Technology for Optical Interconnection in LSI

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1. Research Target: Optical Switch using Ring Resonator with Electro-Optic Material

Recently the clock frequency of the micro processor is saturating because of the signal speed limit of the global metal interconnection in LSI. In order to overcome this problem we are studying optical interconnection in LSI. Our research target is to realize the compact ring-resonator optical switch using electro-optic material, which can be monolithically integrated in LSI (Fig. 1). Operation speed of the ring resonator switch is simulated to be about 100 GHz which is limited by the resonation time[1)] and is faster about one order of magnitude than Si optical modulator switch,[2)] in which the switching speed is determined by the RC time constant (refer abstract of Tanushi in this proceeding). The size of the proposed ring resonator switch is very small compared with the Mach Zehnder Si modulator because the effective refractive index-change of the electro-optic material is very high compared with Si and also the ring resonator structure is used. The operation voltage is also calculated to be 1-100 V depending on the combination of the core and cladding materials. The schematic of the optically interconnected LSI is shown in Fig. 2 and the more detailed structure of the ring resonator optical switch integrated in LSI is shown in Fig. 3. Here, Pt seed layer grown by grapho epitaxy[3)] on the metal interconnect layer is used to obtain a high quality electro-optic material with large electro-optic coefficient. In order to reduce the operation voltage, electro-optic material of $Pb(Zr_yTi_{1-y})O_3$ (PZT) with very high electro-optic coefficient is used as core material and $Pb_{1-x}La_x(Zr_yTi_{1-y})_{1-x/4}O_3$ (PLZT) is used as cladding material. The ring resonator switches should be fabricated at temperatures below 450ºC because they are on the metal interconnection layer.

In this paper we report the recent research results concerning the ring resonator optical switch using electro-optic material.

2. Ring Resonator using Si Nitride

First we started to develop fabrication and measurement technologies of the ring resonator using Si nitride as a core material. Figure 4 shows the SEM image of the race-track ring resonator with Si nitride core fabricated using electron beam lithography. The Si nitride film is deposited by plasma enhanced CVD using SiH_4 and NH_3 at 350ºC. The resonance characteristics is shown in Fig. 5. In the race-track resonator, the coupling efficiency between input or output waveguide and the ring is precisely controlled by the length of the straight part of the ring.[4)] The gap between the waveguide and the ring is narrowed by the additional deposition of Si nitride. The resonation wavelength coincides well with the simulated value. The resonation peak is not sharp yet because the stray light from outside of the waveguide impinges into the detector.

3. Study on Electro-Optic Material

Next we studied the electro-optic material. First we employed $(Ba,Sr)TiO_3$ (BST) because it has been studied as high-dielectric constant material for DRAM.[5)] We have fabricated Mach Zehnder interferometer as shown in Fig. 6 using spin coated BST film (0.2 μm in thickness) annealed at 500ºC. However, the modulation of the output light by the applied bias is not yet achieved. The X-ray diffraction measurement indicated that the spin coated BST film is amorphous. The optical propagation loss is 2.67 dB/cm as shown in Fig.7. Recently we have fabricated poly-crystalline BST film by rf sputtering at 450ºC and confirmed the output light from the waveguide. Now we are trying to realize the Mach Zehnder interferometer using the poly-crystalline BST film. After that the ring resonator switch is scheduled to be realized.

Conclusion

We have proposed the ring resonator optical switch using electro-optic material. The fabrication technology for the ring resonator with Si nitride core is developed and good resonation characteristics are observed. Concerning the electro-optic material, we employed $(Ba,Sr)TiO_3$ film as core material of the waveguide and confirmed the waveguide operation for the poly-crystalline BST core.

References

[1] Y. Tanushi *et al.*, 1st Internat. Conf. on Group IV Photonics (Hong Kong, China, Sept. 29-Oct. 1, 2004) WB3.
[2] A. Lim *et a.l,* NATURE, **427**, Feb. 12, 2004, 615.
[3] Kushida *et al.*, Appl. Phys. Lett, **48**, 1986, 764.
[4] Y. Tanushi, *et al.*, Abst. Int. Conf. on Solid State Devices and Materials (SSDM2004) 940.
[5] B. Nagaraj *et al.*, Appl. Phys. Lett, **74**, 1999, 3194.

