Extended Abstracts of the 2005 International Conference on Solid State Devices and Materials, Kobe, 2005, pp.318-319

E-3-1

Design and Simulation of Ring Resonator Switches using Electro-Optic Materials

Yuichiro Tanushi and Shin Yokoyama

Research Center for Nanodevices and Systems, Hiroshima University
1-4-2, Kagamiyama, Higashi-Hiroshima, 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 is an attractive candidate to solve signal delay of metal interconnection. However 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 monolithically. We are studying tunable microring resonator for optical switches because of its compactness [1]. It has also been shown that microring resonator is an attractive candidate of small size optical filter [2].

In order to realize the ring resonator switches, the waveguide whose refractive index is changed by electric field is needed for high speed switching. There are two solutions to realize such waveguide: Electro-optic (EO) materials core waveguide and Si core waveguide [3]. We focus on EO materials because the faster operation is expected. In this paper ring resonator switches are designed and their operation voltage and speed are estimated.

2. Estimation of operation voltage

Ring resonator switch consists of ring and buses as shown in Fig. 1. This device picks up the light with resonance wavelength. Optical properties are simulated to estimate operation voltage. In these simulations, ring radius and waveguide width were 12 μm and 2 μm, respectively.

Figure 2 shows the structure of the ring waveguide, which consists of EO material core layer, KH_2PO_4 cladding layer which is selected because of its high dielectric constant and low refractive index, and aluminum electrodes. The cladding layer must be thin for applying electric field to EO materials effectively, and so was fixed at 0.1 μm. Figure 3 shows the simulated propagation loss of this waveguide at LD light emission wavelength, 850 nm. The core thickness should be larger than 2.5 μm. Then resonance properties of the ring resonator are simulated as shown in Fig. 4. Refractive index change of 5×10^{-4} is needed for switching operation.

Operation voltage depends on the EO coefficient and dielectric constant of the core materials of the ring. We calculated in the case of $LiNbO_3$ (LN), $(Ba,Sr)TiO_3$ (BST), and $K(Ta,Nb)O_3$ (KTN). LN is widely used for EO materials, but has not been introduced in Si process yet. BST has been already introduced in Si process as ferroelectric material. KTN has very large EO coefficient and recently developed by NTT [4]. The results are summarized in Table 1. KTN is promising if a thin film will be available in Si process. LN and BST have high operation voltage. These values may be reduced by introducing other structure waveguide such as ridge type.

3. Estimation of operation speed

The operation speed is estimated using a simple model. This model neglects waveguides width and assumes equivalent index. We fix equivalent index at 2.0 for EO materials. The other model parameters are *coupling constant* between ring and bus and *bending loss* of the ring. Weaker coupling gives smaller peak power and higher Q-value as shown in Figs. 5 and 6. Full width at half maximum (FWHM) should be less than 0.2 nm for optical switching (see Fig. 4), therefore coupling must be smaller than 0.3. On the other hand, coupling should be larger than 0.1 for strong output.

Figure 7 shows one example of the resonance shape after light propagates in the ring at some rounds. Time dependence of peak power and FWHM are shown in Figs. 8 and 9, respectively. FWHM reaches 0.2 nm within 15 ps except for large bending loss. The operation speed of the ring resonator switches using EO materials depend on not only resonation time but also RC delay and polarization time of the EO materials for refractive index change. Figure 10 indicates that the operation speed is limited by the resonation time. This is different from optical switches using Si core, whose operation speed is limited by free carrier accumulation time, i. e. hundreds ps.

Next, gap dependence of coupling constant between bus and ring is simulated. Device dimension and simulated results are shown in Fig. 11. Coupling constant needed for switching is obtained from 0.15-0.3 μm gap, which can be fabricated in conventional Si process.

4. Conclusion

We have proposed and designed the ring resonator switches using EO materials. The operation voltage and speed were estimated by simulation and the simple model. The ring resonator switches using EO materials are promising devices for their compactness and high operation speed to apply optically integrated LSI.

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.

References

[1] Y. Tanushi *et al.*, 1st Int. Conf. on Group IV Photonics, WB3 (Hong Kong, 2004).
[2] B.E. Little *et al*., J. Lightwave Technol. **15**, 998 (1997).
[3] A. Liu *et al*., Nature **427,** 615 (2004).
[4] S. Toyoda *et al*., Electro. Lett. **40**, 830 (2004).

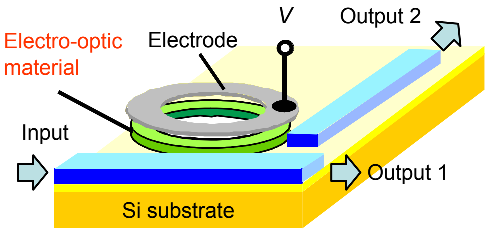

Fig. 1 Ring resonator optical switches using electro-optic materials.

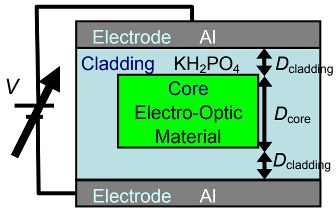

Fig. 2 Cross sectional structure of the ring waveguide.

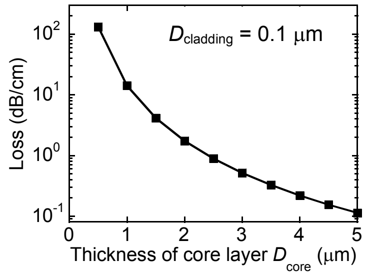

Fig. 3 Simulated propagation loss. The core thickness should be larger than 2.5 μm to reduce propagation loss less than 1 dB/cm.

