

# SOI Rib Waveguide Physical Dimension Dependent Micro Ring Resonator Characterization

A.T.C.Chen\*, M. Rakib Uddin\*\*

\*Department of Electrical and Electronic Engineering, Universiti Teknologi Brunei (UTB), Gadong, Brunei Darussalam

\*\*Department of Electrical and Electronic Engineering, Universiti Teknologi Brunei (UTB), Gadong, Brunei Darussalam  
[angie\\_teo236@hotmail.com](mailto:angie_teo236@hotmail.com) , [rakib.uddin@utb.edu.bn](mailto:rakib.uddin@utb.edu.bn)

**Abstract**— Design and simulation of rib waveguide physical dimension dependent Micro Ring Resonator (MRR) is demonstrated in this paper. In here, the analysis of the effects of SOI rib waveguide dimension is studied which included the width and height of the core/ring, height of rib and height of buried oxide. This analysis is crucial as it provides an initial reference point with regards to varying waveguide dimensions where future research designers can study and make fundamental decisions in designing effective and reliable photonic devices such as optical filter. During fabrication work, the actual device performance might vary from the initial design performance, therefore performing simulations is important to determine the effects of varying dimensions to determine the actual fabricated device outputs. Results shows the performance characteristics of MRR varies significantly when there is a waveguide dimension variation. Based on the simulation results, it is seen that as we increased the width of the core, FSR increased and FWHM decreased as we increased the height of the core and the rib. While Q-factor increased as core and rib height increased. It is also deduced that percentage variation between all different dimensions are less than 30% except for height of buried oxide in which there is no percentage change. However, Q-factor remains at 1573 as we increased buried oxide height. Thus, the dimensions of the SOI waveguide is chosen to be at a core width of 450nm, a core height of 210nm and a rib height of 70nm.

**Keywords**—Rib waveguide, MRR, FSR, FWHM and Q-factor

## I. INTRODUCTION

In photonic integrated circuits (PICs), silicon photonics have become one of the most encouraging platforms due to CMOS compatibility and high integration density [1,2]. In this paper, silicon is used due to its exclusive characteristic of high refractive index contrast which allows the production of sub micrometer waveguide dimensions with tight bends and close spacing [3,4]. In photonic integration, a micro-ring resonator is one of the most engaging elements for an extensive application in future optical network such as wavelength division-multiplexing (WDM) add-drop filters, and optical switches or modulator. This is due to its footprint compactness and functional versatility [1,5]. The achievement of optical communication networks had been accomplished using Micro-Ring Resonator which is one of the potential elements in silicon photonics integrated design [6]. The application of MRR includes optical modulator, sensor, multiplexing and

wavelength filter. This is mainly in the interest of its high Q-factor, compact size, and lower consumption of power [1,6,7,8,9]. The competence of MRR to be fabricated on the SOI presents an important potential in integration with CMOS electronics. Therefore, high index contrast devices can be produced with low fabrication cost. Design and optimization of MRR devices had been famously researched in optical field throughout the time. A good performance MRR exhibits the principles of wide free spectral range (FSR), high Q-factor, large extinction ratio and low insertion loss [6,10,11]. The device efficiency is highly relying on structure perfection resulting from the process of fabrication.

## II. MICRO-RING RESONATOR AND IT'S SPECTRAL CHARACTERISTICS

The basic block diagram of MRR is shown in Figure 1 in which a ring waveguide is coupled with two straight waveguides. The working principle of a MRR is stated as follows: Multiple wavelengths will be input into input port. It only allows specific wavelength of light to gets filter from the waveguide instead of moving around the ring and will eventually couple to the second waveguide and leave through the drop port as output. This specific wavelength must satisfy the resonant condition,

$$n_{eff}L = m\lambda_{res} \quad (1)$$

and is known as resonant wavelength.

