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E-2-3

Imprint Property of Optical Mach-Zehnder Interferometer Using Sputter Deposited (Ba,Sr)TiO_3 at Low Temperature

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1. Introduction

Recently, optical interconnects on a LSI chip have attracted much attention as global interconnections which improve the performance of the LSI [1]. We have proposed a LSI on which the optical modulators using electro-optic (EO) material is integrated as photoelectric conversion devices for the optical interconnect system [2]. We have succeeded in operation of a Mach-Zehnder interferometer (MZI) type optical modulator made of (Ba,Sr)TiO_3 (BST) [3, 4]. The BST film was deposited on Si substrate by RF magnetron sputtering at low temperature (450°C) which is a critical temperature for LSI processes after metallization [5]. However, details of EO effect of the BST are not investigated enough.

In this study, an imprint property, which means the pretreatment before the MZI starts to operate, of the MZI optical modulator using BST by voltage stress is evaluated. As a result, we have found that the imprint effect is most effective at 75°C.

2. Experimental

The fabricated MZI is shown in Fig. 1, where Si_3N_4 and BST waveguides (20 μm wide and 0.27 μm thick) are serially connected to reduce the optical loss. Length of the BST waveguide which acts as a phase shifter for the MZI is 400 μm. The sputtering conditions are listed in Table I. Details of fabrication of the MZI is reported in Ref. 3. Measurement system is shown in Fig. 2. A He-Ne laser light (λ=633 nm) which is transverse electric (TE) polarized is introduced from the cleaved edge of the MZI. A voltage was applied between the electrode and the Si substrate of the MZI, and the modulation of the output light is measured.

3. Results and Discussion

3.1 Imprint property for optical modulation of MZI

At first, the voltage of –200 V (electric field, E_{BST}= -1.2×10^4 V/cm) was applied. However, the output light intensity was hardly modulated. This result suggests that the polarization of the BST is not oriented in the same direction completely. Therefore, we expected that the polarization of the BST will be oriented by an imprint phenomenon. The imprint phenomenon is known as a pre-treatment which makes the polarization of the ferroelectric material align in one direction by applying the external electric field [6]. In this study, the voltage stress is applied to the MZI as follows. At first step, the Si substrate is heated to T_{stress} and DC voltage of –200 V is applied to the MZI. The heating time is defined as t_{heat}. The applied voltage is switched off 30 min after the heater is turned off as shown in Fig. 3. After this imprint treatment with T_{stress}>40°C, the output light of the MZI is started to be modulated. Figure 4 shows the modulation versus T_{stress}. The modulation becomes maximum value 2.8% at T_{stress}=75°C. Figure 5 shows the optical modulation versus t_{heat} when T_{stress} is 75°C. The modulation is saturated at about 3% and saturation time is around 60 min. Next, the sample is heated when the optical modulation of the MZI is measured. As a result, the optical modulation is monotonously decreased with the substrate temperature as shown in Fig. 6. The optical modulation of the TE mode input light is almost the same as that of the TM mode input light as shown in Fig. 7. Figure 8 shows the optical modulation when the voltage of –200V is applied to the electrode of one arm of the MZI and +200 V is applied to the electrode of the other arm. In this case, the optical modulation is twice as large as the optical modulation when the other electrode of the MZI is grounded. This result indicates that the optical modulation is due to the phase shift in the both arms and the two arms of the MZI are almost symmetric.

3.2 Influence of voltage stress on electric properties of BST

In order to evaluate the influence of voltage stress on electric properties of the BST MZI, a capacitor shown in Fig. 9 is fabricated. Figure 10 shows temperature dependence of a leakage current of the capacitor. As shown in Fig. 10, the leakage current increases with temperature when the substrate temperature is higher than 75°C. Here, equivalent circuit of Fig. 1(c) is shown in Fig. 11. In this equivalent circuit, an increase in the leakage current shown in Fig. 10 means a decrease in resistance R_{BST}. Therefore, E_{BST} rapidly decreases when T_{stress}>75°C. This may be the reason for the decrease in the modulation at T_{stress}>75°C in Fig. 4. Figure 12 shows accumulation capacitance after voltage stress application versus T_{stess}. This figure shows the accumulation capacitance is not changed by the voltage stress even though the polarization of the BST is aligned by the imprint treatment.

