Si Photonics Microring Modulators Controlled All Optically

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***Abstract*— Si Microring modulators (MRM) are not only used in data centers but will also be used in radio over fiber applications. This paper presents MRMs controlled all optically, which is suitable for remote operation.**

***Keywords*—Si photonics, microring modulator, all-optic control, radio over fiber**

I. Introduction

IT networks are now primarily composed of wireless and optical fiber communications. The wireless offers high mobility and flexibility, while available bandwidth is limited. The optical fiber has a much wider bandwidth and capable of long-distance transmission, but the flexibility is limited. In this context, radio over fiber (RoF) has been attracting attention as a means to combine wireless and optical fiber communications [1][2]. Previously, we developed an electromagnetic (EM) wave imaging system composed of Si photonics microring modulator (MRM) array based on the RoF concept [3].

In Si photonics, thermo-optic tuning using electrical heaters is used frequently to control light [4]. However, it will be desired to remove electrical wiring if the device is located at far distance. In this presentation, we propose and describe a simple all-optic control of MRMs, which utilizes optical heaters instead of electrical heaters. We have reported the control of Mach-Zehnder interferometer (MZI) optical switch and microring resonator (MRR) controlled by this concept, and found that the optical heater is more efficient than electrical heater [5].

In this study, we combine these two concepts, i.e., all-optic tuning of MRMs for electromagnetic wave imaging and other applications.

II. RoF System and All Optic Control

Let us first describe two concepts in detail. Fig. 1 provides an overview of the RoF system and its operation. RF probes consisting of slot antennas detected 3.5 GHz EM waves from a dipole antenna and directly drove a Si MRM array. The signal from each MRM was transmitted after selecting one MRM using the thermo-optic switch. Repeating this process for all MRMs, the distribution of EM waves was transmitted via fiber, as shown in Fig. 2. The color plots exhibit strong and weak distributions for the same and cross polarizations, respectively. In all cases, a clear intensity distribution was observed for the same polarization, while more than 10 dB suppression was observed for the cross-polarization.

Fig. 3 shows the all-optic controlled Si MRR. The black colored area indicates a highly n-doped region on a control waveguide adjacent to the MRR. Fig. 4 shows the resonance wavelength shift of the MRR, when control light was launched on the control waveguide. The launched power P_{cntrl} shifted the resonance similarly to the case using an electrical heater.

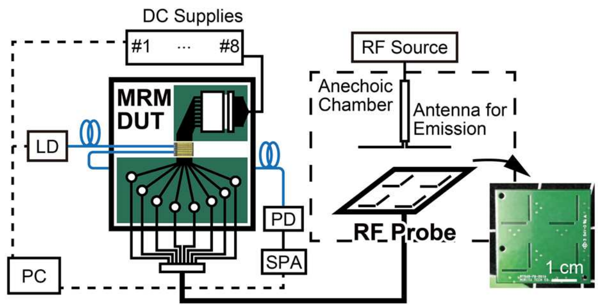

Fig. 1 RoF system for imaging EM waves.

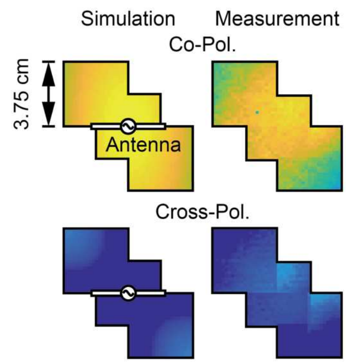

Fig. 2. Experimental setup for EM wave imaging.

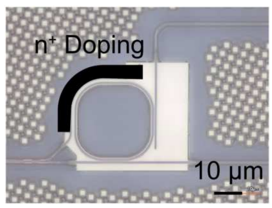

Fig. 3. Fabricated MRR type optical control device.

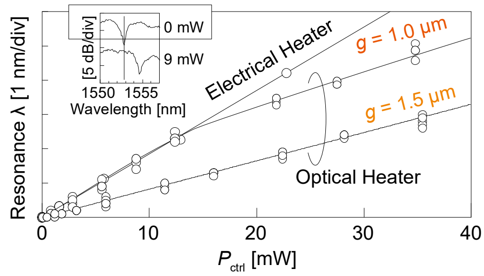

Fig. 4. Resonance tuning characteristics as a function of control power. The inset shows examples of resonance spectrum.

The variable g in the figure refers to the gap between the MRR and the optical control waveguide. The resonance switching operation was available when P_{ctrl} was approximately 5 mW.

