Optical Properties of Ring Resonators on Si Chips
– Race-Track Resonator and Optical Switch using Electro-Optic Material –

Yuichiro Tanushi, Masaru Wake, Keita Wakushima, and Shin Yokoyama

Research Center for Nanodevices and Systems, Hiroshima University,
1-4-2, Kagamiyama, Higashi-Hiroshima, Hiroshima, 739-8527, Japan
Phone: +81-824-24-6265, FAX: +81-824-22-7185, E-mail: tanushi@sxsys.hiroshima-u.ac.jp

1. Introduction

Recently performance of ultra large scale integrated circuits (ULSIs) is limited by signal delay in metal interconnection. To overcome this problem, low-k interlayer materials are investigated. Other solutions of this problem is to replace metal interconnection to other interconnection such as wireless or optical interconnection. We focus on the optical interconnection.

Optical interconnection consists of light-emitting devices, waveguides, optical modulators, and photodetectors. It is not easy to integrate many light-emitting devices made of compound semiconductors on Si chips. More promising method is to integrate optical switches on Si chips as shown in Fig. 1. Tunable microring resonator is useful for optical switch. It has been shown that microring resonator is attractive candidate of small size optical filter [1]. The advantage of the microring resonator is the compact size of only 10 μm order.

As optical switch, the ring resonator must be tunable. At present tunable ring resonator is realized only by temperature control [2]. We propose new tunable ring resonator using electro-optic material, for which the refractive index is changed by electric field.

2. Theory and fabrication of the ring resonator

Ring resonator consists of ring, in this case race-track shape [3], and signal buses as shown in Fig. 2. Light with particular wavelength resonates on the ring and proceeds to output 2 port through gap. Remaining light goes to output 1 port. Resonance wavelength λ of the ring resonator of the race-track shape (see Fig. 2) is given by,

$$\lambda = n_{\mathit{eff}} \frac{2\pi R + 2L}{m}, \tag{1}$$

where n_{eff} is the effective refractive index, and m is an arbitrary integer. For the ring resonators of perfect circular shape, very small gaps are required for large coupling between ring and signal buses. On the other hand, for the race-track resonator the coupling efficiency is easily enhanced by changing the length of straight section.

We fabricated race-track resonators shown in Fig. 3 and Fig. 4. The core layer is silicon nitride with W=2 μm and D_2=0.8 μm, and the cladding layer is SiO_2 with D_1=1.6 μm. The silicon nitride film was deposited by plasma CVD and the refractive index of the film was 1.785. Figure 5 shows the wavelength responses of the output 1 and output 2 of the race-track resonator with R=8 μm, L=18.84 μm, and g=0.2 μm. Dips of output 1 well correspond with peaks of output 2. Observed resonance wavelength roughly agrees with the 2D finite difference time domain (FDTD) simulation. It is next work to find the cause of slight difference between measurement and simulation data.

3. Tunable ring resonator with electro-optic material

The most conventional electro-optic material is $LiNbO_3$. However $LiNbO_3$ is difficult to introduce into silicon process because it contains Li which has large diffusion coefficient in Si and SiO_2. On the other hand, $(Ba,Sr)TiO_3$ (BST), which is also electro-optic material, has already been used as ferroelectric material in silicon process. Therefore, we choose BST as the waveguide core of the ring.

A 700 nm thick BST film was spin-coated as follows. First the following spin coating process was repeated 12 times; (1) spin coating of 60 nm thick film, (2) heating at 150˚C for 20 minutes. Finally the BST film was baked at 700˚C for 1 hour. We will make BST waveguide by damascene method shown in Fig. 6. Silicon nitride thin film is used to prevent diffusion of Ba, Sr, and Ti into SiO_2.