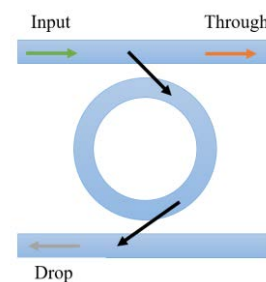


**Figure 1** A basic block of MRR

In order to design MRR with good performance, several important spectral characteristics of MRR must be taken into consideration which are [6]:

1. Free Spectral Range (FSR);
2. Full Width Half Max (FWHM)
3. Quality Factor (Q-Factor)
4. Finesses

A transmission spectrum that depends on coupling coefficient, loss factor and waveguide dispersion is shown in Figure 2.

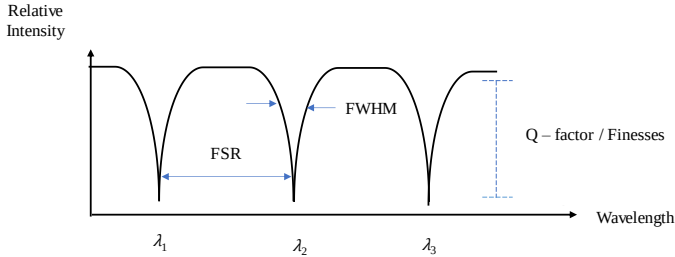


**Figure 2** Spectral responses of ring resonator

**Free Spectral Range:** It can be calculated by the difference between two successive peaks of resonance and the equation is given as follows;

$$FSR = \frac{\lambda_{res}^2}{n_g L} \quad (2)$$

Where, L is the length of the ring =  $2\pi R$ , R is the radius of the ring,  $n_g$  is the group index =  $n_{eff} - \lambda_0 \frac{dn_{eff}}{d\lambda_{res}}$  and  $\lambda_0$  is the wavelength in vacuum.

**Full Width Half Max :** It is defined as the full width at half maximum of one peak and the equation is given as follows;

$$FWHM = \frac{(1-r)a\lambda_{res}^2}{\pi n_g L \sqrt{ra}} \quad (3)$$

Where, r is the self-coupling coefficient and a is the round trip loss coefficient

**Quality Factor:** It is defined as the ratio of resonant wavelength to FWHM and the equation is given as follows;

$$Q - \text{factor} = \frac{\lambda_{res}}{FWHM} \quad (4)$$

**Finesses:** It is defined as the ratio of FSR to FWHM and the equation is given as follows;

$$\text{Finesses} = \frac{FSR}{FWHM} \quad (5)$$

### III. DESIGN OF RIB WAVEGUIDE BASED MICRO-RING RESONATOR

The SOI rib waveguide based micro-ring resonator shown in Figure 3 is designed with a core/ring waveguide width of 450nm and height of 250nm, rib waveguide height of 50nm and buried oxide height of 1000nm. The design and simulation of a ring resonator is carried out by using MODE Solutions.

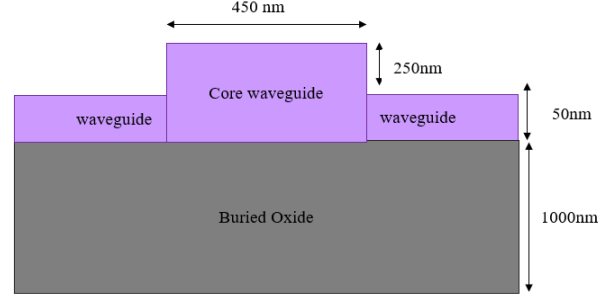


**Figure 3** Cross-section of the rib waveguide based micro-ring resonator

A four-port ring resonator is designed in which the radius of the ring resonator is set to be  $3.1 \mu\text{m}$  with base width of  $0.45 \mu\text{m}$  and base height of  $0.25 \mu\text{m}$ . In this paper, the signal transmitted into the fundamental mode at the through port and drop port can be obtained. Subsequently, the width of the core/ring will be varied from 350nm to 650nm at an interval of 100nm, height of the core/ring will be varied from 190nm to 250nm at the interval of 30nm, the height of rib from 30nm to 90nm at the interval of 20nm and the height of the buried oxide from 500nm to 2000nm at the interval of 500nm. Each of the dimensions will be varied at distinct value with a specific interval and only the results of through port are plotted into graphs. In this paper, Free spectral FSR, FWHM and Q factor are key performance metrics for this silicon on insulator (SOI) based waveguide design. To achieve a good performance of MRR, the MRR must exhibit the characteristics of wide FSR, low FWHM and high Q-factor. The value of wavelength resonance used for calculation of Q factor is dependent on the wavelength selected.

