FABRICATION OF $LiNbO_3$ TE/TM WAVEGUIDES FOR 1.5 μm WAVELENGTH BAND BY Zn/Ni DIFFUSION IN LOW-PRESSURE ATMOSPHERE

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Introduction

$LiNbO_3$ waveguide quasi-phase-matched (QPM) nonlinear-optic (NLO) wavelength conversion devices have been studied for applications in optical communication systems, optical signal processing, etc. Annealed-proton-exchanged waveguides are widely used for such devices[1,2] because of their high resistance to photorefractive damage. However, they support only extraordinary guided modes, and they may suffer limitations in implementation of polarization-independent devices. Ti-diffused waveguides, which can support both ordinary and extraordinary guided modes, are also used.[3,4] But they involve notable photorefractive damage problem. The formation of unwanted domain inverted thin layer during the high temperature process for Ti diffusion may cause problems in fabrication of domain inverted gratings for QPM.[4]

Zn diffusion in $LiNbO_3$ takes place at relatively low temperature, and it can provide Zn-diffused waveguides which can support both polarization modes and are considered to have high resistance to photorefractive damages.[5] They are suitable for applications to QPM-NLO devices.[6] We reported recently Zn-diffused $LiNbO_3$ waveguides for 1.5 μm wavelength band by diffusing from ZnO[7] and their application to QPM wavelength conversion devices[8]. There is also a report on the fabrication of the waveguides for 1.32 μm wavelength by diffusing metallic Zn.[9] However, fabrication techniques of Zn-diffused waveguides have not been fully established yet.

In this study, we fabricated Zn-diffused $LiNbO_3$ waveguides for 1.5 μm wavelength band by diffusing metallic Zn. Pressure control during diffusion was crucial to obtain smooth surface after diffusion. We fabricated the waveguides under various conditions and clarified the condition to provide TE/TM waveguides for 1.5 μm wavelength.

Fabrication

Diffusion of metallic Zn into congruent optical-grade $LiNbO_3$ was examined. Although we tried to deposit Zn directly on the +z surface of $LiNbO_3$ crystal by thermal evaporation, the surface of the deposited Zn film was granular. Insertion of a thin Ni buffer layer allowed deposition of the Zn film with uniform surface.[9] Ni film of 5 nm thickness was first deposited, and then Zn was deposited on it. The Zn/Ni film was diffused using an ordinary quartz-tube electric furnace. The thermal diffusion in air of atmospheric pressure resulted in rough surface, as shown in Fig. 1(a). It was probably caused by Zn-$LiNbO_3$ reaction in the air. We tried the thermal diffusion in air of low-pressure atmosphere.[7] The quartz tube was evacuated by a rotary pump. The pressure was monitored with a Pirani gauge and was controlled by a throttle valve. We found that the smooth surface, as shown in Fig. 1(b), was obtained by diffusion in a low-pressure atmosphere of about 1.0 Torr. The higher pressure than 1.0 Torr resulted in rougher surface, and the lower pressure caused Li_2O outdiffusion.

Zn/Ni stripes of 8 μm width were patterned by lift-off technique, and diffused under various conditions for channel waveguide fabrication. The total thickness of Zn/Ni film, the diffusion temperature, the diffusion time ranged 100-160 nm, 830-890°C, 30-120 min, respectively. The pressure was controlled to be 1.0 Torr. After the thermal diffusion, the end facets were polished for end-fire coupling. The waveguide length was approximately 10 mm. The typical surface morphology of the crystal after diffusion at 890°C for 30 min in 1.0 Torr is shown in Fig. 2.

Characterization

The waveguiding characteristics at 1.55 μm wavelength were examined. A beam from a fiber-pigtailed laser diode was coupled into a waveguide using a 20× lens. We evaluated each waveguide by the full width at half-maximum (FWHM) mode size and throughput. The results are summarized in Table I. In case of diffusion at 890°C, the waveguide #3 supported both polarization modes with relatively high throughput. In cases of diffusion at 830°C (#1) and 860°C (#2), TE mode showed quite low throughput. The waveguide #4 fabricated by diffusion for 120 min had larger mode size; they didn't have so good confinement as the waveguide #3 of 30 min diffusion. It was seen by comparing #3 and #5 that the Zn/Ni thickness should be about 160 nm. We found that the condition to fabricate Zn-diffused channel waveguides with good confinement and high throughput is diffusion of Zn/Ni stripe with 160 nm thickness at 890°C for 30 min in 1.0 Torr air.

Fig 3 shows the mode patterns in the waveguide fabricated by diffusion of under the best conditions. The FWHM mode sizes were 5.5 μm (depth) × 8.5 μm (width), and 6.0 μm × 9.5 μm for TM and TE modes, respectively. The propagation loss was measured as ~1 dB/cm for TM mode by the waveguide Fabry-Perót interference method using a temperature-tuned distributed feedback (DFB) laser.

Summary

We studied fabrication of Zn-diffused $LiNbO_3$ waveguides by diffusing metallic Zn, and we found that diffusion in low-pressure atmosphere is crucial to fabricate waveguides. The process is not complicated and has good reproducibility. We fabricated channel waveguides under various conditions and examined the waveguiding characteristics at 1.55 μm wavelength. We clarified the condition to obtain TE/TM waveguides for 1.5 μm wavelength with good quality.

