation of the Bird-Wing geometry, with PC reflectivities of the order of only 1%.

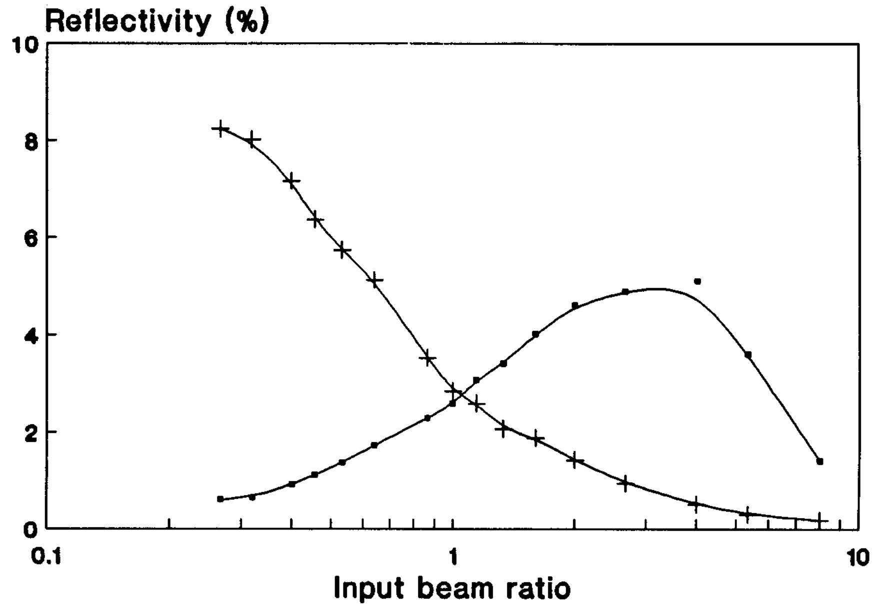

Figure 3: Dependence of the PC reflectivities of (▪) beam 1, and (+) beam 2, upon the input beam power ratio, I_2/I_1.

Methods of reduction of waveguide losses, including annealing and optimisation of implant parameters, are currently being investigated, along with optimised crystal cuts to maximise launch efficiency and allow investigation of the phase conjugate fidelity.

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