FABRICATION AND CHARACTERIZATION OF Er-DIFFUSED Ti:$LiNbO_3$ WAVEGUIDE LASER

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Introduction

Recently, interests in rare-earth doped $LiNbO_3$ waveguide devices are increasing. In such devices the laser action of rare earth elements can be combined with waveguide components, such as a waveguide cavity, an interferometer, and an electrooptic modulator, to implement novel functions. We have demonstrated an efficient CW waveguide laser [1], a Q-switched waveguide laser [2], and a self-frequency doubling waveguide laser [3] in Nd-thermally-diffused $LiNbO_3$. On the other hand, Er doped $LiNbO_3$ waveguide lasers are attractive, because they exhibit laser emission in a wavelength band for optical communication, *i.e.*, ~1.5 μm [4-6]. However, the fabrication techniques of the Er:$LiNbO_3$ waveguide lasers have not been fully-established yet. In this work we studied fabrication of Er-thermally-diffused waveguide lasers. A fabricated device was optically-pumped at wavelength of 1.48 μm, and a CW laser oscillation was achieved at 1.53 μm with a threshold power of 10 mW.

Device Description

An Er-diffused Ti:$LiNbO_3$ waveguide laser is illustrated in Fig.1. A Fabry-Perót laser cavity for a wavelength of 1.53 μm is fabricated on an Er-diffused $LiNbO_3$ crystal. The cavity consists of a Ti-diffused channel waveguide, a dichroic mirror with 97 % reflectivity at wavelength of 1.53 μm and 4 % at 1.48 μm on a waveguide facet, and a Au mirror on the other facet. A pump beam of 1.48 μm is coupled in the cavity through the dichroic mirror. The Au mirror allows double-pass pumping to increase absorption of the pump power. Laser oscillation takes place at 1.53 μm and the output laser beam is obtained from the pump facet.

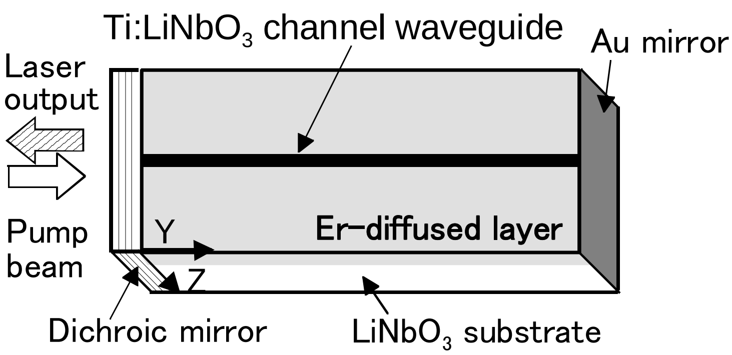

Fig.1 Er-diffused Ti:$LiNbO_3$ waveguide laser.

Device Fabrication

Er thermal diffusion into $LiNbO_3$ is a key process to fabricate the waveguide laser. An Er film of 13 nm thickness was evaporated on a –Z surface of a $LiNbO_3$ crystal and thermally diffused. The Er-diffusion was carried out under the same conditions as Nd diffusion [1]. However, the diffused surface tended to be rough and the Er concentration was sparse, and therefore the laser oscillation was not obtained in a resultant device. We carried out the diffusion under various conditions and found that the diffusion at 1090 °C for 100 h in dry O_2 atmosphere provides a Er-diffused crystal with a smooth diffused surface and an appropriate Er concentration. The microscope photograph of the Er-diffused surface is shown in Fig. 2. The thickness of the Er-diffused layer and surface Er concentration are estimated to be 5.1 μm and 0.18 at.%, respectively [7].

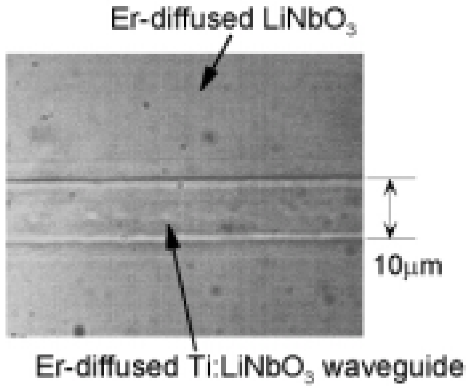

Fig.2 Surface morphology of Er-diffused (Ti:)$LiNbO_3$.