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III. All Optic Control of MRMs

Based on the aforementioned concepts, we propose and design a MRM that can be tuned using optical heaters. The model is shown in Fig. 5(a). The basic concept is that one MRM is sequentially selected from an MRM array using control light power and modulate the incident light near the laser wavelength. Control light (red arrow) is injected into the upper common control waveguide and is partially absorbed in each highly doped region. Let us consider four MRMs as an example. When control light is OFF, the output spectrum of the bus waveguide is as shown at the top of Fig. 5(b), where all the resonant wavelengths of MRMs are almost aligned. When control light power is increased, each MRM is sequentially heated, and each transmission spectrum changes as shown in Fig. 5(b). When the control power required to shift the resonance wavelength of one MRM by Δλ as ΔP. Therefore, the total control power required to shift the fourth MRM by Δλ is $10\Delta P$. With appropriate design, it is expected that all four MRMs can be sequentially tuned to the laser wavelength, and each MRM can be selected for transmitting modulated signals.

To obtain such operation in the MRM array, the power transmittances a_1–a_4 at the optical heater in the control waveguide must satisfy the following condition:

$$\begin{aligned}\frac{\Delta P}{P_{\text{in}}} &= \frac{1}{4}(1-a_1) \\ &= \frac{1}{7}(1-a_1 a_2) \\ &= \frac{1}{9}(1-a_1 a_2 a_3) \\ &= \frac{1}{10}(1-a_1 a_2 a_3 a_4)\end{aligned} \tag{1}$$

where P_{in} is the input optical power. From this equation and a_1–$a_4 < 1$, a_1 must be less than 0.6. Then, the maximum value of ΔP is $P_{\text{in}}/10$. Provided that the maximum input power to Si SSC is 40 mW, the maximum ΔP is 4 mW. To tune the resonance by a HWHM of the resonance (e.g., Q = 3499, HWHM = 0.22 nm), a thermal-tuning efficiency of 0.11 nm/mW is required. Considering the tuning efficiency in our previous work of 0.25 nm/mW [5], the required shift can be achieved reasonably.

Final design of the MRM array with the optical heater is described in Fig. 6(a). The doping profile of the MRM and optical heater are shown in Fig. 6(b). The 10-μm diameter MRM was designed to satisfy the critical coupling condition and have Q = 3500.

IV. Conclusion

This study proposes an all-optic tuning MRM array, which combines two concepts to achieve remote control of RoF devices at far distance. The optical heater eliminates the need for electrical heaters and wiring, reducing the complexity of the system. The RoF system can be free from the constraint of electronics with the optical heater and directly integrated millimeter-wave antennas adjacent to the MRMs on the same chip.

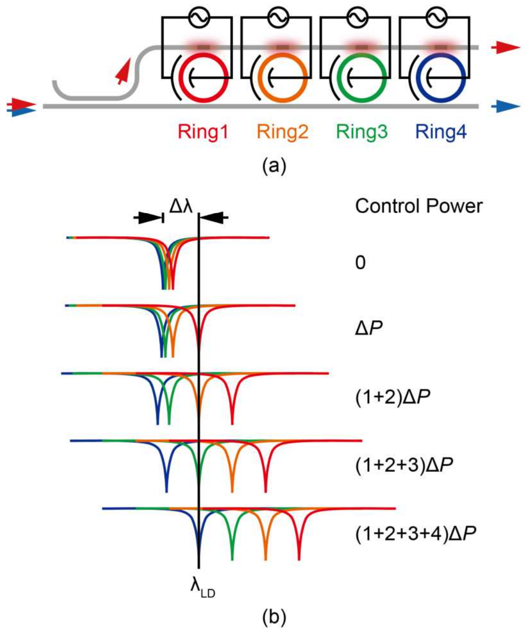

Fig. 5 (a) Fundamental concept of optical controllable microring modulator (array). The rings are heated by optical power absorption in the heavily n+ doped region. (b) The resonances shift to the wavelength of laser by adopting appropriate control power so that each MRM can be selected.

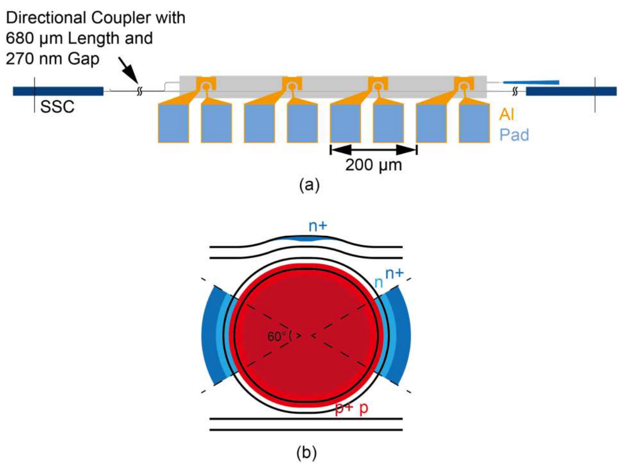

Fig. 6 (a) CAD of designed optical control MRM. (b) Doping configuration of proposed MRM.

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