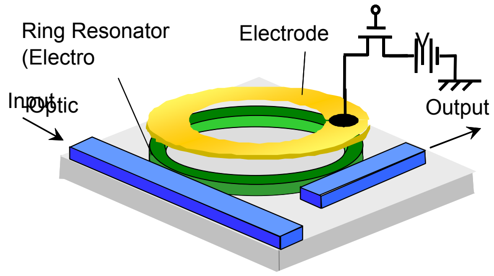

Fig. 1 Ring resonator switch using electro-optic material.

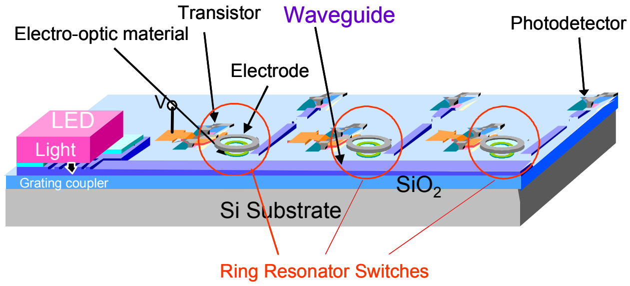

Fig. 2 Optical interconnection in LSI.

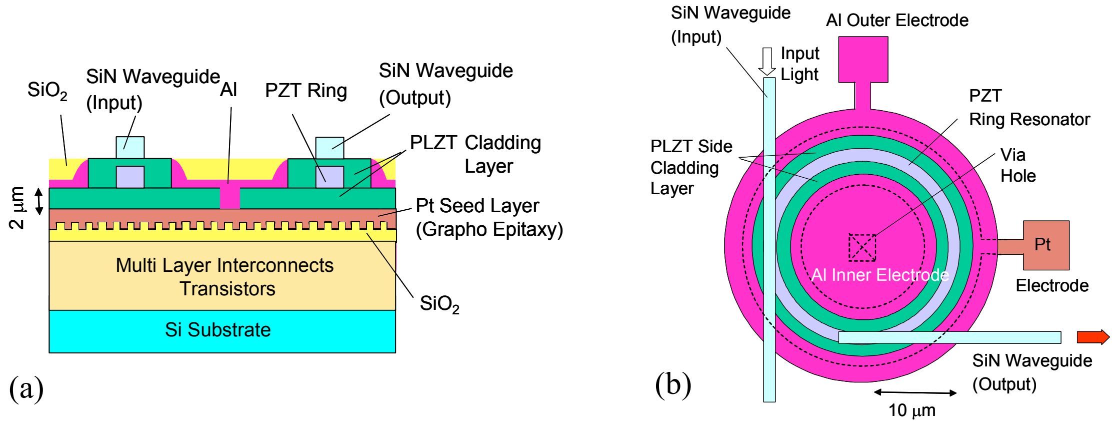

Fig. 3 Detailed structure of the ring resonator optical switch. (a) Cross section. (b) Top view.

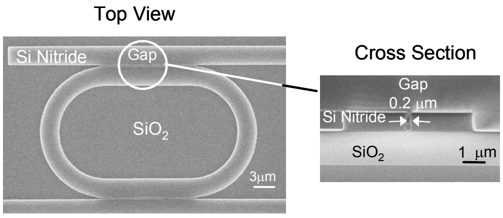

Fig. 4 SEM images of the fabricated race-track ring resonator.

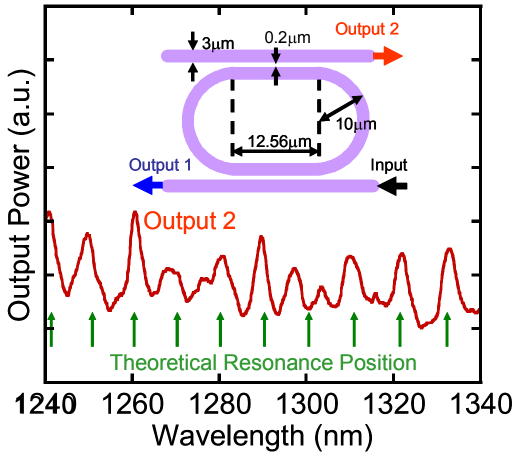

Fig. 5 Resonation characteristics of the race-track resonator.

