Extended Abstracts of the 2012 International Conference on Solid State Devices and Materials, Kyoto, 2012, pp270-271

PZT Optical Waveguide on Silicon Substrate

Takeo Maruyama[1], Shingo Ebuchi[1], Masaki Matsumoto[1] and Koichi Iiyama[1]

[1] Kanazawa Univ.
Kakuma-machi, Kanazawa, Ishikawa 920-1192, Japan
Phone: +81-76-234-4886 E-mail: maruyama@ec.t.kanazawa-u.ac.jp

1. Introduction

The operating speed of large-scale integration circuits (LSIs) has been increased by a miniaturization technology. However, the increasing of operating speed is achieving the limit due to a signal delay at global electrical interconnects in LSIs. The electric resistance and the capacitance of global electrical interconnects have been a bottleneck for the high-speed operation.

To solve these problems, an optical interconnection is proposed on silicon (Si) substrate [1]. The Si has unique optical properties owing to the transparency of Si for wavelengths typically used for optical communications (1.31–1.55 mm) and the large refractive index difference between Si (n = 3.45) and SiO_2 (n = 1.45). This property of Si allows the fabrication of very compact and high-density waveguide circuits. These waveguide structures can be fabricated on a wafer scale using standard complimentary metal–oxide–semiconductor (CMOS) processing techniques [2]. For these above reasons, the optical interconnection based Si is an effective idea to solve the electrical delay. Moreover, optical active devices, such as a laser, a photodetector and an optical modulator, are needed to realize the optical interconnection on LSI chip.

We focus on the optical modulator on Si substrate. The optical modulators based on the free carrier plasma dispersion effect, the electroabsorption effect and the electro-optic (EO) effect. The optical modulators using free carrier plasma dispersion effect on Si substrate were realized by pin diode [3], metal-oxide-semiconductor (MOS) capacitor [4] and photonic crystal structure [5]. The electro-absorption optical modulators of III-V materials on Si substrate have been fabricated by wafer bonding technique [6]. The modulators have been demonstrated with a modulation speed of 10 Gb/s.

The modulation speed of 40 Gb/s have been achieved by EO type modulator using $LiNbO_3$ (LN) on SiO_2. However, the LN optical modulators are large device size and the high operating voltage for low EO coefficient. Therefore, LN optical modulator is not suitable for optical modulator on LSI chip.

We propose $Pb(Zr,Ti)O_3$ (PZT) optical modulator on Si substrate because the EO coefficient of PZT is larger than that of LN [7]. The small and low operating voltage optical modulator can be expected using PZT films. We achieved the crack-free PZT film using sol-gel method on Si substrates with ITO buffer layer [8].

In this study, PZT optical waveguide were fabricated by photolithography and wet chemical etching, and their propagation loss was measured at 1550 nm.

2. Fabrication Process

The PZT film on Si substrate was deposited by sol-gel method. The surface of PZT films was cracked on Si substrate because of the difference of the thermal expansion coefficient. The crack-free PZT film was achieved by indium tin oxide (ITO) buffer layer on silica substrate [9]. The thermal expansion coefficient of ITO is close to that of PZT. The ITO buffer layer was also deposited by sol-gel method.

The molar ratio of Pb/Zr/Ti and In/Sn were 110/52/48, 107/3/52/48 and 95/5 respectively. SiO_2/Si (100) was used as a substrate. The SiO_2 layer was used as an under cladding layer of the optical waveguide. The PZT film was deposited by a spin coating on ITO buffer layer. The PZT film was dried at 200 ºC for 5 min and pre-annealed at 380 °C for 10 min to pyrolyze the residual organic compounds. This process had been repeated ten times and finally annealed at 600 °C for 10 min.

The crack-free PZT layer (1.5 μm-thick) was obtained on ITO buffer layer. The XRD pattern of PZT film on ITO/Si substrate was shown in Fig. 1. This spectrum shows the single perovskite phase of PZT film. The ferroelectric properties of PZT film were obtained. The remnant polarization and coercive field of PZT film were 50 μC/cm2 and 148 kV/cm, respectively.

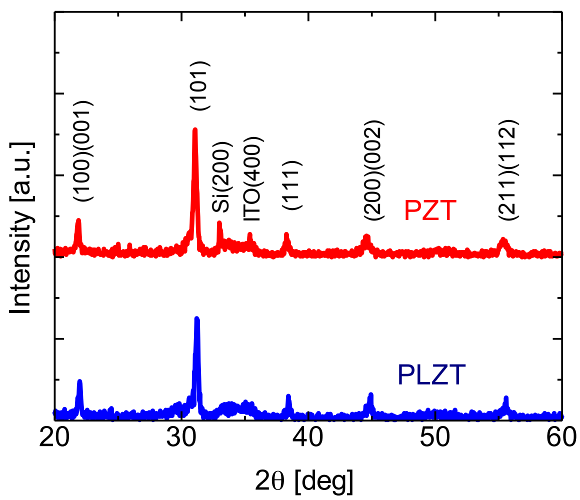

Fig. 1 ω-2θ XRD scan of PZT films on ITO/SiO_2/Si substrate.