4. Conclusions

The imprint property for the optical modulation of the MZI using BST is evaluated. The optical modulation is much improved after voltage stress together with heating of the substrate, and modulation has maximum value when substrate is heated at 75°C. Thus we have, for the first time, pointed out the importance of the imprint treatment of the optical devices using (Ba,Sr)TiO_3 film. The optimum imprint treatment may be different depending on the composition of the BST film. Since the film composition is not optimized yet [3], the optical modulation of the MZI modulator will be improved by optimizing the BST composition.

Acknowledgments

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References

[1] I. Hayashi, Jpn. J. Appl. Phys. **32** (1993) 266.
[2] Y. Tanushi *et al.*, Jpn. J. Appl. Phys. **45** (2006) 3493.
[3] M. suzuki *et al.*, Jpn. J. Appl. Phys. **46** (2007) 2462.
[4] Z. M. Xu *et al*, Appl. Phys. Lett. **88** (2006) 161107.
[5] M. Salib *et al.*, *proc. Int. Conf. Group IV Photonics* (2004) PLE1.
[6] J. M. Menedetto *et al.*, Integr. Ferroelectrics, **10** (1995) 279.

Table I Sputtering condition

RF power	50 W
Base pressure	1.2×10^{-6} Pa
Sputtering gas	Ar : O_2 = 4 : 1
Pressure	2.0 Pa
Substrate temperature	450°C
Deposition rate	1.0 nm/min

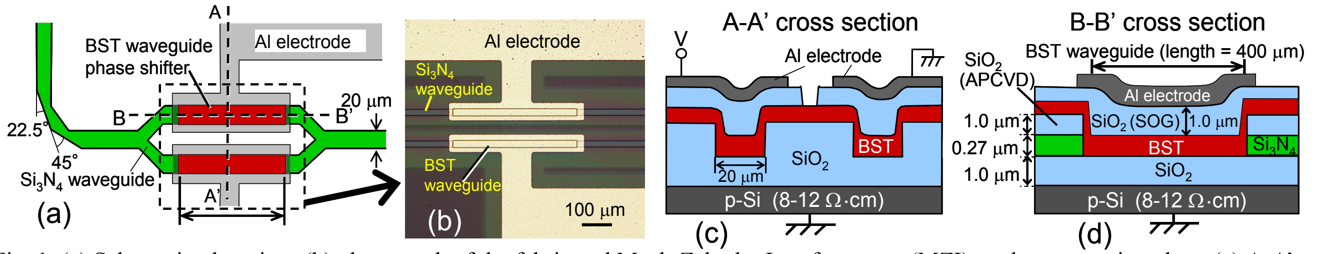

Fig. 1. (a) Schematic plan view, (b) photograph of the fabricated Mach-Zehnder Interferometer (MZI), and cross-section along (c) A-A' and (d) B-B' of Fig. 1(a). Because the optical loss of the BST waveguide is very large (470 dB/cm) [3], the Si_3N_4/BST hybrid structure is used.

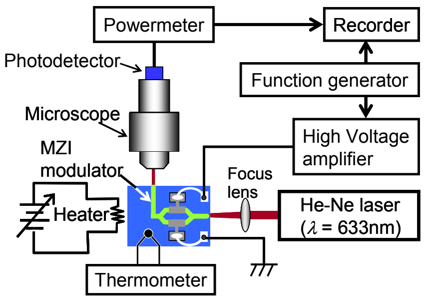

Fig. 2. Optical measurement system for MZI.