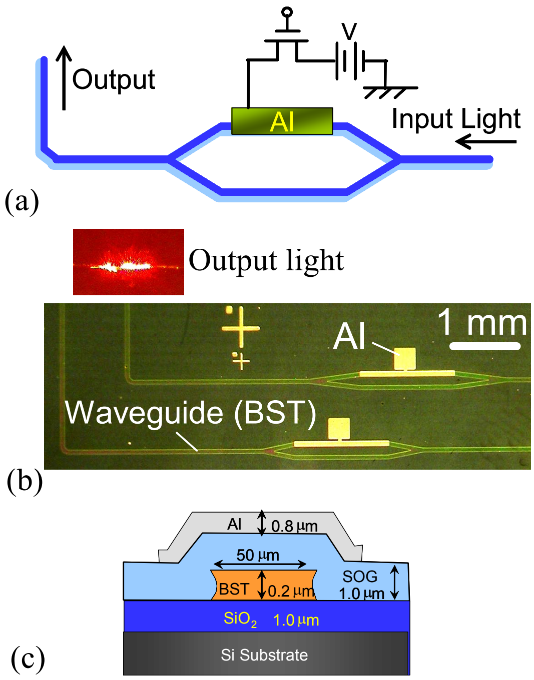

Fig. 6 Mach Zehnder interferometer. (a) Schematic. (b) Optical micrograph. (c) Cross section.

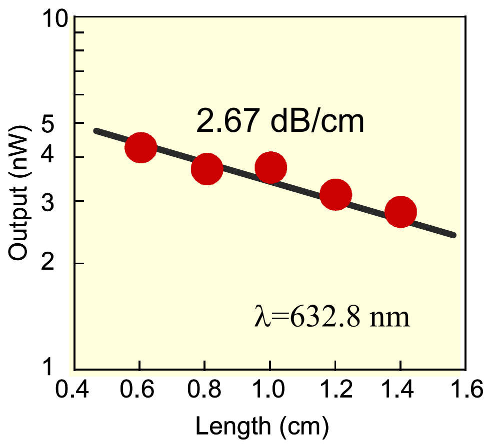

Fig. 7 Light propagation characteristics of BST waveguide.

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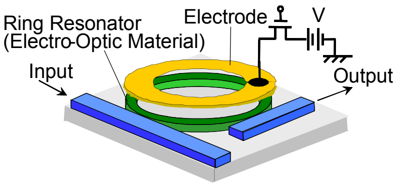
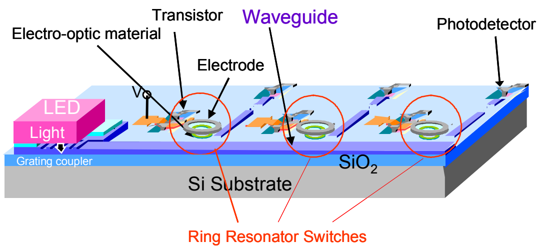
1.Research Target: Optical Switch using Ring Resonator with Electro-Optic Material

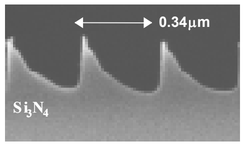


- Monolithically Integrated on Si LSI.
- Compact (a few tens of μm)
- High speed (~100 GHz)

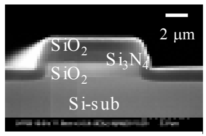
2. Target System: Optically Interconnected LSI



