Design and Fabrication of Race-Track Optical Ring Resonator

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1. Research Target

Signal delay in metal interconnection becomes serious problem to limit performances of ultra large scale integrated circuits (ULSIs) . Optical interconnection is promising method to overcome this problem.

Optical microring resonator, of which size is tens micrometers, is being watched with interest because it was shown that microring resonator can be used for optical filter for visible light and infrared region [1]. Optical filter is indispensable for wavelength division multiplexing which realizes broadband telecommunication by propagating many lights with different wavelengths in one optical fiber or waveguide. Ring resonator is the best device for integrated optical filter in optical interconnection on ULSIs because it can be fabricated on Si process.

Chu *et al.* developed stack ring resonator, in which the ring and the bus waveguides are stacked with the spacer, and the coupling efficiency is precisely controlled by the thickness of the spacer [2]. However, the fabrication process is complicated compared with the planer resonators, in which ring and the buses are fabricated in the same plane as shown in Fig. 1. We have fabricated a planer race-track resonator [3]. The race-track resonator enables the precise control of the coupling efficiency by controlling the coupling length, while circle type ring resonator is difficult to control the coupling efficiency.

2. Research Results

The structure of race-track resonator is shown in Fig. 2. Device parameters are the ring radius R, the coupling length L, and the gap between ring and bus g. Light induced from input port partly moved on ring through the gap. Lights with particular wavelengths have the same phase after propagating around the ring, then resonate on the ring and proceed to output 2 port through the gap. Therefore resonance wavelength is given by

$$\lambda_m = n_{eff} \frac{2\pi R + 2L}{m} \quad (1),$$

where n_{eff} is the effective refractive index, and m integer. The coupling efficiency is determined by the gap g and the coupling length L. The long coupling length L needs for resonance of light on the ring. An advantage of race-track resonator is to design large coupling efficiency with the long coupling length even the gap is relatively wide such as 0.2 μm. However, free spectral range (FSR) is inversely proportional to the circumference of the race-track, therefore the short coupling length is good for wide FSR.

We have fabricated two kinds of race-track resonators with long coupling length (Fig. 3(a)) and short coupling length (Fig. 3(b)). The circumference of the race-tracks for (a) and (b) maintained constant, so both resonators have the same resonance wavelength. The ring radius and the gaps are also the same for both ones. First, we simulated the propagation loss of the waveguide with the structure shown in the inset of Fig. 4 for determination of the widths of the ring and bus. Finite difference method (FDM) is used in the simulator (Apollo Photonics Solutions Suite). As a result we chose a width of 3 μm because the loss is sufficiently low at the wavelength region around 1.3 μm which is used for optical telecommunication. Next, we estimated the dependence of the bending loss on the curvature radius by FDM simulation (Fig. 5). The radius R=10 μm was determined for compactness of resonators and wide FSR even the loss is relatively high.

The fabrication procedure is shown in Fig. 6. After the pattern was formed with electron beam lithography and the reactive ion etching in CF_4+N_2 plasma was carried out. Because the etching rate in narrow resist gaps is small, silicon nitride was not etched until the bottom and the gaps were not formed perfectly.

The measured resonating property of the sample shown in Fig. 3(a) is shown in Fig. 7 together with the simulated one by two dimensional finite difference time domain (2D FDTD). A good agreement between the dip positions in output 1, peak position in output 2, and simulated resonance positions is obtained. Figure 8 compares the intensities of output 2 for the fabricated two kinds of samples shown in Figs. 3(a) and 3(b). The output intensity for the sample with longer coupling length is larger because of the larger coupling efficiency. The peak powers of output 2 for these samples are plotted Fig. 9 with 2D FDTD simulation results. For the experimental data the sample with L=12.6 μm is fit to the simulation because the actual light power is unknown. The simulation assumed the gaps were formed perfectly. Therefore the difference in the experimental data is smaller than that of the simulated data.

3. Summary and Outlook

The design and fabrication of race-track ring resonator has been carried out. Its characteristics have been measured and confirmed good agreement with the simulation. The next plan is to optimize the parameter of the race-track resonator and apply to optical switch controlled by electric field by using electro-optic materials as the core of the ring.

References

[1] B. E. Little *et al.*, J. Lightwave Technol. **15** (1997) 198.
[2] S. T. Chu *et al.*, Photon Technol. Lett. **11** (1998) 691.
[3] W. Lorattanaruangkit *et al.*, Proc. Asia-Pacific Microwave Conf. 1183 (2000).

4. Published Papers and Patents

1. Y. Tanushi, M. Wake and S. Yokoyama, "Race-Track Optical Ring Resonators with Groove Coupling," submitted to Int. Conf. on Solid State Devices and Materials (SSDM2004).
2. Y. Tanushi, K. Wakushima and S. Yokoyama, "Very Small Optical Switch using Tunable Optical Ring Resonator Controlled by Electric Field," Extended Abst. of Spring Meeting of Japan Society of Applied Physics (2004) 29a-ZC-9.

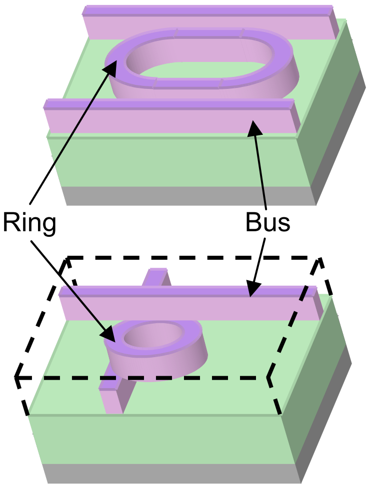

Fig. 1 Planar and Stack ring resonators. Planar resonator has simple structure and can be easily fabricated.

