

# LiNbO<sub>3</sub> optical waveguides fabricated by the ion exchange technique

イオン変換法による LiNbO<sub>3</sub> 光導波路の作成

Yoichi FUJII\* and Hideto HIDAKA\*

藤井陽一・日高秀人

## 1. Introduction

Recently the LiNbO<sub>3</sub> optical waveguide fabricated by the ion-exchange technique which is well known for glass waveguide fabrication has gained practical interest because it gives low-loss waveguide with large  $\Delta n$  and small optical damage,<sup>1)</sup> and requires low temperature and short time for fabrication. Ag<sup>+</sup> - and Tl<sup>+</sup>-exchanged waveguides by the wet process (in which the substrate is immersed in the melt salt) have been already reported.<sup>2),3)</sup> But the possibility of H<sup>+</sup>-exchange by the impurity in the melt<sup>4)</sup> may restrict the applicability of this method. And it seems that the choice of the exchange ions must be further explored. In regard to the exchange with Li<sup>+</sup>-ion, K<sup>+</sup> and Na<sup>+</sup>, for example, are candidates for the exchange ions. Here, K<sup>+</sup>-exchanged waveguide by this technique is reported for the first time (by the wet and dry processes). The H<sup>+</sup>-exchange was not found by the infrared OH<sup>-</sup>-absorption measurement.

## 2. Waveguide fabrication and characterization

Ag<sup>+</sup>- and K<sup>+</sup>-exchanged waveguides were fabricated by the ion exchange technique in which the sample was immersed into a melt salt such as AgNO<sub>3</sub> or KNO<sub>3</sub> ("wet" process, Fig.1) and also by depositing thin film on the substrate and heating ("dry" process, see Fig.2). Table 1 shows the conditions suitable for waveguide fabrication and the result (for the X-cut substrates). In the case of K<sup>+</sup>exchange,  $\Delta n$  is so large (=0.1) that this is liable to be ascribed to the fact<sup>4)</sup> that Li<sup>+</sup> will be exchanged by the H<sup>+</sup> impurity in the melt.

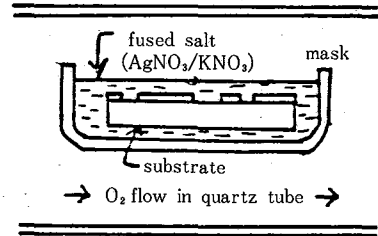


Fig. 1 Fabrication by the wet process

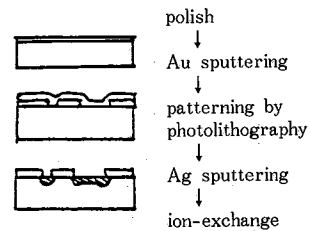


Fig. 2 Fabrication by the dry process

	temp, time	*mode	$\Delta n_e$	$\Delta n_o$	**loss
Ag <sup>+</sup>	350°C, 4hr	2	0.12	0	1 dB/cm
K <sup>+</sup>	350°C, 6hr	1	0.16	0	1 dB/cm
Ti	1000°C, 10hr	2	0.04	0.01	1 dB/cm

\*at 632.8nm, \*\*loss of planar guide

So, H<sup>+</sup> content was estimated by the measurement of the OH<sup>-</sup>-absorption spectrum by the Fourier transform spectroscopy for the substrate before and after the processing. Fig.3(a) shows the example of the entire absorption spectrum (2.5~25  $\mu\text{m}$ ) of the initial substrate. It shows that the substrates used in our experiment have considerably high H<sup>+</sup> content. The process conditions and the strength of the OH<sup>-</sup> absorption peak at 3480 cm<sup>-1</sup>,  $\eta$ , are listed in Fig.3 (b). In our measurement, all samples processed have

\* Dept. of Electrical Engineering and Electronics, Institute of Industrial Science, University of Tokyo.

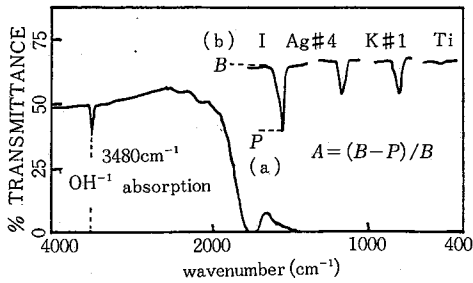


Fig. 3 a) An example of the infrared absorption spectrum and  
b) the absorption peaks corresponding to the fabrication process

lower absorption peak than the initial substrate. In particular, the Ti-indiffused sample(Ti) has much smaller or no peak. There is a certain correlation between the process temperature and the strength of the absorption peak. From these results, it is concluded that there occurs no  $H^+$ -exchange in our process environment. The high process temperature decreases  $H^+$  content and thus optical absorption. But higher temperature( $\sim 1000^\circ C$ ) was found to increase the surface roughness and thus the optical loss. Con-

sidering the optical loss,  $\Delta n$ , and the restrictions on the process conditions,  $K^+$  seems better than  $Ag^+$  as the exchanging ion. And the dry process is very promising in view of impurity and process control.

### 3. Conclusion

$Ag^+$ - and  $K^+$ -exchanged  $LiNbO_3$  waveguides were fabricated and characterized. The possibility of the  $H^+$ - exchange is denied by the result of the infrared absorption measurement and the optimum process conditions are given.

Authors acknowledge with thanks the helpful discussions with Prof. K. Iga of Tokyo Institute of Technology, Prof. J. Hamasaki and Prof.

Y. Arakawa of the Institute of Industrial Science.

(Manuscript received, July 2, 1984)

### References

- 1) J. L. Jackel et al, J. Appl. Phys. 52, 7, 4855 (1981)
- 2) M. L. Shah, Appl. Phys. Lett. 26, 11, 652 (1975)
- 3) J. L. Jackel, Appl. Phys. Lett. 37, 8, 739 (1980)
- 4) J. L. Jackel and C. E. Rice, Appl. Phys. Lett. 41, 6, 508 (1982)

