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Formation of slab waveguides in eulytine type BGO and CaF_2 crystals by mplantation of MeV nitrogen ions

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ABSTRACT

Ion implantation, compared with other waveguide fabrication methods, has some unique advantages. It has proved to be a universal technique for producing waveguides in most optical materials. The authors of the present article reported fabrication of channel and slab waveguides in an Erbium-doped tungsten tellurite glass by implantation of MeV energy N^+ ions. The present article reports successful adaptation of the same technique to the fabrication of slab waveguides in eulytine type bismuth germanate (BGO) and CaF_2 crystals. This is the first report on successful waveguide fabrication in these materials using 3.5 MeV N^+ ions at implanted fluences between 5×10^{15} and 4×10^{16} ions/cm^2. Spectroscopic ellipsometric measurements revealed the existence of guiding structures in both materials. M-line spectroscopic measurements indicated guiding effect in the as-implanted BGO up to 1550 nm and up to 980 nm in the as-implanted CaF_2. Ion implantation induced the appearance of three peaks in the UV/Vis absorption spectrum of CaF_2, that can be attributed to colour centres.

1. Introduction

Ion implantation, compared with other waveguide fabrication methods, has some unique advantages. It proved to be a universal technique for producing waveguides in most optical materials [1]. It has better controllability and reproducibility than other techniques. The first articles reporting fabrication of waveguides by ion implantation appeared between the end of 1960s and early 1980s [2–5]. The first ion implanted waveguides were produced in 1968 by proton implantation into fused silica glass [2], and the index changes for H^+, He^+ and N^+ ions have been characterised by several other groups [3–5]. A detailed review on ion-implanted optical waveguides has been published recently [6]. We have recently reported fabrication of channel waveguides in an Er-doped tungsten tellurite glass [7].

Calcium fluoride is an excellent optical material, due to its good optical characteristics from UV wavelengths up to near IR. Recently it has become a promising host material, doped with rare earth elements [8–10]. Successful waveguide fabrication in alkali fluoride and alkali earth halide crystals using only light ions (H^+ and He^+) has been reported so far [11,12]. Based on our successful previous experiments with N^+-implanted waveguides in both amorphous and crystalline materials, we decided to try to fabricate optical waveguides in CaF_2 single crystal samples via implantation of MeV energy N^+ ions.

Bismuth germanate is a well known scintillator material. It has high electro-optic coefficients (3.3 pm/V for $Bi_{12}GeO_{20}$), making it useful in nonlinear optics for building Pockels cells, and can also be used for photorefractive devices. Formation of planar waveguides in $Bi_4Ge_3O_{12}$ (eulytine) crystals by implantation of He^+ ions of the 1–2 MeV energy range was first reported by Mahdavi et al. [13]. Here we present our preliminary results in fabricating slab waveguides in eulytine type bismuth germanate crystals using a medium-sized ion, N^+, instead of the light ions used in the above mentioned works.

2. Waveguide fabrication and SRIM simulations

We fabricated two types of slab waveguides using the following ion–target combinations: 3.5 MeV N^+ ions implanted into CaF_2 single crystal and 3.5 MeV N^+ ions implanted into $Bi_4Ge_3O_{12}$ (eulytine) single crystals.

Irradiations were carried out with a 3.5 MeV N^+ collimated beam from a Van de Graaff accelerator (available at the Research Institute for Particle and Nuclear Physics, Budapest), at 7° incidence angle on the crystal samples, to avoid channelling. Lateral homogeneity of the irradiation was ensured by defocusing the

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Table 1
Implanted fluences of the slab waveguides in CaF_2 and BGO crystals.

Name of the target	Implanted fluences ($\times 10^{15}$ ions/cm^2)			
	A	B	C	D
CaF_2	5	10	20	40
$Bi_4Ge_3O_{12}$	2	4	8	16

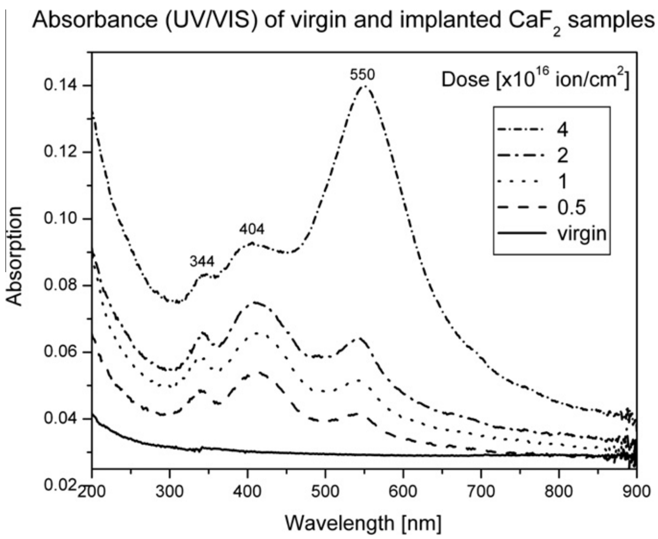

Fig. 1. Absorbance of virgin and N^+-implanted CaF_2 samples.