A prototype device was fabricated as shown in Fig. 3. Er-diffusion was carried out as described in the previous paragraph at first, and a channel waveguide was fabricated by thermal diffusion of a Ti stripe of 10 μm width and 92 nm thickness in dry O_2 atmosphere at 1050 °C for 10 h. The microscope photograph of the waveguide is shown in Fig. 2. The waveguide facets were polished, and a dichroic mirror was attached using a UV adhesive on one of the facets. A Au film of ~0.1-μm thickness was deposited by evaporation on the other facet. The resultant cavity length was 29 mm.

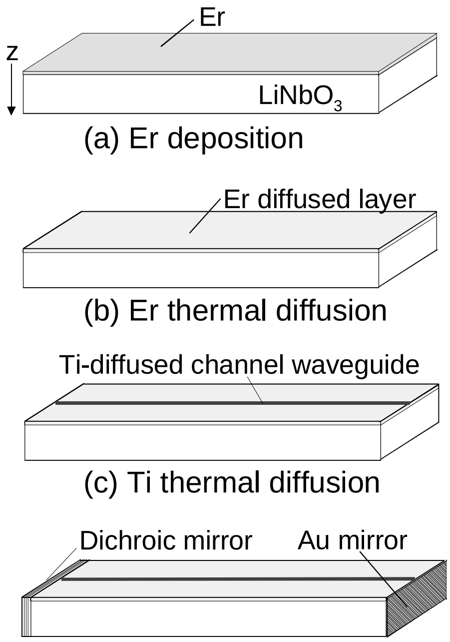

Fig.3 Fabrication process of Er-diffused Ti:$LiNbO_3$ waveguide laser.

Experimental Results

Single-pass gain in the waveguide at 1.53-μm wavelength was measured before attaching the cavity mirrors. A TE-polarized pump wave of 1.48-μm wavelength and a TM-polarized signal wave of 1.53-μm were combined by a dichroic beam splitter and coupled in the waveguide by end-fire coupling using a x20 objective. The input pump and signal powers were measured in front of the pump facet. The output signal wave was detected by an optical spectrum analyzer. The gross gain was measured by comparing the detected powers with and without pumping. The net gain was estimated by taking account of the scattering loss (-0.35dB) in the waveguide and ground state absorption(GSA) (-4.3dB). The scattering loss in the waveguide was assumed to be equal to the propagation loss of a reference waveguide on a non-doped crystal, i.e., -0.12 dB/cm. The GSA was estimated from the difference between the output power from the Er-doped waveguide without pumping and that from the non-doped reference waveguide. Fig. 4 shows the net gain dependent on the input pump power for input signal power of 0.7 mW. Laser oscillation was expected in the pump region where the net gain was higher than the loss at the cavity mirrors.

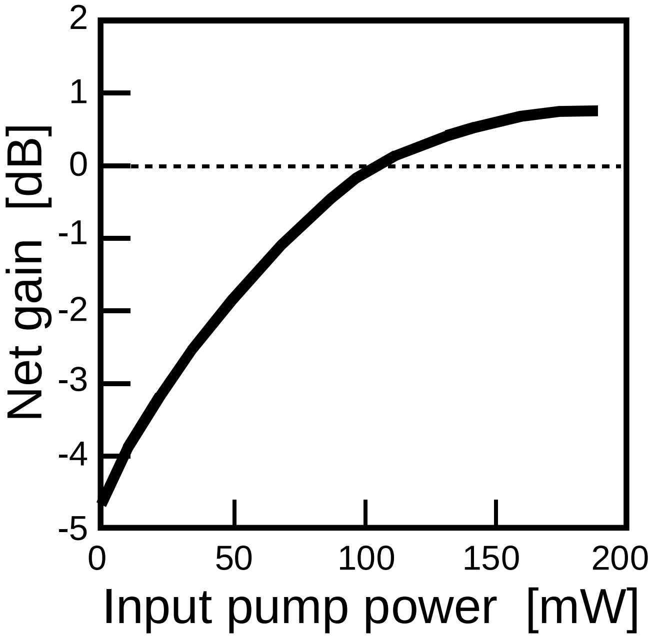

Fig.4 Net gain dependent on the input pump power.

