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Ti:LiNb0$_3$ waveguide polarizer with a Zn-doped overlayer prepared by liquid-phase epitaxy

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Ti:LiNb0$_3$ waveguide polarizers werc obtained by an epitaxial growth of a Zn-doped LiNb0$_3$ Iayer on the Ti:LiNb0$_3$ waveguide. The film growth was carried out by a liquid-phase-epitaxy technlque using a Li_2O-V_2O_5 fiux. Such an X-cut waveguide polarlzer achieved a TE-mode (extraordinary ray) propagation wlth an extinction ratio over 30 dB at a light wavelength of 1.55 μm. This technique can be easily applied to Z- and Y-cut waveguide polarizers with TM- and TE-mode propagation, respectively.
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LiNb0$_3$ (LN) is a promising material for optoelectronic devices, and several methods have been attempted to fabricate optical waveguides on this material. For instance, a thermal diffusion of Ti metal is used to obtain a low propagation loss waveguide. In the Ti-indiffused area, both the ordinary and the extraordinary refractive indices increased slightly, providlng the optical waveguide for both TE- and TM-mode propagation. Therefore, for a device application using a specific electro-optic constant of the LN crystal, an optical polarizer must be installed in the waveguide.

Previously, several methods were proposed to realize the LN waveguide polarizer, such as a metal cladding surface layer,[1] a proton-exchange waveguide,[2] and an additional Ti-indiffusion on both sides~ of the waveguide.[3] However, the previous methods had the following problems. For waveguides with the metal cladding layer, it was difficult to achieve a sufficiently high extinction ratio without an excess loss in the propagating light. Further, the propagation mode was restricted by the orientation of the LN wafers. The proton-exchange waveguides vanish easily during the succeeding thermal process, such as deposition and annealing of the SiO_2 buffer layer at the temperature range from 500 to 650 ℃. Although the additional Ti-indiffusion on both sides of the waveguide provided an excellent structure to obtain a higher extinction ratio without an excess loss, the optimum design for the additional Ti-indiffusion might change largely depending™ on the optical properties of the waveguides.

Here, in order to achieve the waveguide polarizer without an excess propagation loss, a structure using an anisotropy of the LN crystal, as schematically shown in Fig.1 , was considered. This structure consisted of the Ti-indiffused waveguide and the dielectric film over the waveguide. As an example of the die]ectric film, Murakami, Masuda, and Koyama reported the sputtering-deposited Nb_2O_5 film, in which the refractive-index value was adjusted by changing O_2 pressure of the sputtering gas.[4] Such LN waveguide po-larizers leaked an extraordinary ray and propagated an ordinary ray, because the extraordinary refractive index of the waveguide was smaller than the refractive index of the Nb_2O_5 film. However, because the electro-optic coefficient of the LN crystal for the ordinary ray is only one third of that for the extraordinary ray, the waveguide polarizer with the Nb_2O_5 film was not suitable for the optoelectronic devices. For realization of the extraordinary ray-pass waveguide po-larizer, a large anisotropy in the refractive indexes Is neces-sary, i.e., $n_1<2.2$ and $n_2>2.29$ in Fig. 1, Recently, Terashima and Ito reported a decrease of the extraordinary refractive index (n_e) and an increase of the ordinary refrac-tive index (n_o) for LN by doping with Zn0.5 This Zn-doped LN was suitable as the dielectric layer for the extraordinary ray-pass waveguide polarizer, and we attempted here to form the epitaxially grown Zn-doped LN Iayer on the Ti:LN waveguide.