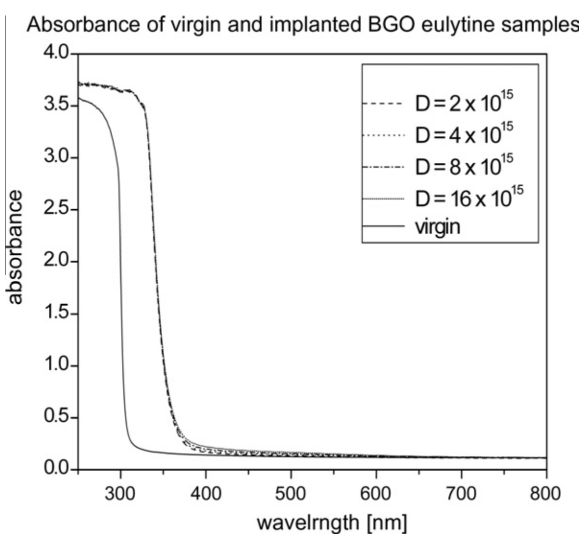

Fig. 2. Absorbance of virgin and N^+-implanted $Bi_4Ge_3O_{12}$ samples.

ion beam with a magnetic quadrupole and by scanning the sample under a 2×2 mm beam. Useful size of the implanted waveguides was 6×6 mm.

Names and implanted fluences of the slab waveguides implanted in CaF_2 and $Bi_4Ge_3O_{12}$, all by 3.5 MeV N^+ ions, are shown in Table 1. Structure of the ion implanted slab waveguides is determined mainly by the energy and fluence of the implanted ions. Distribution of the implanted ions or that of the collision events along the depth of the implanted sample can serve as rough estimation of the refractive index profile of the implanted waveguide. We used SRIM 2008 [14] code (Stopping and Range of Ions in Matter) to simulate the fabrication of the ion-implanted slab waveguides. We performed SRIM calculations for each experiment.

Table 2
Results of spectroscopic ellipsometric measurements of eulytine type BGO waveguides.

Names of the waveguides	A	B	C	D
Fluences ($\times 10^{16}$ ions/cm^2)	0.2	0.4	0.8	1.6
Thickness of layer$_2$ [nm]	2552.70 ± 0.9	2575.80 ± 1.1	2632.96 ± 0.9	2628.09 ± 0.8
Refractive index of layer$_2$ at 635 nm	2.115	2.121	2.202	2.350
Thickness of layer$_1$ [nm]	337.90 ± 10.59	287.91 ± 2.90	346.38 ± 4.243	412.89 ± 4.59
Refractive index of layer$_1$ at 635 nm	2.116	2.131	2.110	2.125
Refractive index of the non-implanted glass at 635 nm	2.086	2.086	2.086	2.086

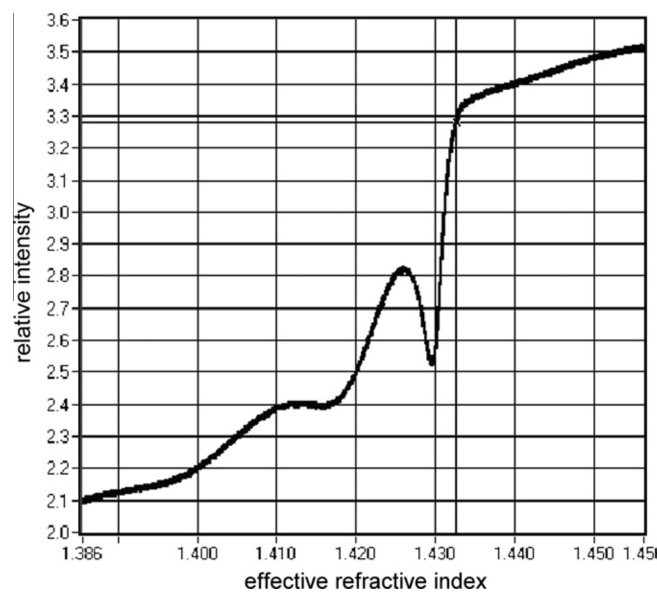

Fig. 3. M-line spectrum of a CaF_2 waveguide at 635 nm. Fluence = 2×10^{16} ions/cm^2.

In case of the CaF_2 sample and 3.5 MeV energy of the implanted N^+ ions maxima of the range and the vacancy distributions are around 3.0 μm. In case of eulytine bismuth germanate crystals the maximum of the range distribution is at approximately 2.5 μm. One can expect waveguide operation even at infrared wavelength in case of the 3.5 MeV energy N^+ implantation since in both materials it produces a guiding layer of over 2.0 μm width.

3. Optical absorption measurements

UV/Vis spectra of all the nonimplanted samples and the implanted waveguides have been measured using a JASCO Corp. V-550 spectrophotometer to check the effects of ion implantation on absorption of the samples in the 190–900 nm wavelength range. Implantation of the CaF_2 crystal with high fluences of N^+ ions resulted in the appearance of new absorption bands in the visible–UV spectrum, due to the colour centres created by the irradiation. There are three new absorption bands in the UV/VIS