B-2-04
Extended Abstracts of the 2019 International Conference on Solid State Devices and Materials, Nagoya, 2019, pp73-74

Crossbar array of Si microring resonators for deep learning accelerator

Shuhei Ohno, Kasidit Toprasertpong, Shinichi Takagi, and Mitsuru Takenaka

Department of Engineering and Information Systems, School of Engineering, The University of Tokyo
7-3-1, Hongo, Bunkyo-ku
Tokyo 113-8654, Japan
Phone: +81-3-5841-6733 E-mail: ohno@mosfet.t.u-tokyo.ac.jp

Abstract

We propose a deep learning accelerator scheme on a Si photonic platform that uses microring resonator crossbar array. The drop operation of the microring for multi-wavelength optical signal enables the multiply operation in optical domain. We numerically revealed optical neural network based on the proposed Si photonic circuit can be used for simple pattern recognition task. We experimentally demonstrated the feasibility of the proposed device.

1. Introduction

Deep learning is one of the most growing technologies in various fields [1]. For further improvement in computation speed and efficiency for learning and inference tasks, a new deep learning hardware is needed to overcome issues in today's von Neumann computing schemes. In particular, optical neural network (ONN) based on Si photonics has recently attracted big attention since simple vowel recognition task with photonic integrated circuit (PIC) composed of cascaded Mach-Zehnder interferometer (MZI) switches was demonstrated in 2017 [2]. However, an MZI switch is not sufficiently small for large-scale integration, making it difficult to realize a practical-size circuit on a single die. In this paper, we focus on microring resonator (MRR) [3] which is smaller than MZI and propose MRR crossbar array for ONN as shown in Fig. 1. We assign a resonance wavelength of each MRR periodically to avoid wavelength contention. When we input multi-wavelength optical signals ($\boldsymbol{x}$ in Fig. 1), an MRR works as multiplier through the drop operation for an assigned wavelength. We can tune each component of a weight matrix (W in Fig. 1) by tuning a resonance wavelength of each MRR with a phase shifter. Finally, all dropped signals are added by converting multi-wavelength optical signals into electric signal using a photodetector (PD). Based on this scheme, the proposed PIC enables the multiply-accumulate (MAC) operation, which can be used as an accelerator for deep learning. We numerically evaluated its capability for training task and experimentally demonstrated simple MAC operation.

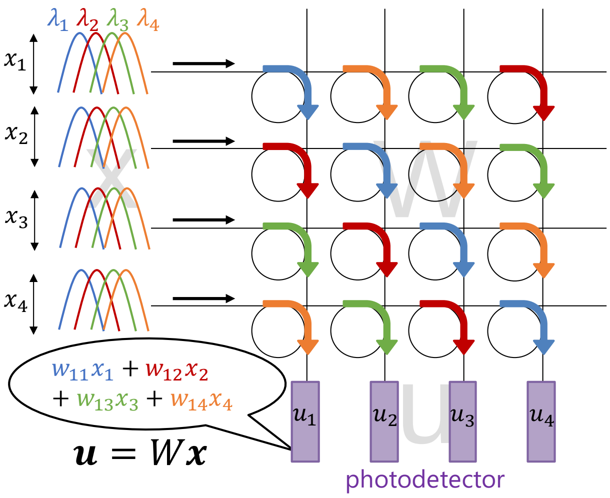

Fig. 1 Photonic integrated circuit for optical neural network using crossbar array of microring resonators.

2. Simulation of training task

We first simulated training of ONN using MRR crossbar array and compared its performance with ONN using cascaded MZI [2] to check its capability. ONN composed of input/output layers and one hidden layer with four neurons were assumed. Iris dataset [4] was used for training data by applying min-max normalization, in which three different types of iris (Setosa, Versicolour, and Virginica) are distinguished by four features (their length/width of sepal and petal). Procedure of training was same as [2]. Theoretical equations of optical transformation of MZI and MRR were referred from [2] and [3] respectively. Figure 2 shows simulation result of training. As shown in the figure, the correct rate of the MRR-

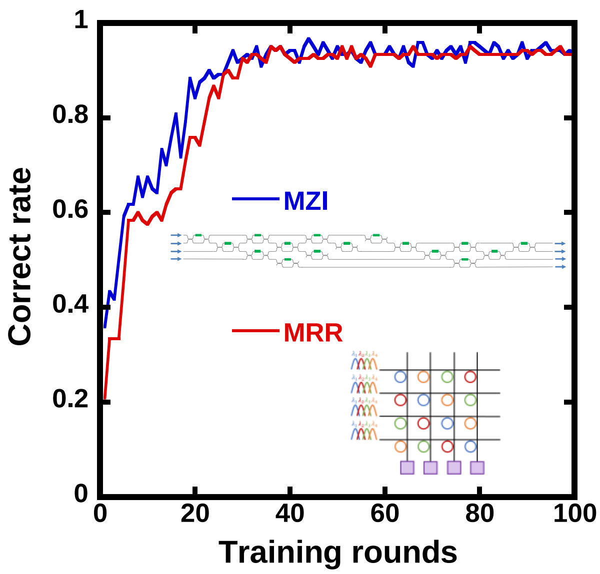

Fig. 2 Training simulation of ONN implemented with MZI switch (blue) and MRR (red). Insets are schematics of assumed PICs.

