Optical Routers based on Microring Resonator for Optical Networks-on-chip

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Abstract— **Optical technology has boosted the revolution of Optical Networks-on-Chip (ONoC). In this paper, a passive microring resonator (MRR) semiconductor switching element is proposed. The design of a resonator router based on high-order of microring resonators is demonstrated in Silicon-on-Insulator (SOI). The suitability of the MRR as the basic building block for ONoC applications was investigated based on the insertion loss, extinction ratio (ER) and FSR. This model was designed on the silicon and modeled using COMSOL software. The result shows that excellent performance was achieved with huge FSR, low insertion loss, 3-dB bandwidth of less than 2nm and high extinction ratio.**

Index Terms— **Silicon photonic, microring resonator, optical filter.**

I. INTRODUCTION

Electrified by silicon photonic technology, Optical Networks-on-Chip (ONoC) has the potential to be the key emerging technology in communication industries. Chip-scale photonic interconnection networks has gained explosive interest with the recent demonstrations of silicon-on-insulator (SOI) based photonic modules such as lasers, modulators, wavelength division multiplexing (WDM) filters and many others [1-3]. ONoC is a novel technology that overcomes the bottleneck in traditional electrical interconnections such as the inability to support higher data rates, limited bandwidth, poor scalability and high power consumption [4]. The state-of-art ONoC is an on-chip photonic interconnection network which is composed of silicon and optical routers [5]. A potential element in silicon photonic technology which can be served as a router is an optical resonator, which enables the switching functionality to routes data packets between a set of input and output ports. Thus, they become a crucial building block to create switching elements in on-chip optical interconnection networks.

Optical resonator architectures have been proposed as a main switching element or optical router by previous researches [6, 7]. Optical network on chip architecture mainly consists of three blocks: transmitter, optical router and receiver, as shown in Figure 1. The transmitter, which input is from generic NoC protocol converter (GNoCPC) converts electrical signal to optical signal and the receiver transforms the signal back to electrical signal. The microring resonator architecture studied in this research is proposed to be applied in the optical router block, served as a routing element.

In this paper, we focus on the development of microring based optical wavelength router for passive ONoCs.
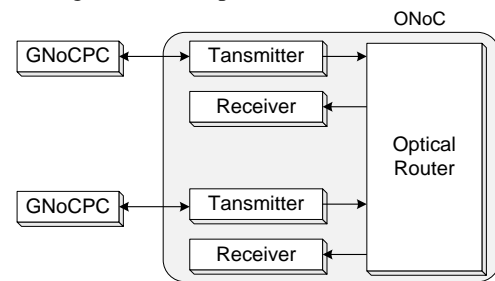

Figure 1: Architecture of Optical Network-on-Chip [8].

II. THEORY

The mechanism of a microring resonator as the switching element can be explained by referring to Figure 2. In ONoC applications, an incoming optical signal from the transmitter can be either evanescently coupled to the ring waveguide (if the signal is ON the resonance state) and exited at the drop port or it can travel along the straight waveguide and pass the signal to the through port (OFF resonance state). This mechanism permits the switching function where input signal can be routed to a different output port, depending on the ring resonance wavelength.
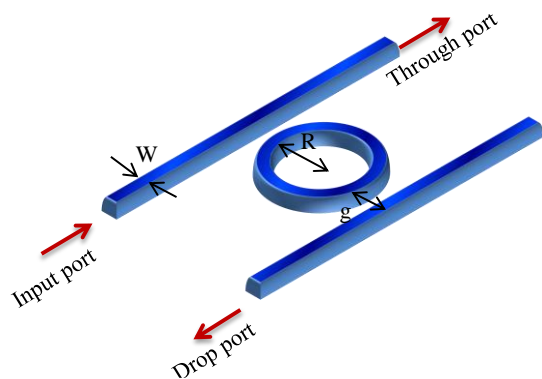

Figure 2: Schematic layout of the single MRR

The design parameters for the proposed MRR are listed as in Table 1. Silicon-on-Insulator (SOI) has been chosen as the

platform for design construction with silicon dioxide as insulator. The refractive index for silicon and silicon dioxide is 3.47 and 1.47, respectively. SOI has been chosen as it can be easily integrated with other photonic devices and mature fabrication process [9-10]. Other design parameters considered are W, R and g, where W is the width of waveguides, R is ring radius and g is gap separation between the ring and the straight waveguides. P_{in}, P_{drop}, $P_{through}$ and P_{add} are the four ports for the four terminal MRR, which includes input port, drop port, through port and add-drop port, respectively.