The fabrication process of the waveguide polarizer is illustrated in Fig. 2. The straight channel waveguides for l.5-μm-wavelength light were made by a conventional ther-mal diffusion of metallic Ti on the *X* face of the LN wafers along the *Y* directlon. The metallic Ti strip lines for the waveguides were formed on the LN wafer by a vacuum evaporation deposition and a photolithography process. The width of the Ti strip lines was changed from 4 to 7 μm while the thickness was kept at 90 nm. Then, these wafers were heat treated at 980 ℃ for 20

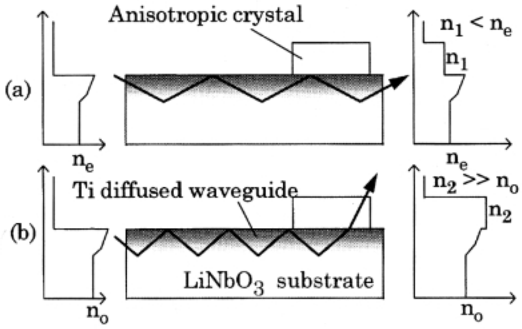

FIG. I . Schernatic diagram of the structure of the waveguide polarizer. The extraordinary ray is guidcd in the waveguide (a), and ordinary ray leaks out to the anisotropic crystal (b).

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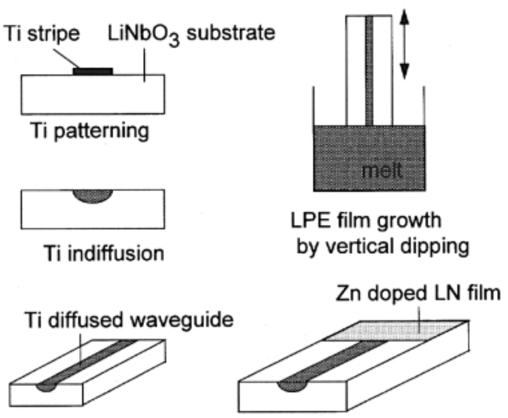

FIG. 2. Fabrication process of the polarizer.

h. The fabricated waveguide yielded a single-mode propagation for both TE and TM modes. At the next step, the Zn-doped LN film was formed over one end of the LN substrates, consisting of the Ti:LN waveguides, by a solid-liquid coexisting liquid-phase-epitaxy (LPE) technique using a Li_2O-V_2O_5 flux system.[6] The chemical composition of the flux was 50 mol % Li_2O, 40 mol % V_2O_5, and lO mol % Nb_2O_5. Into this flux, ZnO (12.5 mol %) was added. The mixture was kept at 850°C and melted, then the end part of the waveguide substrate was dipped into it for 60 min. The length of the dipped area was 10 mm. By such a simple method, the 20-μm-thick Zn-doped LN film grew epitaxially on the LN substrate. The refractive indexes of the Zn-doped LN film were measured with a prism coupler (Metricon PC-2000) at a wavelength of 0.633 ILm to be 2.2930 and 2.2195 for ordinary and extraor-dinary rays, respectively.

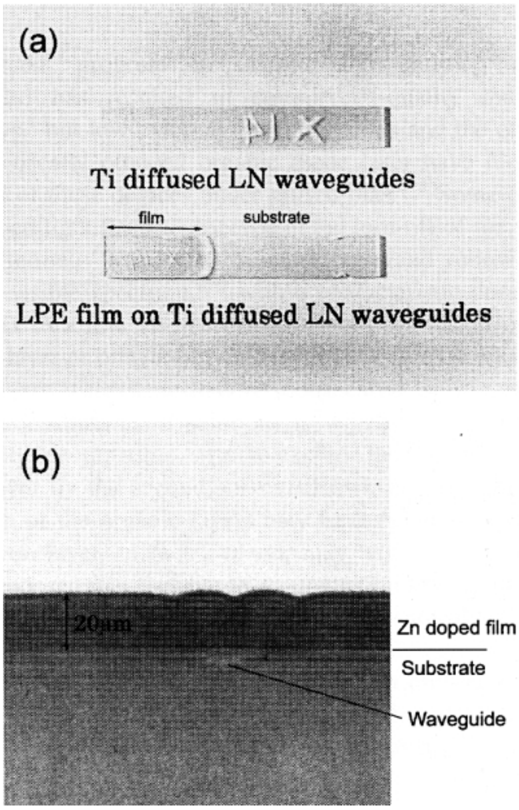

FIG. 3 . Ti-diffused waveguide and polarizer. The surface is rough just above the Ti-diffused waveguide. The size is 40 mm X 5 mm (a). Photograph of cross-sectional view of the polarizers. The thlckness of the Zn-dopcd film is larger on the Ti-diffused area (b).

