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Optical ridge waveguides in Nd:LGS crystal produced by combination of swift C^{5+} ion irradiation and precise diamond blade dicing

Yazhou Cheng [a], Jinman Lv [a], Shavkat Akhmadaliev [b], Shengqiang Zhou [b], Feng Chen [a,*]

[a] School of Physics, State Key Laboratory of Crystal Materials and Key Laboratory of Particle Physics and Particle Irradiation (MOE), Shandong University, Jinan 250100, China
[b] Helmholtz-Zentrum Dresden-Rossendorf, Institute of Ion Beam Physics and Materials Research, Dresden 01314, Germany

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ABSTRACT

We report on the fabrication of optical ridge waveguides in Nd:LGS crystal by using combination of swift C^{5+} ion irradiation and precise diamond blade dicing. The ridge structures support guidance both at 632.8 nm and 1064 nm wavelength along the TE and TM polarizations. The lowest propagation losses of the ridge waveguide for the TM mode are ~1.6 dB/cm at 632.8 nm and ~1.2 dB/cm at 1064 nm, respectively. The investigation of micro-fluorescence spectra and micro-Raman spectra indicates that the Nd^{3+} luminescence features have been well preserved and the microstructure of the waveguide region has no significant change after C^{5+} ion irradiation.

1. Introduction

As one of the most intriguing piezoelectric materials, lanthanum gallium silicate ($La_3Ga_5SiO_{14}$, or LGS) crystal has attracted considerable attention owing to its promising applications in surface acoustic wave (SAW) and bulk acoustic wave (BAW) technologies [1,2]. The LGS single crystal is usually grown via the conventional Czochralski technique [3] and belongs to the point group 32 and space group p321 [4]. It possesses the outstanding properties of relatively high electromechanical coupling coefficient [5,6], and therefore allows the development of new-generation miniature communication devices [7,8]. As the LGS crystal does not undergo any phase transitions and retains its piezoelectric properties until the melting temperature of 1470 °C [9], it is particularly applied in high-temperature microbalances and gas sensors. In addition, when doped with Nd^{3+} ions, the Nd:LGS crystal can be used as an excellent gain medium for both continuous-wave (CW) and Q-switched laser generation systems [10]. With the broad emission bands and large birefringence, Nd:LGS crystal is also applicable for self-tunable laser gain operation using laser diode pumping [11].

Optical waveguides are basic components in integrated photonics, which can confine the light propagation in very small volumes with dimensions of several microns, achieving relatively higher optical intensities with respect to the bulk. Several techniques, such as metal-ion indiffusion [12], ion exchange [13], epitaxial layer deposition [14], ion implantation/irradiation [15,16], and femtosecond (fs) laser micromachining [17–20] have been used to fabricate optical waveguides in various materials. The swift heavy ion irradiation (usually with energy higher than 1 MeV) is an efficient technique to modify the refractive index of the materials for optical waveguide construction. Compared with normal ion implantation (with energy of 400 keV to a few MeV), swift heavy ion irradiation has advantages of ultralow ion fluences and reduced irradiation time for effective refractive index changes. In addition, during swift heavy ion irradiation process, the electronic damage created by the incident ions is dominant over the nuclear damage during most of the ion trajectory [21], which is different from the normal light ion implantation mechanism (nuclear damage dominant). Different from one-dimensional (1D) waveguides (planar or slab waveguides), two-dimensional (2D) waveguides (typically with channel or ridge geometries) can confine light propagation in two transverse dimensions and achieve much higher optical density. In practice, 2D waveguides has attracted much attention due to the superior guiding performance and therefore be applied to the construction of more complex integrated photonic devices. In recent years, diamond blade dicing technique is becoming an increasingly fascinating technique to construct high-quality ridge waveguides owing to the advantages of precise cutting and surface polishing. As of yet, by utilizing technique of diamond blade dicing, ridge waveguides

* Corresponding author.
E-mail address: drfchen@sdu.edu.cn (F. Chen).

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have been successfully fabricated in $LiNbO_3$ [22], PPMgSLN [23], Nd:CNGG [24] and Nd:YAG [25] crystals.

In this work, we have fabricated ridge waveguides in Nd:LGS crystal by using combination of swift C^{5+} ion irradiation and precise diamond blade dicing. The guiding properties, micro-fluorescence spectra and micro-Raman spectra of the Nd:LGS waveguides have been investigated in detail.

2. Experiments in details

The *x*-cut Nd:LGS crystal (doped with 1 at% Nd^{3+} ions) used in this work was cut with dimensions of $10\,(x)\times 10\,(y)\times 2\,(z)\ mm^3$ and was polished to high optical quality. Fig. 1 depicts the schematic fabrication process of the Nd:LGS ridge waveguides. In the first step, one of the sample surface ($10\,(x)\times 10\,(y)\ mm^2$) was irradiated with C^{5+} ions at energy of 17 MeV and fluence of 2×10^{14} ions/cm^2 by utilizing the 3 MV tandem accelerator at Helmholtz Zentrum Dresden-Rossendorf, Germany. The incident ions beam was tilted by 7° off the normal direction of the sample surface to minimize the channeling effect and the ion current density was kept at a low level (around $6-8$ nA/cm^2) to avoid the heating and charging of the sample. In this way, a planar waveguide layer with a thickness of 10 μm was formed beneath the crystal surface. In the second step, we utilized a rotating diamond blade (with the rotating velocity of 10,000 rpm), which moved along the *x*-axis of the sample (with the moving speed of 0.1 mm/s), to construct parallel air grooves on the planar waveguide layer [26]. The width of the ridge structure was