Table 1
Design Parameters

Parameters	Value
Gap size between the ring and straight waveguide, g	100 nm
Ring radius, R	4.5 µm
Waveguide width, W	300 nm
Refractive index of Silicon, n_{si}	3.47
Refractive index of Silicon Dioxide, n_{sio2}	1.47

In order to investigate the device performance of higher order parallel cascaded MRR, different MRR configurations were studied, which are the 1st, 2nd and 3rd order of MRR. Coupled MRRs can be realized in either a serial or parallel cascaded configurations. In this paper, the topology of higher order MRR is illustrated as in Figure 3 by considering the parallel coupling for double and triple MRR, where the microrings are only coupled to bus waveguide but not to each other.
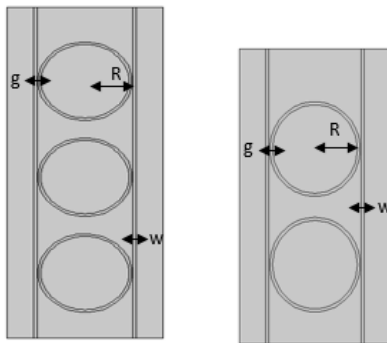

Figure 3: Schematic layouts of the 3rd and 2nd order MRRs.

As listed in Table 1, the three parameters that have a huge effect on the design performance are the ring radius (R), gap separation between the ring and the straight waveguide (g) and waveguide width (W). In this work, TE-light was propagated in the waveguide in a range of 1530-1610 nm, which is in the range of C-band wavelength.

The characterization of the MRR performance was based on three parameters: the free spectral range (FSR), insertion loss (IL) and extinction ratio (ER). FSR is the difference between two successive peaks of resonance and is given by [11]:

$$FSR = \frac{\lambda_o^2}{n_g L} \qquad (1)$$

where n_g is the group index, L is the physical path length.

ER is the terms of quality that determines the through-port output power. It is defined as the minimum power of the through-port at resonance with respect to the off-resonance power. The impact of ER on communication system's performance is very important. As ER improves, the crosstalk will be minimized and the bit-error ratio (BER) can be improved. As a result, the number of errors is reduced. ER is defined as the ratio between the output and the input power. In addition, IL is the ratio between the received and input power.

The quality factor (Q-factor) is important in analyzing the spectral range of the resonance condition for MRR. The quality factor reflects the amount of the losses in MRR, where large losses produce low Q- factor. However, in this paper, the effect of Q-factor is neglected.

III. RESULT AND DISCUSSION

The simulation was done with 1st, 2nd and 3rd order of MRR parallel cascaded microrings. The first investigation was carried out to ensure the proposed designs resonate at a certain wavelength. From the simulation, it was observed that the signal resonates at 1562 nm, where it is in the range of C-band wavelength. Figure 4(a) depicts the MRR in OFF resonance state, while Figure 4(b) in ON resonance state for single MRR configuration.

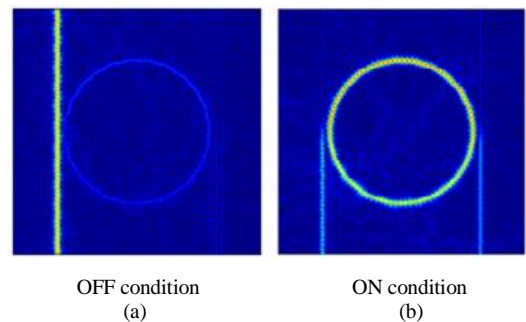| OFF condition	ON condition
(a)	(b)

Figure 4: Single MRR conditions

Meanwhile, Figure 5 and 6 present the 2nd and 3rd order MRR configurations where the microrings are in OFF and ON resonance. In these parallel cascaded coupled microring configurations, each mirroring acts as a reflection component. The phase connection among the reflected signals from each microring will be contributed to the filter response, especially in terms of ER.
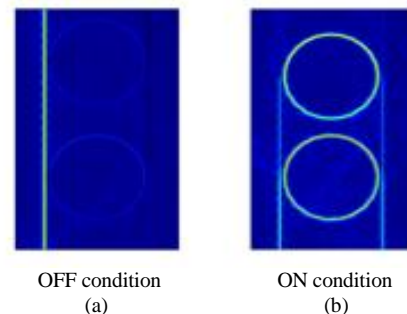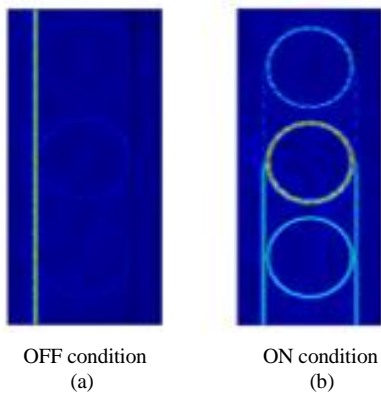