Since the electro-optic coefficient of BST film is not reported, we measured it by using optical interferometer for the sputtered BST film, which has better crystallinity than spin-coated film, on Ir metal. The sample structure is shown in Fig. 7. The refractive index of BST changes when bias is applied, therefore, output interference pattern between reflection light from the top and bottom of BST film changes. We observed that the refractive index decreased about 0.1 % under electric field of 2×10^5 V/cm. Therefore, index decreases 0.2 % at 4×10^5 V/cm, which is sufficient for the optical switch as shown in Fig. 8. The electro-optic coefficient of the spin-coated BST film may be a little smaller than that of the sputtered film.

4. Conclusion and future plan

We propose optical switch using tunable optical ring resonator with electo-optic material. The characteristics of the race-track resonators were simulated using 2D FDTD method. We made the race-track resonators consisting silicon nitride core and SiO_2 cladding layers. We chose BST as electro-optic material and measured its refractive index and electro-optic coefficient.

The next step is to make tunable ring resonator using BST core and measure its characteristics. Study on new structure is also needed to obtain more sharp resonant characteristics.

References

[1] B. E. Little, S. T. Chu, H. A. Haus, J. Foresi, and J.-P. Laine, J. Lightwave Technol. **15**, 998 (1997).

[2] Y. Kokubun, Oyo Buturi **72**, 1364 (2003) (in Japanese).

[3] M. K. Chin and S. T. Ho, J. Lightwave Technol. **16**, 1433 (1998).

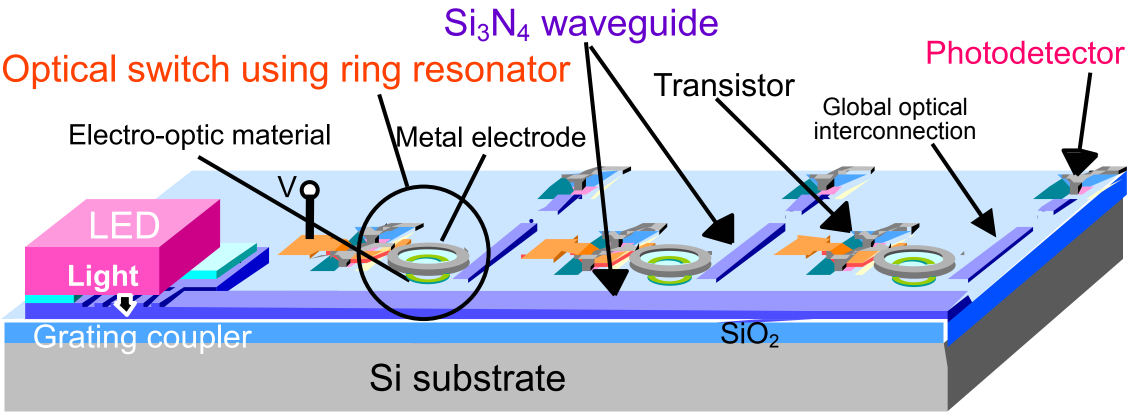

Fig. 1 Outline of the optical ULSI we are studying and developing.

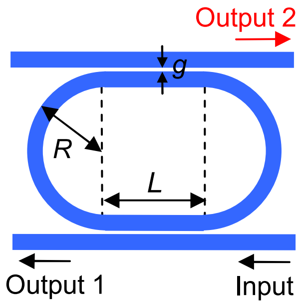

Fig 2 Structure of the ring resonator.

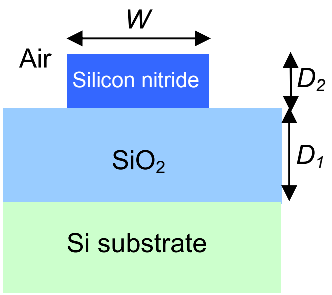

Fig 3 Cross section of silicon nitride core waveguide.

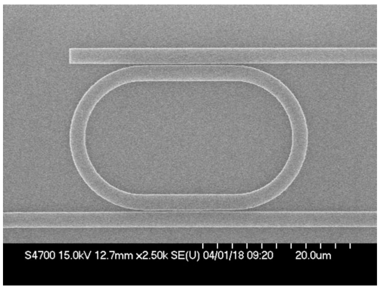

Fig. 4 An example of SEM image of race-track resonator.