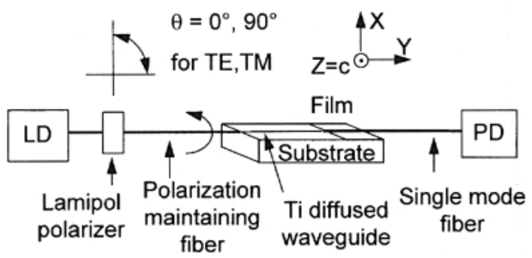

FIG. 4. Schematic diagram of thc sctup to measure the insertion loss and the extinction ratio of the polarizers.

Figure 3 shows the top view and the cross section of the optical waveguide with the Zn-doped LN overlayer. Both end faces of the waveguide were polished for coupling to optical fibers, and for observation of a near-field pattern of the optical output from the waveguides. The observed output intensity profile revealed that the state of extraordinary ray propagation (TE mode) was multimode for the 6- and 7-μm-wide waveguides, while it was single mode for 4- and 5-μm-wide waveguides. On the other hand, for the ordinary ray propagation (TM mode), the output intensity was very weak, suggesting a leak of this ray from the waveguide to the Zn-doped LN film.

At last, the optical insertion loss and the extinction ratio were measured using a polarization-maintaining fiber and a single-mode fiber which were coupled to the input and the output ends of the waveguide, respectively, as schematically illustrated in Fig. 4. The linearly polarized light (wavelength 1 .55 pam) was inserted into the waveguide through the polarization-maintaining fiber, and the direction of the polar-ization was inclined to 0 °(TE mode) and 90 °(TM mode) from the LN substrate surface. The optical output was intro-duced to an optical power meter through the single-mode fiber. The extinction ratio was calculated as a ratio of the output power for the TE mode to that for the TM mode. Figure 5 shows the dependency of the optical loss and the extinction ratio on the width of the waveguides. The high extinction ratio over 30 dB was obtained for the waveguides with 4 and 5 μm width. The total insertion loss for the TE mode, including the fiber coupling losses, was 2.1 dB for the -5-μm-wide waveguide. The insertion loss for the waveguide without the Zn-doped LN film was similarly measured to be 2.0 dB. The results indicate that the excess loss caused by the LPE film was less than 0.1 dB. In

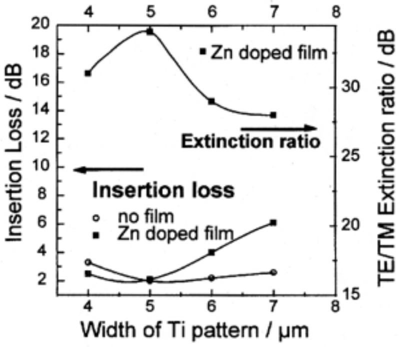

FIG. 5. Insertlon loss and extinction ratio of~ the polarizers fabricated by Zn-doped LPE film growth and by Zn-doped LPE film growth.

addition, the insertion loss and the extinction ratio for the 5-μm-wide waveguide were measured by a cutback method to be 2.0 and 32 dB, respec-tively. The propagation loss and the coupling loss for the TE mode were calculated to be 0.2 dB/cm and I .9 dB/2 faces, respectively.

In conclusion, the TE-mode pass waveguide polarizers were installed on X-cut Ti:LiNbO$_3$ waveguides by LPE growth of a Zn-doped LN overlayer. The extinction ratio exceeded 34 dB and the total insertion loss was only 2.1 dB for the I .5 Ihm wavelength light. Because wavelength depen-dencies of the refractive indexes of the constituent materials are small, this waveguide polarizer is expected to work sta-bly as a component of the optoelectric waveguide devices throughout a wide wavelength range for the fiber communi-cation systems. Further, this fabrication technique of the po-larizer, using the LPE, can be applied similarly to other LN wafer orientations.

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