OFF condition	ON condition
(a)	(b)

Figure 5: 2nd order MRRs conditions

OFF condition   ON condition
(a)   (b)

Figure 6: 3rd order MRR conditions

Figure 8: IL for each configurations of MRR

Some of the performance indicators such as the ER, IL and FSR were analyzed to determine the achieved performance in the device. Figure 7 portrays the filter response of the 1st, 2nd and 3rd order of MRR microrings. The results of the simulation showed the improvement of the extinction ratio with an increase in the rings number. For the 1st order MRR, at the wavelength 1606 nm, the extinction ratio was ~25 dB, meanwhile the 2nd order MRR was ~27 dB and the 3rd order MRR was ~40 dB. This simulation results confirmed with the theory by [11]. The author claimed that high ER is important in WDM applications, and more than 30 dB can be achieved with cascaded MRR.
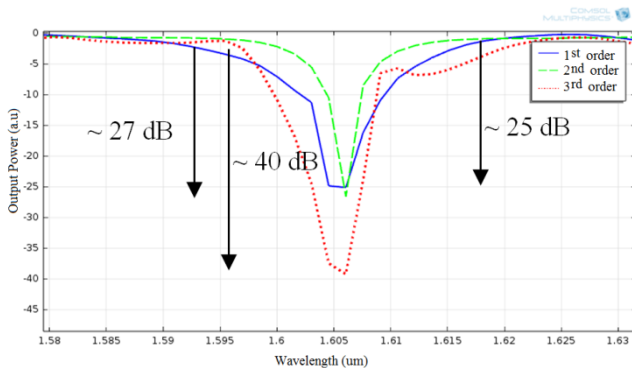

Figure 7: ER observed at through-port

In addition, according to transmission spectrum at drop-port in Figure 9, the 3-dB bandwidth can be determined. The resonant wavelength centered at 1562 nm exhibited a 3-dB bandwidth of less than 2 nm which is required by WDM systems.

Figure 9: Transmission spectrum of higher order MRR

The result of the IL analysis is shown in Figure 8. It can be observed that IL is becoming poor as the ring number is added. For example, IL of the 1st order MRR was 0.1 dB as compared to the 3rd order MRR was 0.35 dB. Nevertheless, the loss is still within the acceptable range where the maximum allowable loss for high speed transmission is 0.5 dB [12]. It is strongly followed by the theory [13] stated that in terms of insertion loss, there is an increasing loss between the 1st order and the 3rd order microrings due to the longer transmission length.

Two successive peak or FSR also can be observed from Figure 9. It is noticeable that wide FSR was achieved with 42.5 nm for each design, respectively. For comparison, it is noted that FSR should be equal or has a very slight difference for each structure and this results are strongly verified by theory [13]. It is interesting to note that this large FSR increases the quality of MRR due to the fact that FSR is related to the device finesse calculation.
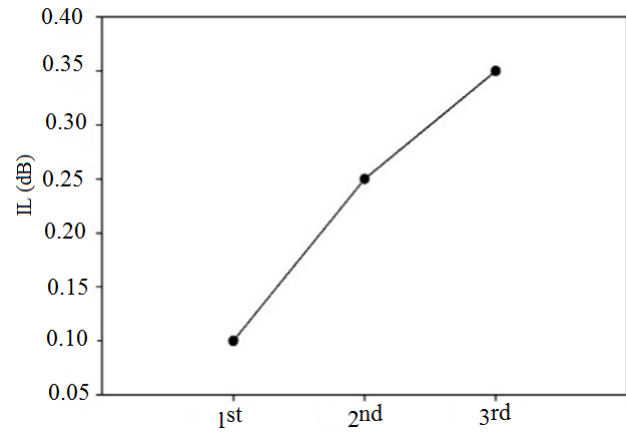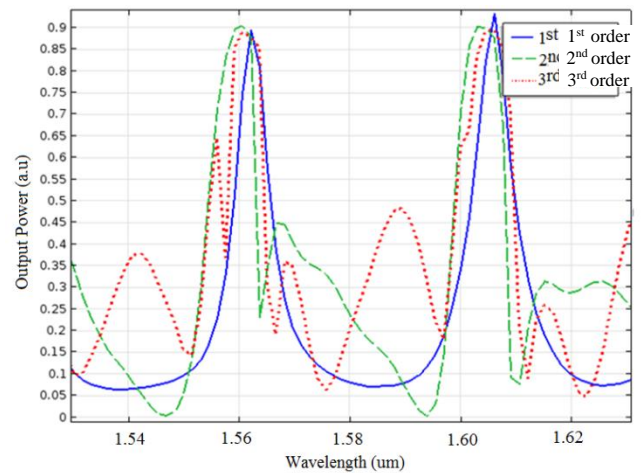
IV. CONCLUSION