We fabricated prototype QPM-SHG devices using these Zn-diffused waveguides, and encouraging results were obtained.

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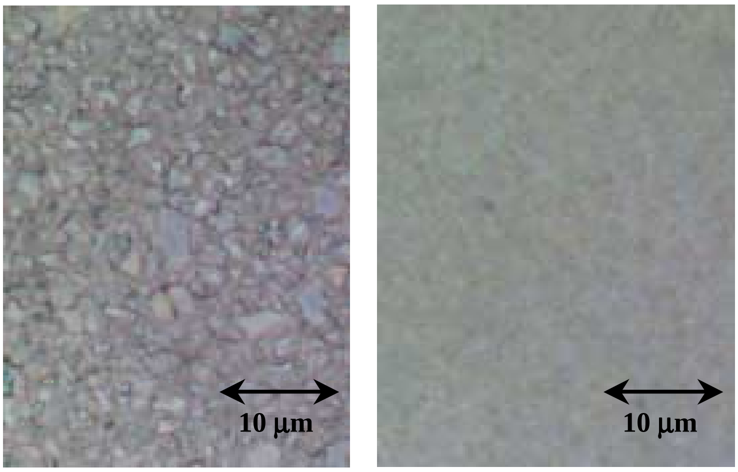


(a) (b)

Fig. 1. Optical microscope photographs of the surfaces after diffusion at 890°C for 30 min in (a) atmospheric pressure and (b) 1.0 Torr.

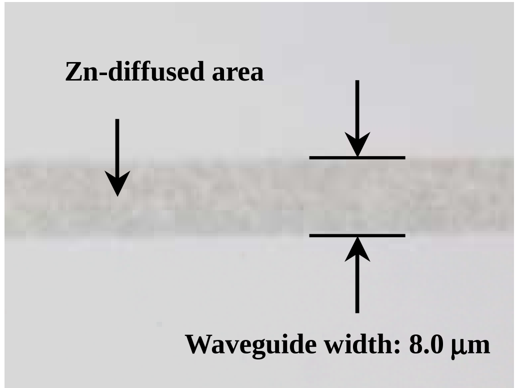
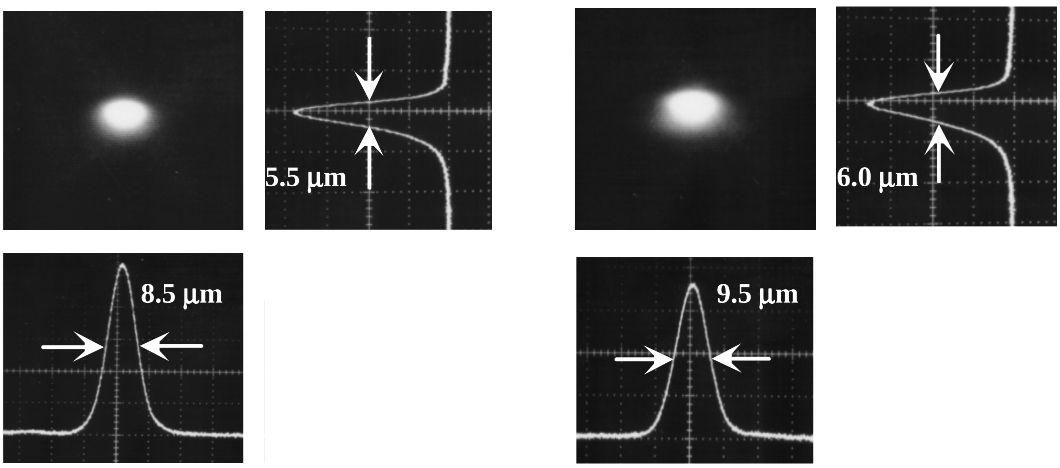


Fig. 2. The surface of Zn-diffused channel waveguide.

Table I. Result of the optical guiding test of the fabricated channel waveguides.

Waveguides	Diffusion Temperature, Time, Pressure	Zn/Ni stripe thickness	FWHM mode size Width / Depth	Throughput
#1	830°C, 30min, 1.0 Torr	160 nm	TM: 8.0 μm / 5.0 μm TE: 8.5 μm / 5.5 μm	TM: 21 % TE: 2 %
#2	860°C, 30min, 1.0 Torr	160 nm	TM: 7.5 μm / 5.5 μm TE: 8.5 μm / 5.5 μm	TM: 22 % TE: 4 %
#3	890°C, 30min, 1.0 Torr	160 nm	TM: 8.5 μm / 5.5 μm TE: 9.5 μm / 6.0 μm	TM: 17 % TE: 12 %
#4	890°C, 120min, 1.0 Torr	160 nm	TM: 14.6 μm / 9.7 μm TE: 13.7 μm / 9.3 μm	- -
#5	890°C, 30min, 1.0 Torr	100 nm	TM: 13.0 μm / 10.0 μm TE: 19.5 μm / 12.0 μm	TM: 17 % TE: 3 %



(a) **(b)**

Fig. 3. Near field patterns of guided modes at 1.55 μm wavelength for (a) TM mode and (b) TE mode.