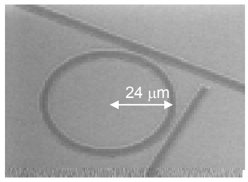
3. Previously Developed Technologies



Asymmetric Grating Coupler

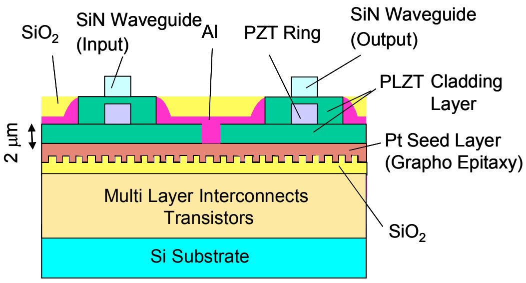


Compact Waveguides

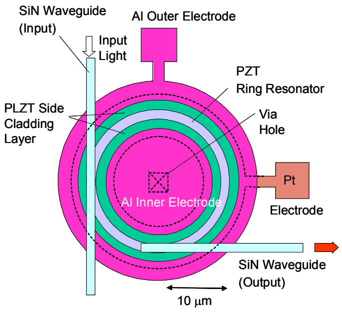


Optical Ring Resonators

4. Newly Proposed Ring Resonator Optical Switch



Cross Section

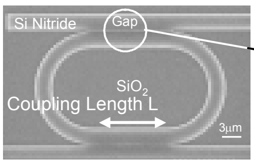


Plan View

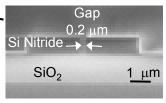
5. Ring Resonator using Si Nitride

Race-Track Resonator

Top View

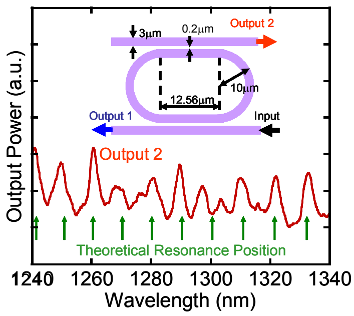


Cross Section

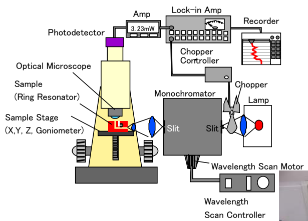


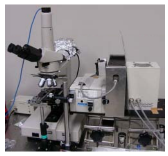
Coupling efficiency is controlled by coupling length L, and gap g.

Resonance Characteristics of Race-Track Resonator



Measurement System

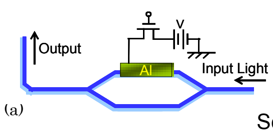




6. Study on Electro-Optic Material

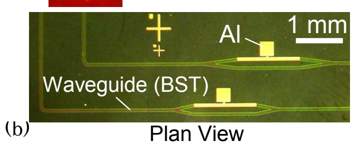
Mach Zehnder Interferometer using BST

$(Ba,Sr)TiO_3$ (BST) : already studied as *high-k* material for DRAM.

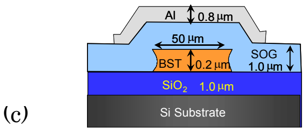


Schematic

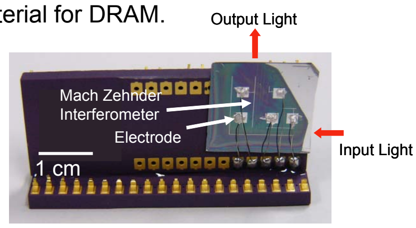
Output Light



Plan View

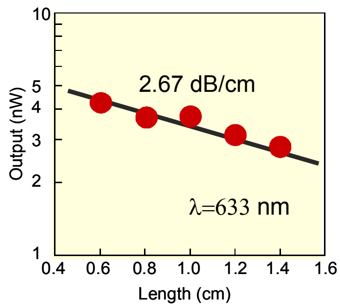


Cross Section



Modulation of output light intensity is not succeeded yet.

Light Propagation Loss of BST Waveguide



7. Conclusion

- Proposal of ring resonator optical switch using electro-optic material.
- Development of fabrication technology for ring resonator with Si nitride core.
- Fabrication of Mach Zehnder interferometer with $(Ba,Sr)TiO_3$ core (electro-optic material).
- Measurement of light propagation loss of BST waveguide.