### IV. SIMULATION AND RESULTS

In this section, the width of the core/ring are varied from 350nm to 650nm at an interval of 100nm, height of the core/ring from 190nm to 250nm at the interval of 30nm, the height of rib from 30nm to 90nm at the interval of 20nm and the height of the buried oxide from 500nm to 2000nm at the interval of 500nm in which all other parameters are kept constant. The signal transmitted into the fundamental mode at the through port for various dimensions are shown in Figure 4 to 7, respectively. In this simulation, Q factor is calculated by using this equation as follows:

$$Q - \text{factor} = \frac{\text{resonance}}{FWHM} \quad (6)$$

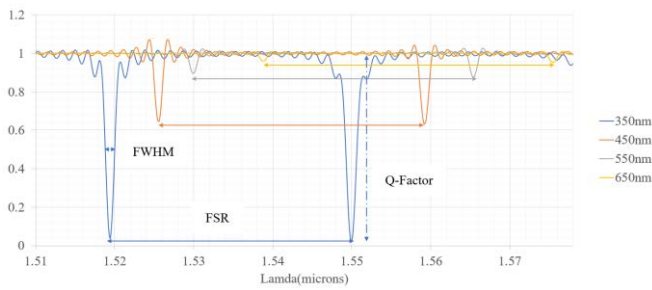


**Figure 4** Through port transmission of varied width of core

From the results in Figure 4, it is seen that as the width of the core increases, FSR increases from 30.7nm to 36.4 nm at a rate of less than 9% per interval. The FWHM for 350nm, 450nm, 550nm and 650nm are 1.35nm, 0.97 nm, 1.17nm and 0.99nm, respectively. As we increased the width of the core by 100nm, the percentage of FWHM between each interval are 28.1%, 20.6% and 15.4%, respectively. Thus, Q-factor for 350nm, 450nm, 550nm and 650nm are calculated to be 1125, 1513, 1308 and 1554, respectively. As we increased the width of the core by 100nm, the percentage of Q-factor between each interval are 25.6%, 15.7% and 15.8%, respectively. Based on the results, it is clearly seen that a compromise must be considered, thus a core width of 450nm is chosen due to the balance criteria (best Q-factor and high FSR with low FWHM).

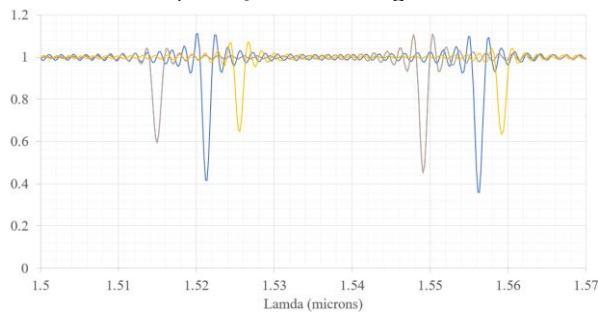


**Figure 5** Through port transmission of varied height of core

As it can be seen from Figure 5, as the height of the core increases, FSR decreases from 35.0nm to 33.6nm at a rate of less than 3% per interval. The FWHM for 190nm, 210nm, 230nm and 250nm are 1.16nm, 0.95nm, 0.95nm and 0.94nm, respectively. As we increased the height of the core by 20nm, the percentage of FWHM between each interval are 22.1%, 0% and 1.1% respectively. As a result, Q-factor for 190nm, 210nm, 230nm and 250nm are calculated to be 1312, 1595, 1595 and 1623, respectively. As we increased the height of the core by 20nm, the percentage of Q-factor between each interval are 17.7%, 0% and 1.7%, respectively. From the results, it is clearly observed that a compromise must be considered, thus core height of 210nm is chosen due to the balance criteria (best Q-factor, high FSR with low FWHM).