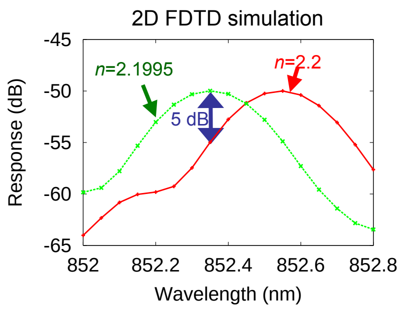

Fig. 4 Simulated resonance properties for different refractive index of core.

Table I Operation voltage for ring resonator switches with various EO materials. Operation voltage is determined by EO coefficient and dielectric constant.

	LN	BST	KTN
EO coefficient (pm/V)	30.8	23	600
Dielectric constant	28	300	666
Operation voltage (V)	8.0	19.6	0.73

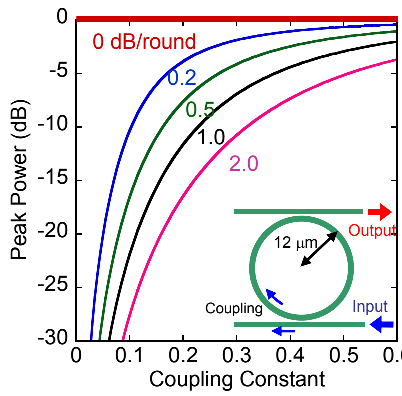

Fig 5 Coupling constant and bending loss dependence of peak power. Weaker coupling gives lower height.

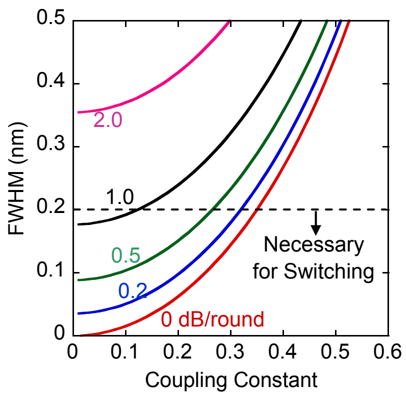

Fig. 6 Coupling constant and bending loss dependence of FWHM. Weaker coupling gives narrower width.

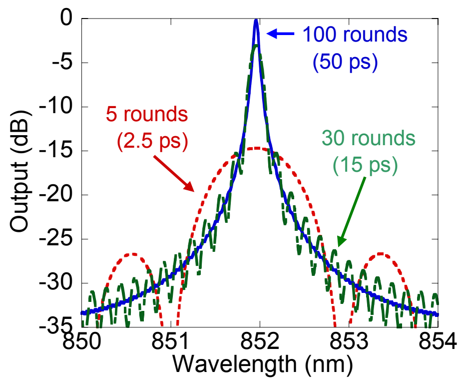

Fig. 7 Time dependence of resonance characteristics for coupling constant 0.2 and no bending loss.

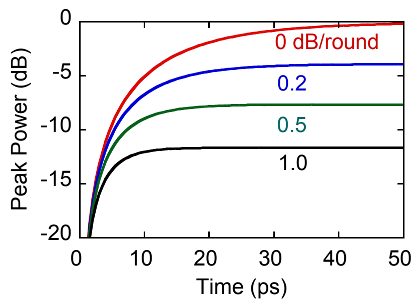

Fig. 8 Time dependence of peak power for coupling constant 0.2.

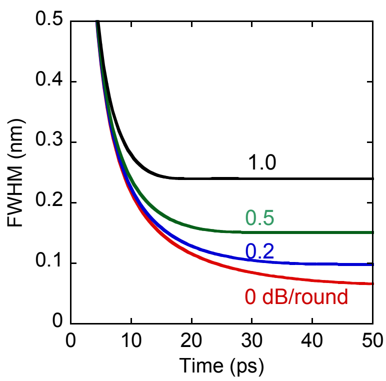

Fig. 9 Time dependence of FWHM for coupling constant 0.2. It takes less than 15 ps to reach FWHM to 0.2 nm if bending loss is sufficiently small.

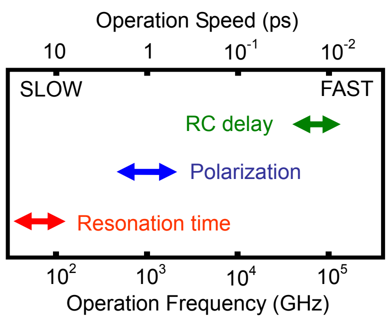

Fig. 10 Operation speed and frequency of ring resonator switches using EO materials.

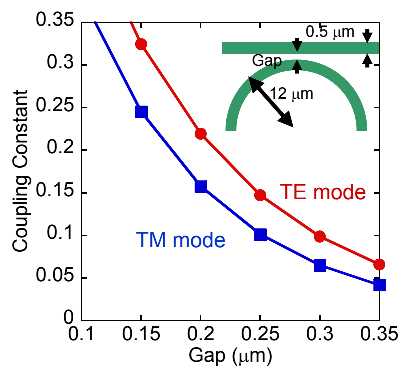

Fig. 11 2D FDTD simulation of the coupling constant. Difference in the coupling constant between TE and TM mode comes from waveguide structure.