Loss Measurements of Stoichiometric Ti and O Implanted LiNbO₃ Waveguides

E. K. WILLIAMS[†], D. ILA[†], S. SARKISOV[‡] AND P. VENKATESWARLU[‡], D. B. POKER^{*}

[†]Center for Irradiation of Materials, P.O. Box 1447; [‡]Center for Nonlinear Optics, Alabama A&M University, Normal, AL 35762, U.S.A., ^{*}Solid State Division of Oak Ridge National Laboratory, P.O. Box 2008, MS 6048, Oak Ridge, TN 37831, U. S. A.

ABSTRACT

Planar waveguides created by the implantation at 500°C of 2.5×10^{17} Ti ions/cm² and 7.5×10^{17} O ions/cm² have been characterized for loss by the scattered light technique. Preliminary results indicate losses of less than 2.5 dB/cm.

INTRODUCTION

Lithium niobate is a commercially important electro-optical material, part of the advanced technology effort in optical communication and computing. Electro-optical devices are now used to substitute traditional electronic devices in communications and in information processing. Integrated optical LiNbO₃ devices include couplers, switches, modulators, multiplexers and others[1,2]. Three different techniques have been employed to create waveguides in lithium niobate: proton exchange, Ti diffusion and ion implantation[3,4,5]. Ion implantation allows tighter control over device geometry, dopant concentration and dopant profile than the diffusion and proton exchange methods[6].

EXPERIMENTAL

The optically polished x-cut crystals were purchased from Crystal Technology, Inc. The implantation was carried out using the Surface Modification and Characterization Facility at Oak Ridge National Laboratory.

Following the process established by Poker and Xia [7], stoichiometric Ti and O implants of 2.5 and 7.5×10^{17} /cm² were performed at 500°C. Titanium was implanted at 320 keV followed by an oxygen implantation at 120 keV. The ratio of Ti to O energy was computed using TRIM92 [8] to give equal ranges of 180 nm. The width of the waveguide is determined by the thickness of the implanted Ti layer and can be approximated by the straggling value given by TRIM as 65 nm. Implantation at a temperature slightly above the recrystallization temperature reduces amorphization of the crystal by the implanted ions[7]. The fluences were based upon previous Ti implantation research which found that a high Ti dose is necessary to replicate the low loss guides that are produced by Ti indiffusion[3]. The combination of high temperature and O implant stabilizes the position of the Ti implant and prevents the formation of an oxide layer on the surface[7]. Transmission electron microscopic analysis[9] indicates that the implanted Ti layer remains below the crystal surface, suggesting that the guiding region is completely buried.

The implanted crystals were dark after the Ti implantation but were a light grey after the oxygen implant. The crystals were annealed at 1000°C for 4 h in O₂ bubbled through de-ionized water. After annealing the crystals return to a clear state.

The waveguides were tested and characterized at 632.8 nm with a Metricon 2010 automated prism coupler equipped with a rutile prism. Analysis of the number, intensity and angular spacing of the modes yields information on the index and thickness of the guide. Due to the limitations of the prism coupler only TE modes could be investigated in LiNbO₃. After implantation the ends of the crystal were polished and end-fire coupling, using 40x microscope objectives, TE polarized 672 nm laser light and an Electrim 753 x 244 element CCD camera were used to estimate the losses in the guides. The public domain NIH Image program (available on the Internet by anonymous ftp from zippy.nimh.nih.gov) for Macintosh computers was used to analyze the digital images from the CCD camera.

Attenuation

Several techniques are available to measure attenuation of optical waveguides: sliding prism, cut-back and scattering are three of the most common. In this work we report loss measurements made using the scattering technique[10]. The edge of the 1 cm x 1.5 cm crystals were blacked out with a permanent marker to reduce scattering from the edges. As illustrated in Figure 1, screens were used to reduce stray light reflected from the input and output microscope objectives. A macro lens was used that resulted in each column of 11.5 µm wide pixels in the digital image corresponding to a distance of 42 µm along the length of the crystal. A 20x output microscope objective was used to project the output of the waveguide onto a distant screen so that proper alignment of the 40x input objective could be made. Focussing of the input onto the

Figure 1. Schematic of loss measurement set up. CCD camera records light scattered from the waveguide.

Figure 2. Negative image of light streak from Ti/O implanted LiNbO₃ waveguide.

crystal was judged by reflections onto a screen/aperture placed between the light source and the objective.

The digital image, the negative image of which is shown after a background subtraction in Figure 2, was analyzed by integrating one pixel wide cross sections of the scattered light streak. To keep the background constant a fixed number of pixels were used for each measurement. Figure 3 shows a plot of average intensity versus propagation distance after a background subtraction and removal of scattering from dust particles. The fit to the data indicates an attenuation of 2.5 dB/cm.

Figure 3. Mean intensity of scattered light vs. propagation distance.

Williams E.K.

3 7

CONCLUSION

Stoichiometric Ti and O implantation at 500°C produces waveguides that are stable over time, without segregation of Ti or Li to the surface and which exhibit reasonable losses. The attenuation measured in this work is well above the oft cited goal of 1 dB/cm for practical applications but should be considered as an encouraging first result that may well be reduced with further study.

ACKNOWLEDGMENTS

This research is supported by the Center for Irradiation of Materials at Alabama A&M University, by the Division of Materials Sciences, U.S. Department of Energy, under contract DE-AC05-96OR22464 with Lockheed Martin Energy Research Corp., and by DOE-SPSCoR-Alabama, and Alabama Space Grant Consortium.

REFERENCES

1. A. Selvarajan and J. E. Midwinter, *Optical and Quantum Electronics* **20** (1989) 1.
2. R. R. A. Syms, *Optical and Quantum Electronics*, **20** (1989) 189.
3. B.R. Appleton, G.M. Beardsley, G.C. Farlow, W.H. Christie and P.R. Ashley, *J. Mater. Res.* **1** (1986) 104.
4. L. McCaughan in: *Integrated Optics and Optoelectronics*, eds. K. Wong, M. Razeghi (SPIE, Washington, 1993) p. 15
5. Ch. Buchal, P. R. Ashley and B. R. Appleton, *J. Mater. Res.* **2** (1987) 222
6. G. L. Destafanis, J. P. Gailliard, E. L. Ligeon and S. Valette, *J. Appl. Phys.* **50** (1979) 898.
7. D. B. Poker and W. Xia, in: *Beam Solid Interactions :Physical Phenomena*, eds. J. A. Knapp, P. Borgensen and R. A. Zuhr (Mat. Res. Soc., Pittsburgh, 1990) p. 531
8. Ziegler, J. F., J. P. Biersack, U. Littmark *The Stopping and Range of Ions in Solids* (Pergamon, New York, 1985).
9. D. B. Poker, Solid State Division, Oak Ridge National Laboratory, personal communication.
10. Y. Okamura, S. Yoshinaka and S. Yamamoto, *Appl. Opt.*, **22** 3892 (1983).

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.