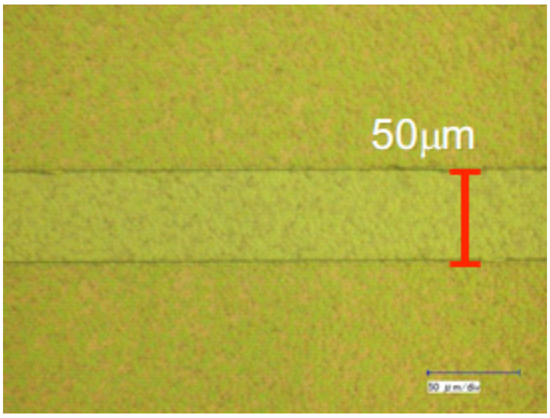

Fig. 2 Top view of PZT optical waveguide.

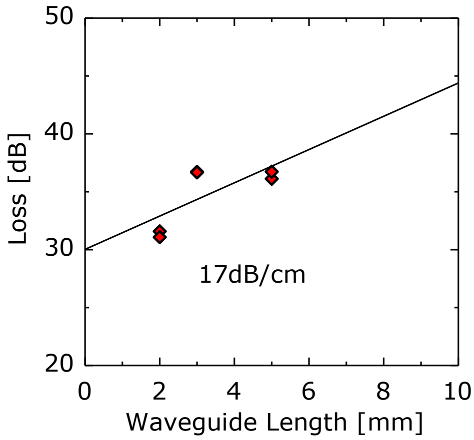

Fig. 3 Propagation loss of the PZT optical waveguides.

PZT optical waveguides were fabricated by photolithography and CF_4 reactive ion etching. The photoresist (SHIPLEY S1808) was coated by spin coating on PZT/ITO/SiO_2/Si after Al evaporation. The Al stripe pattern was formed by lift-off process. The Al pattern was used as a etching mask for CF_4 reactive ion etching. The PZT layer was etched by CF_4 plasma gas at 100 W for 120 min. The waveguide width was 50 μm. The facet of the waveguide was formed by cleaving method. The top optical microscope image of the waveguide is shown in Fig. 2.

3. Optical Loss Measurement

The propagation optical loss of fabricated PZT optical waveguides was measured by the cutback method at the wavelength of 1550 nm. Single-mode lensed optical fibers were used for input and output coupling. This setup has no polarization control. A scattered propagation light from the surface of the optical waveguide was observed to align the lensed fiber with the waveguides. The transmitted power through different lengths of the waveguides was measured. Figure 3 shows the measured optical power for various waveguide lengths. The propagation loss was obtained by linear regression of the output power versus the length of the waveguides. The propagation loss of 17 dB/cm and the coupling loss of 30 dB were measured.

4. Conclusions

We fabricated PZT/ITO/SiO_2/Si structure using sol-gel method. The crack-free PZT film was deposited on ITO buffer layer. The single perovskite phase of PZT film on ITO/SiO_2/Si substrate was achieved. We fabricated the a-Si optical waveguide using photolithography and wet chemical etching. The propagation loss measurement shows the waveguide loss of 17 dB/cm and the coupling loss of 30 dB at 1550 nm. These film can be expected to realize the high-speed optical modulator on silicon substrate.

Acknowledgements

The authors would like to thank Y. Tsukada, Prof. T. Kawae and Prof. A. Morimoto of Kanazawa University for help in ferroelectric testing. This research was partially supported by a Grant-in-Aid for Scientific Research (# 19002009) from the Ministry of Education, Culture, Sports, Science and Technology (MEXT).

References

[1] D. A. B. Miller, *Proceedings of the IEEE* **97** (2009) 1166.
[2] W. Bogaerts, R. Baets, P. Dumon, V. Wiaux, S. Beckx, D. Taillaert, B. Luyssaert, J. V. Campenhout, P. Bienstman and D. V. Thourhout, *J. Lightw. Technol.* **23** (2005) 401.
[3] W. M. J. Green, M. J. Rooks, L. Sekaric and Y. A. Vlasov, *Opt. Exp.* **15** (2007) 17106.
[4] A. Liu, R. Jones, L. Liao, D. S. Rubio, D. Rubin, O. Cohen, R. Nicolaescu and M. Paniccia, *Nature* **427** (2004) 615.
[5] H. C. Nguyen, Y. Sakai, M. Shinkawa, N. Ishikura and T. Baba, *Opt. Exp.* **19** (2011) 13000.
[6] Y. Tang, H. W. Chen, S. Jain, J. D. Peters, U. Westergren and J. E. Bowers, *Opt. Exp.* **19** (2011) 5811.
[7] M. Nakada, K. Ohashi and J. Akedo, *Jpn. J. Appl. Phys.* **44** (2005) L1088.
[8] S. Ebuchi, M. Matsumoto T. Maruyama and K. Iiyama, *MRS 2012 Spring Meeting*, San Francisco (2012) M5.4.
[9] T. Ohno, M. Fujimoto and H. Suzuki, *Key. Eng. Mat.* **33** (2006) 44.