Extended Abstracts of the 2006 International Conference on Solid State Devices and Materials, Yokohama, 2006, pp. 44-45

B-2-2

Compact Multi-Mode Optical Ring Resonators for Interconnection on Si Chips

Yuichiro Tanushi and Shin Yokoyama

Research Center for Nanodevices and Systems, Hiroshima University
1-4-2 Kagamiyama, Higashi-Hiroshima 739-8527, Japan
Phone: +81-82-424-6265, FAX: +81-82-424-3499, E-mail: tanushi@sxsys.hiroshima-u.ac.jp

1. Introduction

Optical interconnection on ultra large scale integrated circuits (ULSIs) is one of the promising methods to overcome signal delay in metal interconnection [1]. Multi-mode waveguide (WG) confines light strongly, thus propagation loss due to surface roughness becomes smaller and bending loss is smaller than single-mode WG with the same bending radius. The latter property is especially important for making small devices, therefore suitable for interconnection on ULSIs. Modal dispersion, which is a disadvantage of multi-mode WG, may be not serious problem for short distance communication.

Optical ring resonators, of which size are tens micrometers, are attracting much interest because it was shown that ring resonators can be used for optical filters [2] as shown in Fig. 1. Single-mode ring resonators have been already reported [3,4]. It is believed that single-mode WG is a must for ring resonators because multi-mode disturbs the resonance characteristics. In this paper we show that even multi-mode ring resonators have good characteristics and suitable as optical filters for interconnection on ULSIs.

2. Experimental

Race-track resonator is fabricated as shown in Fig. 2. Fabricated WG has the width of 2.0 μm and is multi-mode as shown in Fig. 3. Coupling between multi-mode WGs is small, therefore race-track is adopted in order to obtain sufficient large coupling constant. Resonance wavelength of race-track resonator with radius R and coupling length L is given by

$$\lambda_{\mathrm{res}} = n_{\mathrm{eq}} \frac{2\pi R + 2L}{m}, \qquad (1)$$

where n_{eq} is the equivalent index of WG and m is an arbitrary integer. The ring radius R = 10 μm and the coupling length L = 12.56 μm are adopted to obtain sufficiently large free spectral range of more than 10 nm. The gap, which defines coupling constant, is 0.05 μm and 0.10 μm.

Figure 4 shows fabrication process. The lower cladding layer is formed by thermal oxidation to a thickness of 1.6 μm. Then 0.9 μm thick silicon nitride (n = 1.80 at λ = 1.3 μm) is deposited by plasma enhanced chemical vapor deposition. Ring resonators are defined by electron beam lithography and reactive ion etching. SEM photographs of the fabricated gap portion are shown in Fig. 5. The wavelength dependences of the ring resonators were measured by using tunable laser (λ = 1280-1320 nm) and InGaAs photodetector as shown in Fig. 6.

3. Results and Discussion

Figure 7 shows the wavelength dependence of optical power of output 1 and output 2 ports of ring resonators (see Fig. 2). In both devices, valleys of output 1 correspond to the peaks of output 2. Measured resonance wavelength agrees with theoretical values given by Eq. (1). Clear sub-peaks by second order mode are not observed and resonance characteristics behave as if single-mode ring resonators. The second order mode is weakly confined than fundamental mode in WG and has larger bending loss. Therefore, light with second order mode does not sufficiently accumulate in the ring and resonance from second order mode hardly appears.

The resonance shape of the resonance wavelength λ_{res} defined by Eq. (1) and a full width at half maximum (FWHM) λ_{FWHM} is given by following Lorentz function,

$$I(\lambda) \propto \frac{1}{(\lambda - \lambda_{\mathrm{res}})^2 + (\lambda_{\mathrm{FWHM}}/2)^2}. \qquad (2)$$

The fitting results are shown in Fig. 8. Wavelength dependence of resonance curve is fitted by Lorentz function very well. The ring resonator with wider gap has smaller FWHM because wider gap gives smaller coupling constants, in which lifetime of the light in the ring becomes longer.

Figure 9 shows the dependence of bending loss on bending radius by simualtion. Bending radius of multi-mode is reduced about 25 % compared with that of single-mode WG to obtain the same bending loss. This is the advantage of multi-mode for realizing compact devices.