We have demonstrated a simple configuration and compact integrated MRRs in SOI material to be considered as a basic building block for ONoC applications. The results verified that it is suitable to be implemented in high speed optical communications link with the FSR of 42.5 nm, low insertion loss of < 0.5 dB, 3-dB bandwidth of <2nm and high extinction ratio of ~40 dB.

REFERENCES

[1] A.A. Nadia, H. Hazura, A.R. Hanim, "The Potential of Silicon Photonic Devices based on Micro-Ring Resonator," in *Journal of Telecommunication, Electronic and Computer Engineering (JTEC)*, vol 7(1), 2015, pp. 17-20.

[2] H. Haroon, S. Shaari, P.S. Menon, H. Abdul Razak and M. Bidin, "Application of statistical method to investigate the effects of design parameters on the performance of microring resonator channel dropping filter", *International Journal of Numerical Modelling: Electronic Networks, Devices and Fields*, vol 26, no 6: 670–679. doi: 10.1002/jnm.1899,2013.

[3] M.Savanier, R. Kumar, and S. Mookherjea, "Photon pair generation from compact silicon microring resonators using microwatt-level pump powers", *Optics Express*, 24 (4), 2016, pp. 3313-3328.

[4] Y. Chen, H. Zhang, F. Liu and H. Gu, "An optimization framework for routing on optical Network-on-Chips (ONoCs) from a networking perspective", *2015 IEEE International Conference on Signal Processing, Communications and Computing (ICSPCC)*, 20   15, pp. 1-5.

[5] Xianfang Tan, Mei Yang, Lei Zhang, "A Generic Optical Router Design for Photonic Network-on-Chips', *Journal of Lightwave Technology*, Vol. 30, No. 3, February 1, 2012, pp. 368-376.

[6] Atef Allam, Ian O'Connor, Alberto Scandurra, Optical network-on-chip reconfigurable model for multi-level analysis, in: *Proceedings of IEEE International Symposium on Circuits and Systems, ISCAS*, 2010, pp. 3609–3612.

[7] M. Briere, et al., System level assessment of an optical NoC in an MPSoC platform,in: *Proceedings of International Conference on Design, Automation and Test in Europe*, 2007.

[8] Suvarna S. Patil , Bharat S. Chaudhari, Baojun Li," Coherent crosstalk in passive microring based Optical Networks-on-Chip, *Optik 123 (2012)*, pg. 2204– 2207

[9] H Hazura, AR Hanim, B Mardiana, S Shaari, PS Menon, "Free carrier absorption loss of pin silicon-on-insulator (SOI) phase modulator," *American Institute of Physics Conference Series*, vol. 1341, pg. 241-244, 2011.

[10] AR Hanim, B Mardiana, H Hazura, S Saari, "On the modulation phase efficiency of a silicon pin diode optical modulator," *2010 International Conference on Photonics (ICP)*, Langkawi, Malaysia, pg. 1-3, 2010.

[11] Zen Pheng, "Coupled Multiple Micro-Resonators Design And Active Semiconductor Micro-Resonator Fabrication", *Thesis Dissertation University Of Southern California*, 2007.

[12] Van Thourhout, D., Spuesens, T., Liu, L., Roelkens, G., Kumar, R., Morthier, G., Rojo-Romeo, P., Mandorlo, F., Regreny, P., Raz, O. and Kopp, C., 2010. Nanophotonic devices for optical interconnect. *IEEE Journal of Selected Topics in Quantum Electronics*, 16(5), pp.1363-1375.

[13] Y. B.E. Little, S.T. Chu, H.A Haus, J.Foresi, and J-P. Laine, "Microring Resonator Channel Dropping Filter", *J.of Lightwave Technol.*, 15 1997, pp. 998-1050.