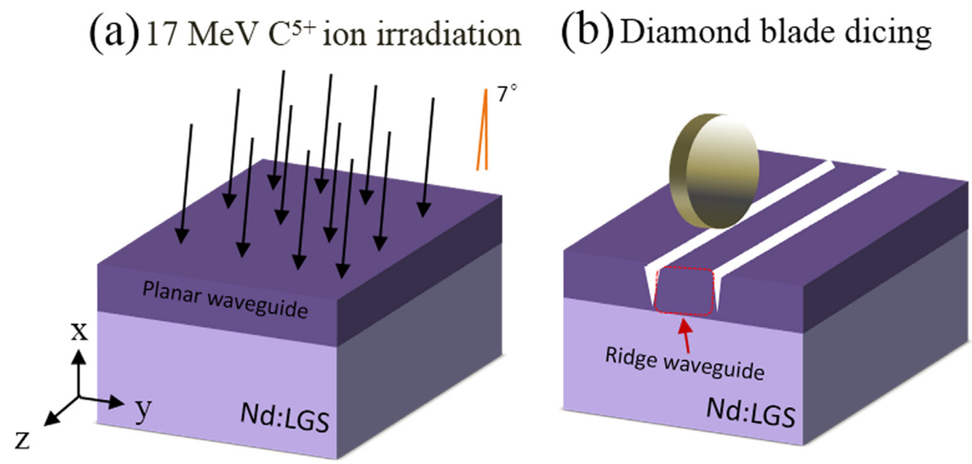

Fig. 1. Schematic fabrication process of the Nd:LGS ridge waveguides: (a) 17 MeV C^{5+} ion irradiation and (b) diamond blade dicing.

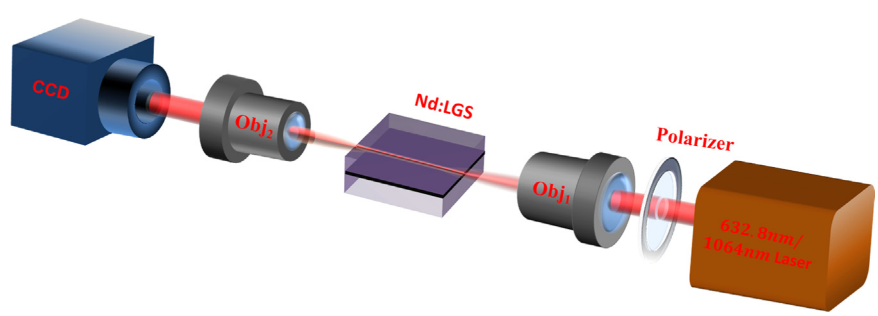

Fig. 2. Schematic plot of the end-face coupling arrangement utilized to investigate the guiding properties of the Nd:LGS waveguides.

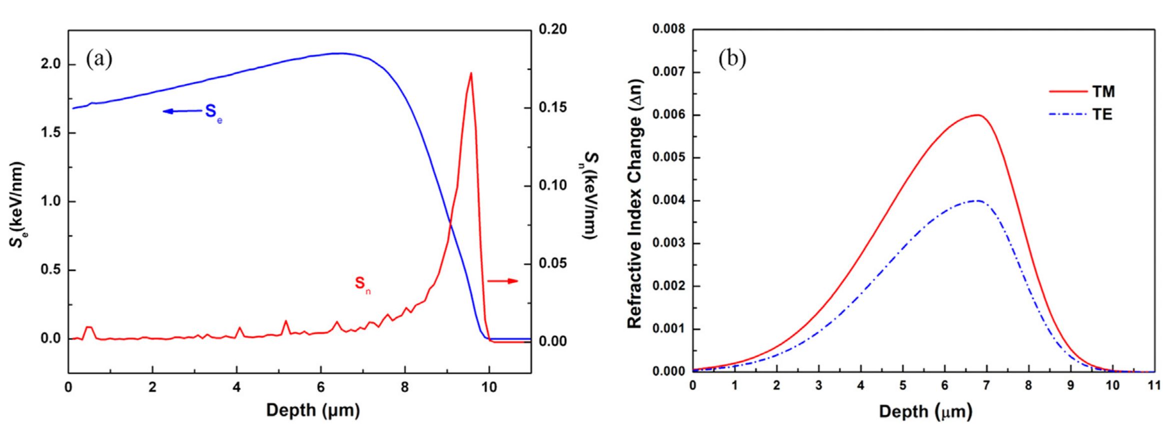

Fig. 3. (a) Electronic (blue line, S_e) and nuclear (red line, S_n) stopping powers as function of penetrate depth from the surface of the 17 MeV C^{5+} ion irradiated Nd:LGS crystal and (b) reconstructed refractive index changes (Δn) of the 17 MeV C^{5+} ion irradiated planar waveguide at 1064 nm for both TE (blue line) and TM (red line) polarization. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)