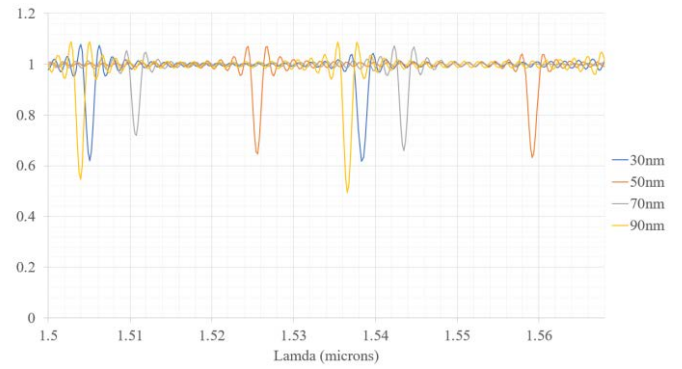


**Figure 6** Through port transmission of varied height of rib

The simulated results in Figure 6 showed that as the height of the rib increases, FSR decreases from 33.3nm to 32.6nm at a rate of less than 3% per interval. The FWHM for 30nm, 50nm, 70nm and 90nm are 1.14nm, 0.97nm, 0.96nm and 0.94nm, respectively. As we increased the height of the rib by 20nm, FWHM decreases by a percentage of 17.5%, 1.0% and 2.1%, respectively. Thus, Q-factor for 30nm, 50nm, 70nm and 90nm are calculated to be 1320, 1573, 1574 and 1600, respectively. As we increased the height of the rib by 20nm, Q-factor increases by a percentage of 16.1%, 0.06% and 1.6%, respectively. Based on the results, it is clearly seen that a compromise must be considered, thus rib height of 70nm is chosen due to the balance criteria (best Q-factor and high FSR with low FWHM).

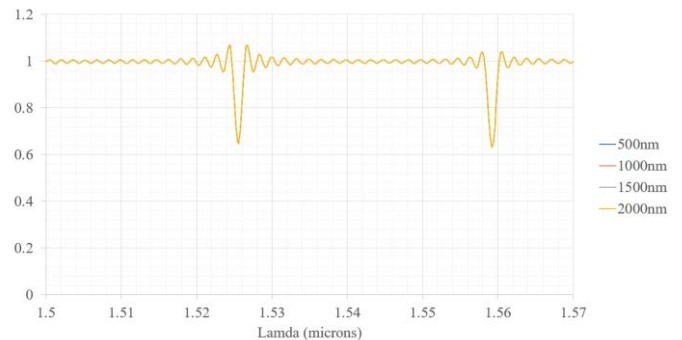


**Figure 7** Through port transmission of varied height of buried oxide

In Figure 7, it is seen that as the height of the buried oxide increases, FSR remains the same at a value of 33.6nm. As we increased the height of buried oxide, FWHM is remains at the same value of 0.97nm while Q-factor is calculated to be 1573. From the results, it is clearly observed that varying in height of buried oxide have no effect on its FSR, FWHM and Q-factor.

## V. CONCLUSION

The rib waveguide based micro-ring resonator on SOI platform has been successfully designed with a core/ring waveguide width of 450nm and a height of 250nm, rib waveguide height of 50nm and buried oxide height of 1000nm. Simulations have

been carried out and the signal transmitted into the fundamental mode at the through port and drop port are observed. Furthermore, simulations on the variation of the width and height of the core/ring, height of rib and height of buried oxide are carried out for the study of the effects of SOI rib waveguide. From the simulation results obtained, FSR, FWHM and Q factor are analyzed. In conclusion, FSR increased as the core width increases and FSR decreases as the core height and the rib height increased. When the width of the core increased, Q-factor initially increased before decreasing and increasing again. As the height of the core and rib increased, Q-factor also increased. Lastly, Q-factor is 1573 as the height of buried oxide is increased. As a conclusion, it is recommended to design a SOI waveguide at the core width of 450nm, the core height of 210nm and the rib height of 70nm in which there is a good compromise between FSR, FWHM and Q-factor.