Lasing experiments were performed in a optical system shown in Fig. 5. A TE-polarized pump wave was coupled in the cavity by end-fire coupling. An output beam of 1.53-μm wavelength from the pump facet was extracted by a dichroic mirror, and detected by the optical spectrum analyzer. A CW laser oscillation was achieved as shown in Fig. 6. The threshold input power was 147 mW, which agreed fairly well with theoretical simulation based on rate equation analysis [8]. The absorbed pump power was estimated by taking account of the input coupling efficiency to the cavity, 47 %, and the round-trip absorption, 15 %, which were measured in preliminary experiments. The corresponding threshold absorbed power was 10 mW. The maximum output laser power obtained so far was 100 μW. The slope efficiency was 2.4 %. The laser light was TM polarized. The spectrum of the laser emission is shown in Fig. 7. The peak wavelength was 1.5307 μm, and the FWHM bandwidth was 0.23 nm. The laser oscillation should consist of 12 longitudinal modes, although they were not observed due to insufficient resolution of the spectrum analyzer.

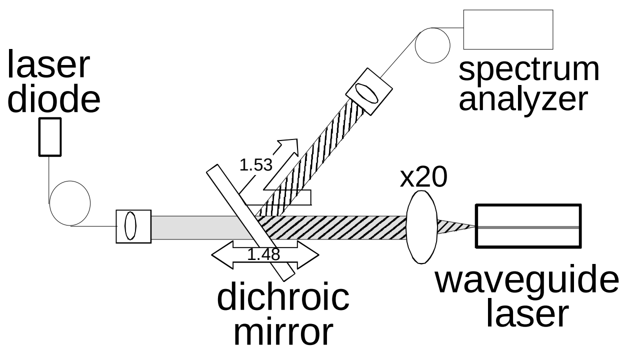

Fig.5 Optical system for lasing experiments.

Conclusions

We fabricated Er-diffused Ti:$LiNbO_3$ waveguide laser, and achieved a CW laser oscillation at

1.531 μm with threshold power of 10 mW. Further experimental work to improve laser performances includes optimization of Er-concentration profile, selective doping of Er, and so on.

Acknowledgements

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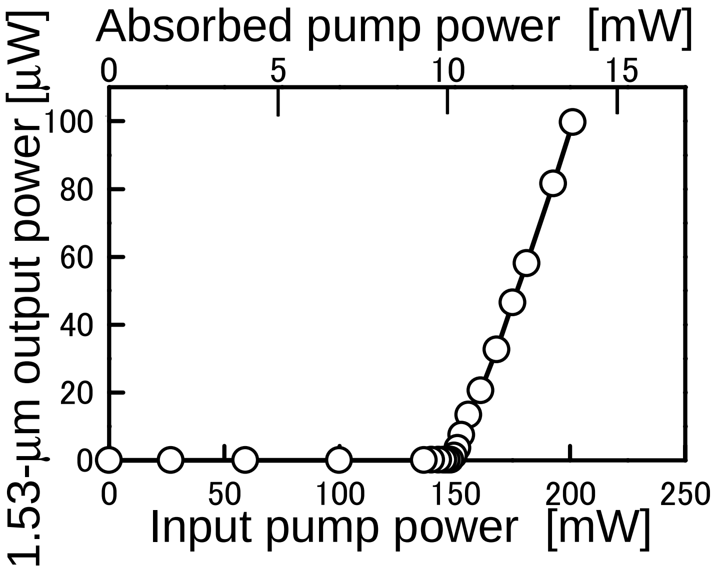

Fig.6 Lasing characteristics of the fabricated waveguide laser.

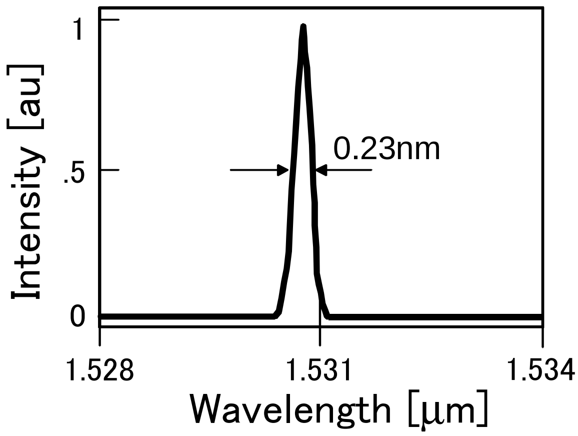

Fig.7 Laser emission spectrum.