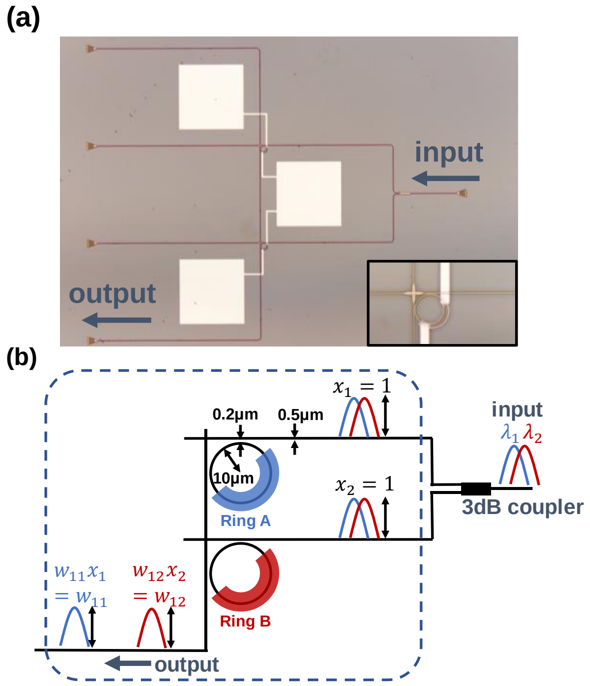

Fig. 3 Test device for demonstration of MAC operation. (a) Plan-view photograph. Inset is an enlarged view of MRR. (b) Schematic of MAC operation.

based and MZI-based circuits reached almost same value (~0.95). Thus, we numerically revealed that ONN using MRR crossbar array can be used for deep learning.

3. Demonstration of MAC operation

For the feasibility study of MAC operation of the proposed circuit, we fabricated a test device as shown in Fig. 3 (a). An SOI wafer with a 220-nm-thick Si layer was used for fabrication. Si strip waveguides were formed by electron-beam (EB) lithography and dry etching with SF_6 and CHF_3. After SiO_2 passivation, tungsten heater was formed on each MRR as a thermo-optic phase shifter. Grating couplers were also integrated for optical coupling between a Si waveguide and a cleaved optical fiber. As an inset of Fig. 3 (a), a waveguide crossing which consists of four eclipses [5] was employed to reduce diffraction loss and crosstalk.

The schematic of this device is presented in Fig. 3 (b). Two MRRs in the device were set to have different resonance wavelengths for MAC operation. Because of restriction of measurement system, multiple inputs were implemented using 1 × 2 multimode interference (MMI) coupler. By input optical signal which consisted of two resonance wavelengths of the MRRs, the results of MAC operation (as $w_{11}x_1 + w_{12}x_2$ in Fig. 3 (b)) can be obtained by detecting the output signal. In this experiment, we used an optical spectrum analyzer to integrate the two wavelength signals instead of a PD.

Figure 4 shows the output spectra when applied voltages to Ring A and B were varied to set w_{11} and w_{12}. As shown in Fig. 4(a), w_{11} can be tuned independently by changing an applied voltage for Ring A. w_{12} can also be tuned similarly as shown in Fig. 4(b). Assuming $x_1 = x_2 = 1$, the test device can compute MAC operation in a range of $0 \leq w_{11}x_1 + w_{12}x_2 \leq 2$ by normalize these outputs (It means matrix element can be tuned as $0 \leq w_{11}, w_{12} \leq 1$).

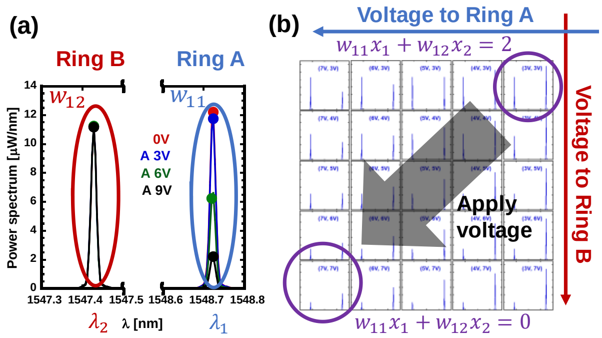

Fig. 4 Measured output spectra of test device. (a) Sweeping voltage to phase shifter of Ring A. (b) Sweeping voltages to phase shifters of Ring A and Ring B.

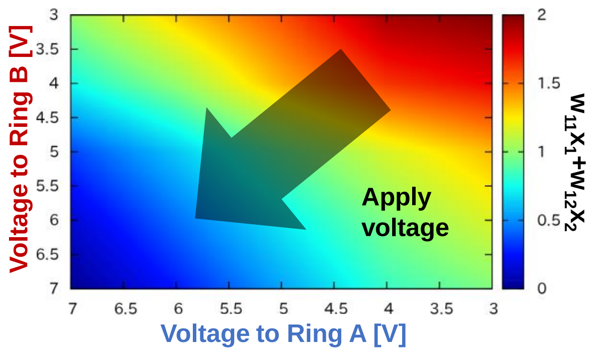

Fig. 5 MAC operation result calculated from Fig. 4 (b).

Figure 5 shows results of MAC operation computed in the above procedure. As applying voltages to Ring A and B, the output was shifted from 2 (Red) to 0 (Blue) almost linearly. Thus, we successfully showed the feasibility of MAC operation using the MRR crossbar array.

4. Conclusions

We have successfully demonstrated the concept of MRR crossbar array on Si photonics platform for ONN. Since a 1MRR is much smaller than an MZI switch, the proposed MRR crossbar array is promising for building large-scale ONN for deep learning accelerator.

Acknowledgements

This work was partly commissioned by the New Energy and Industrial Technology Development Organization (NEDO).

References

[1] D. Silver *et al.*, Nature **52** (2016) 484.
[2] Y. Shen *et al.*, Nat. Photon. **11** (2017) 441.
[3] W. Bogaerts *et al.*, Laser & Photonics Reviews **6** (2012) 47.
[4] R. A. Fisher, Annals of eugenics **7** (1936) 179.
[5] F. Shinobu *et al.*, Electronics Letters **46** (2010) 1149.