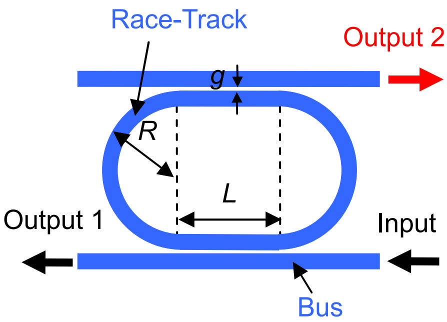

Fig. 2 Structure of race-track resonator. Device parameters are the ring radius *R*, the gap g, and the coupling length *L*. The resonating wavelength depends on *R* and *L*, and the coupling efficiency depends on *g* and *L*.

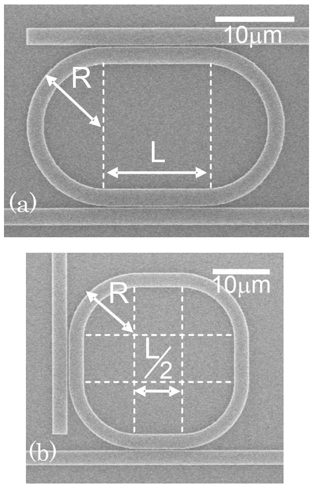

Fig. 3 SEM photographs of the fabricated two kinds of race-track resonators. The coupling length L is (a) 12.6 µm and (b) 6.3 µm respectively. The ring radius R is 10 µm and the gaps are 0.2 µm in both samples.

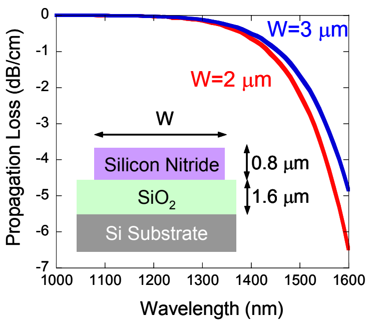

Fig. 4 Simulated propagation loss by FDM. The cross section of the waveguide is also shown.

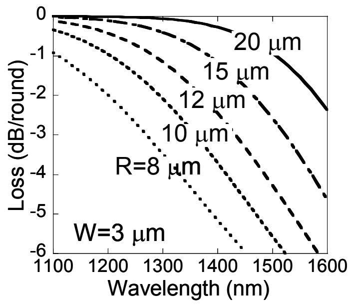

Fig. 5 Simulated bending loss by FDM. The structure of the waveguide is the same as the one in Fig. 4

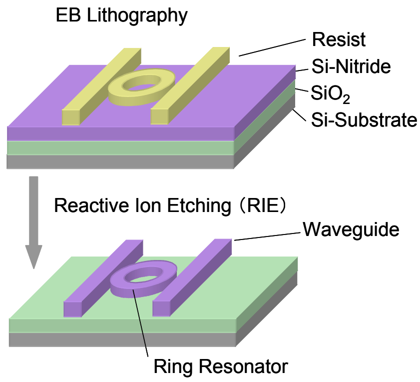

Fig. 6 Fabrication process of the race-track resonator. Silicon nitride film is deposited by plasma enhanced chemical vapor deposition (PECVD) and SiO_2 cladding layer is thermally oxidized.

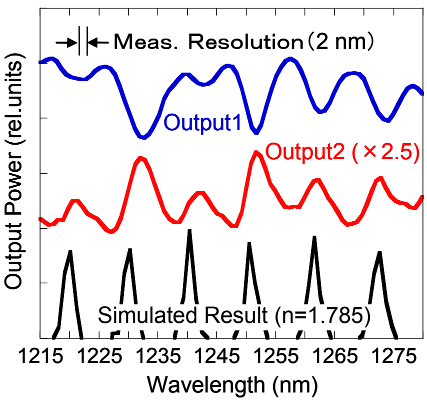

Fig. 7 Measured resonating property of the sample shown in Fig. 3(a). Simulated result is also shown. Simulation method is 2D FDTD.

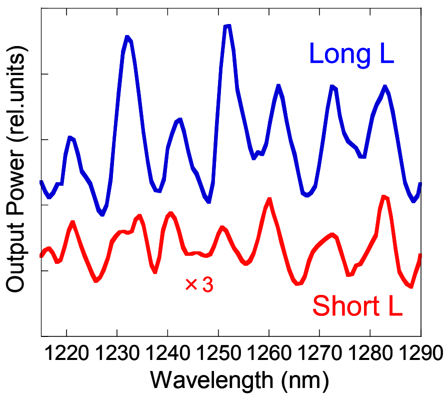

Fig. 8 Comparison between the intensities of output 2 for the fabricated two kinds of samples shown in Figs. 3(a) and 3(b).

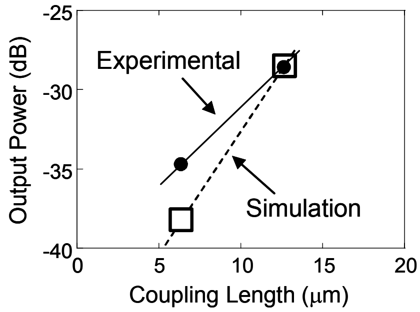

Fig. 9 Power of output 2 for samples (a) and (b) in Fig. 3. In the simulation it is assumed that the groove reaches to the bottom cladding layer.