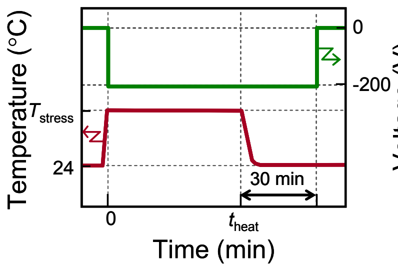

Fig. 3. Transition of substrate temperature and applied voltage to MZI for imprint treatment.

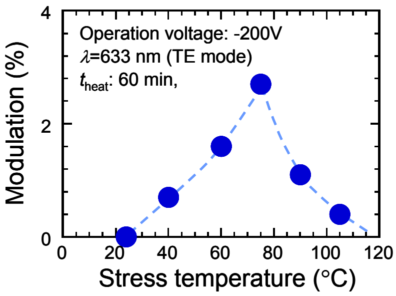

Fig. 4. Optical modulation of MZI versus stress temperature T_{stress}.

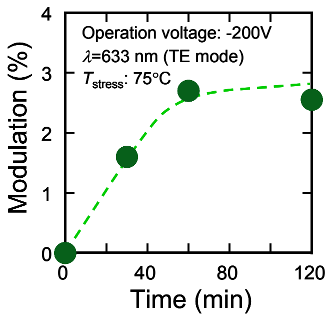

Fig. 5. Optical modulation of MZI versus stress time t_{heat}.

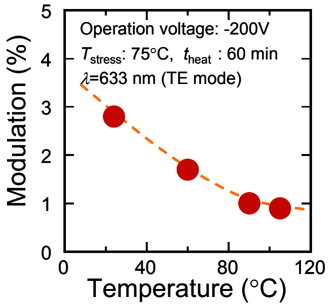

Fig. 6. Optical modulation of MZI versus substrate temperature at operation.

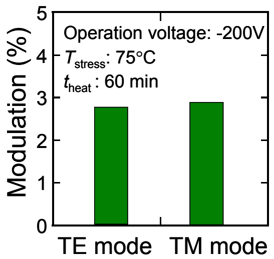

Fig. 7. Optical modulation when input light is TE mode and TM mode respectively.

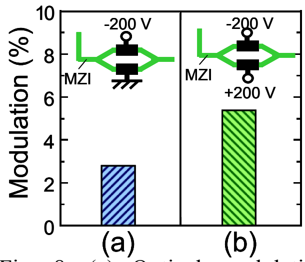

Fig. 8. (a) Optical modulation when -200 V is applied only to one arm, and (b) that when –200V is applied to one arm and +200 V is applied to other arm.

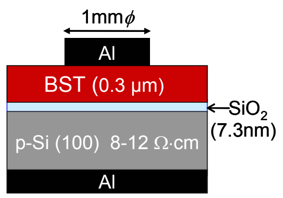

Fig. 9. Cross section of Al/BST/SiO_2/Si capacitor. In order to evaluate capacitance of BST layer, thickness of SiO_2 layer is very thin (7.3 nm).

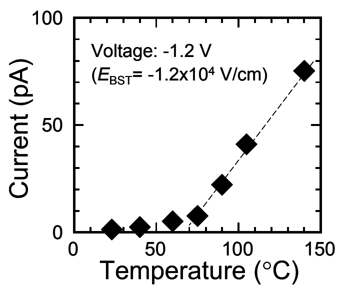

Fig. 10. Leakage current of the Al/BST/SiO_2/Si capacitor shown in Fig. 9 versus substrate temperature.

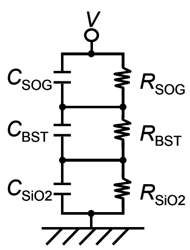

Fig. 11 Equivalent circuit of the left half of the Fig. 1(c).

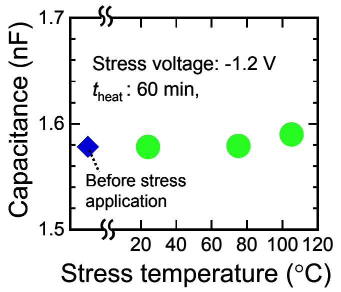

Fig. 12. Accumulation capacitance after voltage stress application versus T_{stess}.