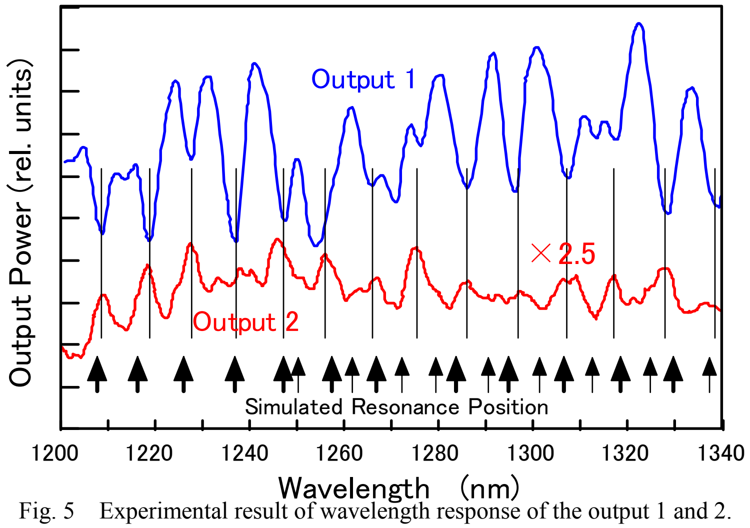

Fig. 5 Experimental result of wavelength response of the output 1 and 2. Dips of output 1 well correspond with peaks of output 2. Measured resonance wavelengths are roughly consistent with the simulation result shown by arrows.

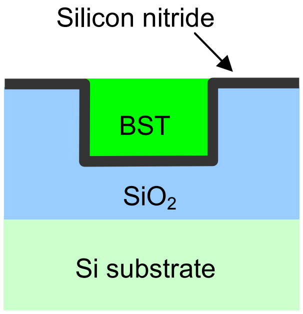

Fig. 6 Cross section of BST core waveguide made by damascene method.

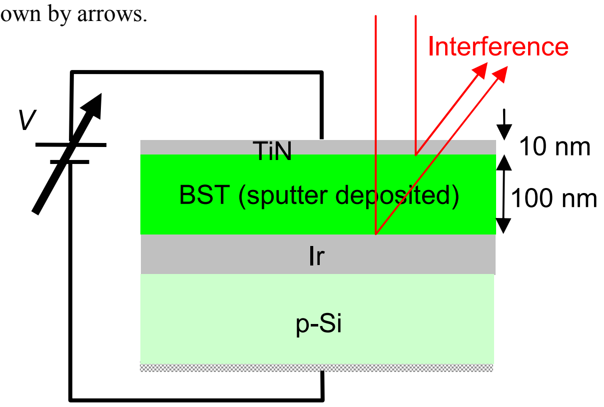

Fig. 7 Measurement method of electro-optic effect.

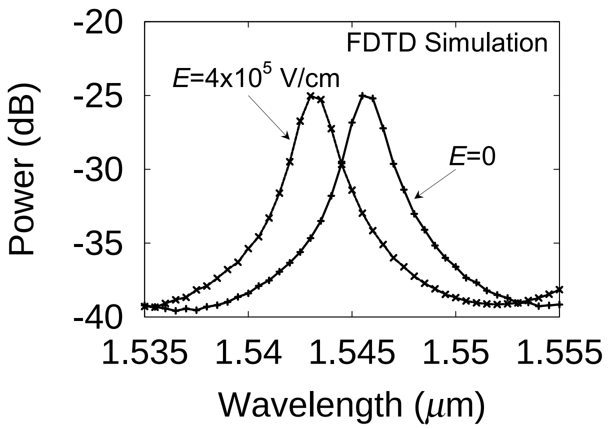

Fig. 8 Wavelength response of the output 2 of the tunable ring resonator with BST core by simulation.