4. Conclusion

We have fabricated multi-mode ring resonators. The resonance characteristics behaves as if single mode ring resonator. It is shown that multi-mode ring resonators are useful as optical filters for interconnection on ULSIs because they can be fabricated more compactly.

Acknowledgements

This study was supported in part by 21st Century COE program "Nanoelectronics for Tera-Bit Information Processing," from the Ministry of Education, Culture, Sports, Science and Technology of Japan.

References

[1] I. Hayashi, Jpn. J. Appl. Phys. **32** (1993) 266.
[2] B.E. Little *et al.*, J. Lightwave Technol. **15** (1997) 998.
[3] T. Naganawa *et al.*, Jpn. J. Appl. Phys. **43** (2004) 5780.
[4] T. Naganawa *et al.*, Photon. Technol. Lett. **17** (2005) 2104.

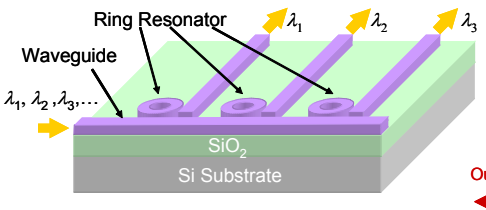

Fig. 1 Schematic of wavelength division multiplexing optical interconnection on ULSI. Ring resonators are used as optical filters.

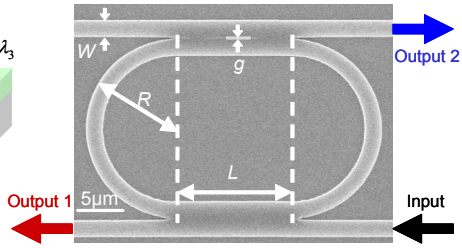

Fig. 2 Race-track type resonators. Larger coupling between I/O WG and ring can be obtained by long coupling length L.

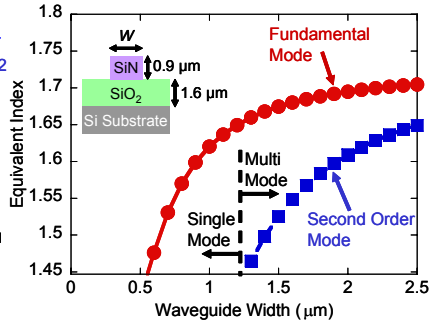

Fig. 3 Waveguide width dependence of equivalent index at $\lambda = 1.3$ μm by simulation. 2.0 μm width waveguide is multi-mode.

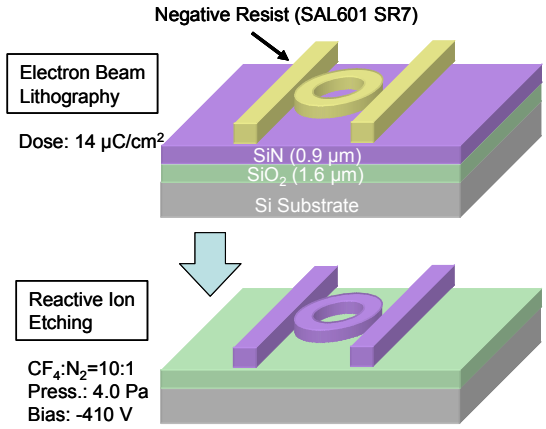

Fig. 4 Fabrication process of ring resonators.

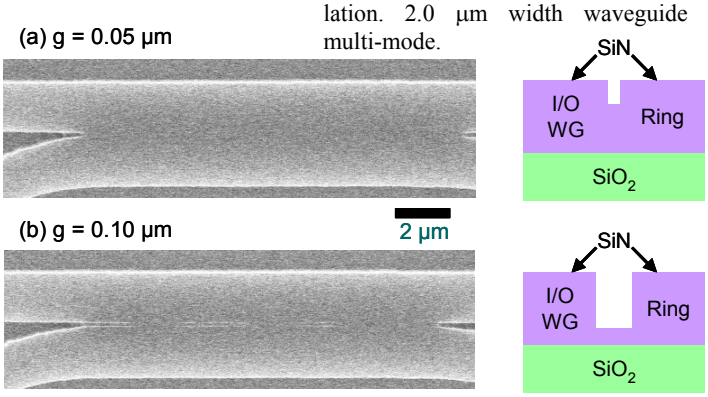

Fig. 5 Plan view SEM photographs and cross sectional figures of fabricated gaps between I/O WG and ring of (a) 0.05 μm and (b) 0.10 μm. Gap is not created for $g = 0.05$ μm and for $g = 0.10$ μm the gap is partially made.

