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Optical Waveguides in Lead Germanate Formed by MeV Proton and Helium Ion Implantation[1])

D. Kip (a), S. Mendricks (a), and P. Moretti (b)

(a) Universität Osnabrück, Fachbereich Physik, D-49069 Osnabrück, Germany
(b) Laboratoire de Physico-Chimie des Matériaux Luminescents, Université Claude Bernard Lyon 1, 69 622 Villeurbanne, France

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Lead germanate single crystals ($Pb_5Ge_3O_{11}$, PGO) exhibit considerably large electrooptic coefficients of $r_{33} = 15.3$ pmV^{-1} and show interesting photorefractive properties [1]. For bulk material and at moderate cw input power, time constants for the build up of a refractive index pattern in the range below one second have been observed [2]. These properties make the material an interesting candidate for integrated optics: The high light intensities that can be reached easily in waveguides together with the observed fast photorefractive effect may enable soliton interaction, beam-coupling or phase conjugation [3,4] even in the kHz range.

The implantation of light ions with an energy of some MeV into oxide crystals leads to the formation of a buried layer with reduced refractive index. Light can be guided in the surface layer by total internal reflection at this refractive index barrier. Up to now, this technique has been successfully applied to a wide range of linear and nonlinear optical materials, including photorefractive crystals like $LiNbO_3$, $KNbO_3$, $BaTiO_3$ or SBN [5,6,7,8]. In this note we report on the fabrication of planar waveguides in PGO crystals by H^+ and He^+ implantation.

For our investigations we used nominally pure PGO crystals. All samples with dimensions of $2.0 \times 2.5 \times 5.0$ mm^3 have been precisely polished for endface coupling. The samples were slightly tilted with respect to the beam axis and irradiated with H^+ ions at an energy of 1.0 MeV and doses of 2 and 10×10^{15} cm^{-2}, and He^+ ions at an energy of 2.0 MeV and doses of 1 and 4×10^{15} cm^{-2}, respectively. The crystal temperature was stabilised to about 20 °C and the beam flux was about 0.06 μA cm^{-2}.

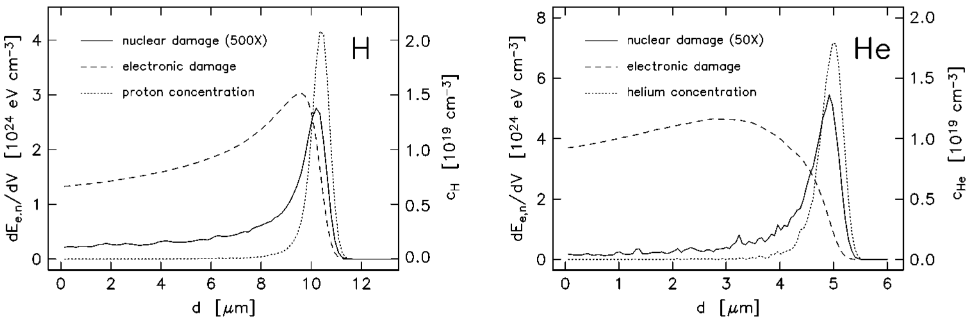

Fig. 1. TRIM simulation of implantation of 1 MeV H^+ at a dose of 2×10^{15} cm^{-2} (left), and 2 MeV He^+ at a dose of 1×10^{15} cm^{-2} (right). Nuclear and electronic energy losses, dE_n/dV and dE_e/dV, and H and He concentrations, c_H and c_{He}, are measured from the substrate surface

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Table 1

Effective refractive indices n_{eff} of guided TE and TM modes for different implanted samples. H2, H10: 1 MeV H^+ ions at a dose of 2 and 10 $\times$ 10^{15} cm^{-2}, respectively; He1, He4: 2.0 MeV He^+ ions at a dose of 1 and 4 $\times$ $10^{15}\mathrm{cm}^{-2}$, respectively. The refractive indices of the substrate are $n_{\mathrm{e}} = 2.204$ and $n_{\mathrm{o}} = 2.168$

sample	H2	H10	He1	He4
TE_0	2.2028	2.2022	2.2023	2.2013
TE_1	–	2.2014	–	2.1993
TM_0	2.1674	2.1661	2.1669	2.1641
TM_1	–	2.1618	–	2.1588

A TRIM simulation of the implantation of either H^+ or He^+ into PGO is shown in Fig. 1. The obtained refractive index change of the implanted barrier is related to the nuclear damage, whereas electronic damage may result in a refractive index decrease of the whole waveguiding layer. As can be seen, the nuclear damage for helium implantation (dose of $1 \times 10^{15}\,\mathrm{cm}^{-2}$) is much stronger compared to that of proton implantation (dose of $2 \times 10^{15}\,\mathrm{cm}^{-2}$).

The waveguiding properties of the implanted samples were investigated by dark line spectroscopy. We used a well characterised strontium titanate prism and a rotary stage with an angular encoder system to measure the effective refractive indices n_{eff} of the waveguides. Both, TE and TM modes were excited by extraordinarily and ordinarily polarised light (514.5 nm), respectively, propagating along the x-axis. The absolute accuracy for the determintion of n_{eff} is about 2×10^{-4}, whereas the relative accuracy is about one order of magnitude higher.

All implanted samples guide either one or two modes for each polarisation. The measured values for n_{eff} are given in Table 1. The smaller decrease of the buried refractive index barrier for proton implantation is at least partially compensated by the larger thickness of the waveguiding layer: The value of n_{eff} of TE and TM modes for the two single mode waveguides (H2 and He1) are very similar. When the implanted dose of both ion species is increased (samples H10 and He4), the waveguides contain one additional TE and TM mode. The optical loss of the waveguides has been measured by coupling light into and out of the endfaces of the samples. We estimated a launch efficiency of 80 % (thus taking into account the non-perfect aperture matching and crystal edge polishing) and corrected the data for Fresnel reflections. For the single mode waveguides we find a loss of about $0.2\,\mathrm{cm}^{-1}$, whereas the damping coefficients for waveguides with higher doses are slightly higher.

In summary, low loss, single mode planar optical waveguides in PGO crystals can be formed by proton and helium ion implantation. The investigation of the electrooptic and photorefractive properties of these samples is now in progress.

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