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Double waveguide in $NdLiP_4O_{12}$ laser crystal formed by MeV He^+ ion implantation

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Abstract

$NdLiP_4O_{12}$ crystals can be used for low-threshold, miniature laser. A double waveguide structure in a $NdLiP_4O_{12}$ laser crystal formed by ion implantation is for the first time reported. Double waveguide in $NdLiP_4O_{12}$ laser crystal is formed with 2.8 and 1.8 MeV He ions to the same dose of 1.5×10^{16} He ions/cm^2. The refractive index distribution of the double waveguide in the $NdLiP_4O_{12}$ laser crystal is given based on the reflectivity calculation method.

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Keywords: Ion implantation; MeV He ion; Double waveguide

1. Introduction

Optoelectronics is established as a major growth industry. The key features are the use of optical waveguides and new electro-optic materials [1]. In the recent years a considerable interest concerning the possibility to realize optical devices has grown, with the aim to integrate active and passive components on the same substrate. MeV light ions such as He^+ ions were extensively used to form the waveguides in a variety of optoelectronic materials [2–4]. Waveguide lasers are attractive because the pump threshold can be remarkably reduced in a waveguide relative to the bulk material. There are two approaches to form waveguide laser. The first is to add active lasing ions by implantation or other methods such as pulsed laser deposition, and the second is to define a waveguide in a lasing

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host material. The first waveguide laser in Nd:YAG produced by ion implantation has been reported by Chandler et al. [5]. The $NdLiP_4O_{12}$ crystal is a direct compound laser crystal. A single waveguide in the $NdLiP_4O_{12}$ laser crystal was formed with 2.8 MeV He ions to the dose of 1.5×10^{16} ions/cm^2. The composition of the $NdLiP_4O_{12}$ laser crystal was analyzed by Rutherford backscattering of 2.1 MeV He ions and the lasing characterization was measured by photoluminescence (PL) spectrometry [6]. In the case of $NdLiP_4O_{12}$, the concentration of Nd^{3+} ions is $4.37 \times 10^{21}\,cm^{-3}$ which is 30 times higher than in Nd:YAG [7].

The greatest advantage of the ion implantation is to produce two or more superposed waveguides at different depths beneath the crystal surface. Double waveguides are useful for both the non-interacting case such as interconnects between different surface regions and interacting devices such as tuned filters. They can be implemented in optical interlayer connectors for multilayer integrated optical systems. However, a few papers have been published about the double waveguide fabrication by ion irradiation [8,9]. Chandler et al. for the first time reported on double waveguides in the nonlinear optical crystal $LiNbO_3$ and quartz by ion implantation.

A waveguide is characterised by a region of high refractive index bounded by regions of lower index. Ion beams produce damage and ionization. In optoelectronic crystals the damage can induce major changes of the refractive index which may vary in degree and even in sign depending on ion energy, dose, species, temperature and material structure. There are minor ionization effects in actual guiding region. The nuclear damage causes lattice disordering mainly at the end of the ion track, reducing the refractive index and forming an optical barrier. The guiding region itself is usually subject to electronic damage and a small amount of energy deposited into nuclear processes which causes defects in this region as well. These defects affect light scattering and attenuation, but can usually be annealed by thermal treatment.

In the present paper, we report on double waveguide fabrication and the refractive index distribution in the $NdLiP_4O_{12}$ laser crystal formed by MeV He ion implantation.

2. Experimental

X-cut $NdLiP_4O_{12}$ samples were provided from the College of Chemistry, Shandong University. Before ion implantation, the samples were optically polished and the refractive index was measured. The MeV He ion implantation was performed at the 1.7 MV tandem accelerator of Peking University. The deep optical barrier was formed with 2.8 MeV He ions and the shallow optical barrier with 1.8 MeV He ions to the same dose of 1.5×10^{16} ions/cm^2 at room temperature, respectively. The sample was first implanted with the high-energy, then followed by low-energy. The beam current was less than 300 nA/cm^2. The ion beam was electrically scanned to insure a uniform implantation over the $NdLiP_4O_{12}$ sample. A conductive paint was applied between the sample and the fixture to improve the conductivity of the sample during the implantation. In order to avoid the channeling effect, the sample was tilted by 7° off the beam direction. The prism coupling method was used to measure the dark modes in the waveguide film [10]. In the present work, we have used the model 2010 prism coupler made in Metricon Corporation, USA. A laser beam with a wavelength of 632.8 nm strikes the base of a high refractive index prism and is reflected onto a photodetector. The sample is brought into contact with the prism base by means of a pneumatically operated coupling head. The angle of incidence of the laser beam was varied by means of a rotary table.

3. Results and discussion

Fig. 1(a) shows the relative light intensity as a function of the effective refractive index n_m obtained for the double waveguide in the $NdLiP_4O_{12}$ laser crystal. The reflection spikes correspond to the waveguide modes. For comparison, the spacing and the intensity of the modes of single barrier waveguides are given in Fig. 1(b). For the single