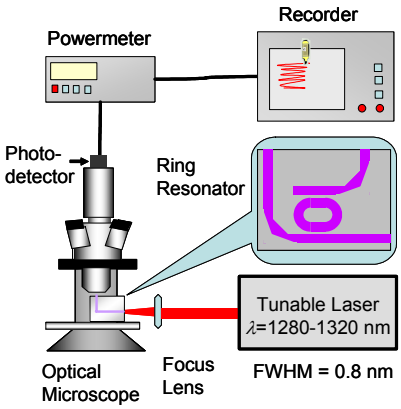

Fig. 6 Measurement system for ring resonators.

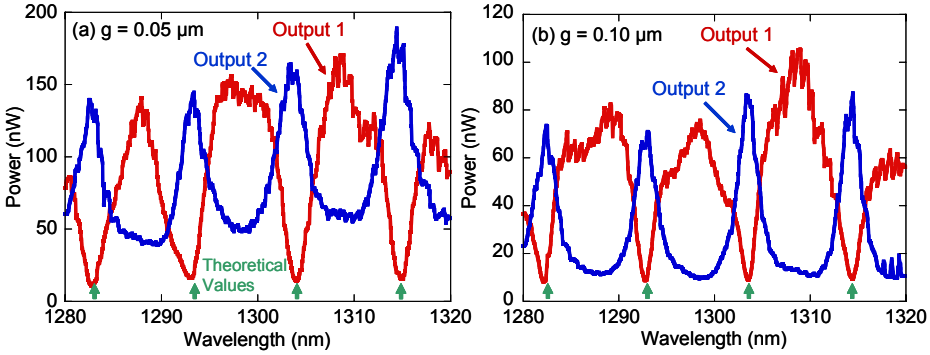

Fig. 7 Wavelength dependence of ring resonators with gap of (a) 0.05 μm and (b) 0.10 μm. Measured resonance wavelength agrees with theoretical values which are indicated by arrows. Clear subpeaks by second order mode is hardly observed.

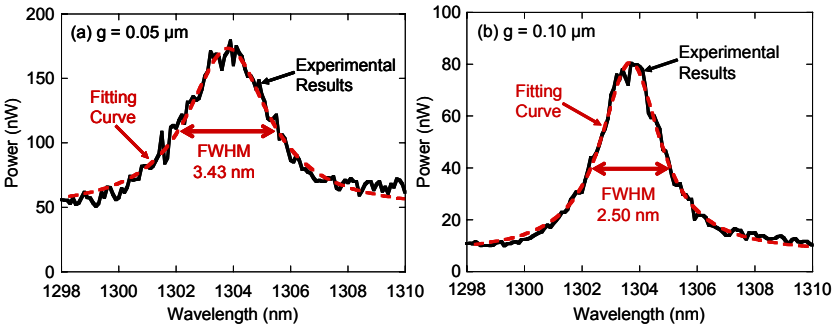

Fig. 8 Measured characteristics (solid line) and fitting curve by Lorentz functions (dashed line). The FWHM of ring resonators with gap of 0.05 μm and 0.10 μm are 3.43 nm and 2.50 nm, respectively.

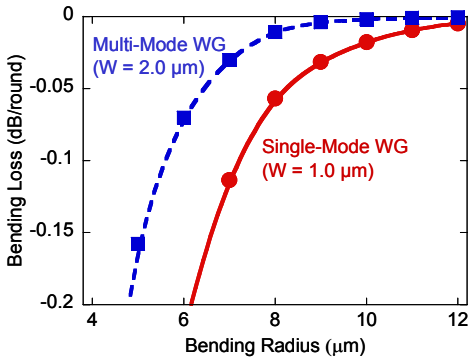

Fig. 9 Dependence of bending loss on bending radius at $\lambda = 1.3$ μm by simulation. Bending loss of multi-mode WG is smaller than that of single-mode WG, therefore compact devices can be realized using multi-mode WG.