#### ACKNOWLEDGMENT

We would like to thank Universiti Teknologi Brunei (UTB) for financial support to carry on this research.

#### REFERENCES

- [1] DaJian, L., Chong, Z., Di, L. and DaoXin, D., 2020. Submicron-resonator-based add-drop optical filter with an ultra-large free spectral range. *Optics express*, 27(2).
- [2] A. T. C. Chen, M. R. Uddin and F. K. Law "Dimension Dependent Silicon Photonics Rib Waveguide Characterisation", International Conference of Advanced Communications Technology, February 2020.
- [3] Qin, Y., Yu, Y., Wu, W., & Zhang, X. (2016). Integrated tunable optical add/drop filter for polarization and wavelength multiplexed signals. *Optics Express*, 24(7), 7069.
- [4] W. Bogaerts and L. Chrostowski, "Silicon photonics circuit design: methods, tools and challenges," *Laser Photonics Rev.* 12(4), 1700237 (2018).
- [5] Zheng, S., Chen, H., & Poon, A. W. (2006). Microring-Resonator Cross-Connect Filters in Silicon Nitride: Rib Waveguide Dimensions Dependence. *IEEE Journal of Selected Topics in Quantum Electronics*, 12(6), 1380–1387.
- [6] N. N. A Aziz, H. Haroon and H. A. Razak (2016). "Compact Optical Filter based on Microring Resonator," *ARPN Journal of Engineering and Applied Sciences*, 11(5), 3320.
- [7] H. Jayatilaka, K. Murray, M. Caverley, N. A. F. Jaeger, L. Chrostowski and S. Shekhar (2016). "Crosstalk in SOI Microring Resonator-Based Filters," *Journal of Lightwave Technology*, 34(12), 1.
- [8] M. Prabhu, A. Tsay, Z. Han and V. Van (2010). "Extreme Miniaturization of Silicon Add-Drop Micro-ring Filters for VLSI Photonics Applications," *IEEE Photonics Journal*, 2(3), 3, 436.
- [9] Branislav D. Timotijevic, Graham T. Reed, Richard Jones, Ansheng Liu, Albert Michaeli, and Goran Z. Mashanovich "Optical filters in silicon-on-insulator: design considerations for devices based upon strip and rib waveguides", *Proc. SPIE 6350, Workshop on Optical Components for Broadband Communication, 63500K* (6 July 2006).
- [10] N. A. Cholan, S. Khabollah and R. Talib, "Analysis and design of micro-ring resonator as an add drop filter for Coarse Wavelength Division Multiplexing (CWDM) application," *IEEE International RF and Microwave Conference*, Kuala Lumpur, 2008, pp. 348.
- [11] Hyun-Tae Kim and Miao Yu, "High-speed optical sensor interrogator with a silicon-ring-resonator-based thermally tunable filter," *Optical Letters*. Volume 42, Issues 7, 1305 (2017)



A.T.C.Chen (M'21). Angie Teo Chen Chen was born in Brunei Darussalam on June 23, 1995. She received her BSc in electrical and electronic engineering from Universiti Teknologi Brunei, Brunei Darussalam in 2014. She is currently having her PhD degree in electrical and electronic engineering in Universiti Teknologi Brunei, Brunei Darussalam and started since 2019.

She has three papers in international conference proceedings. She had presented her first paper in Brunei Darussalam for Brunei International Conference on Engineering and Technology (BICET) in 2018. In 2019, she had presented her second paper in Kuala Lumpur for 4th IEEE International Circuit and System Symposium (ICSyS). Her third paper is presented in South Korea for 22nd International Conference of Advanced Communications Technology in 2020. Her research focuses mainly on various nano-scale waveguide structure to see the device performance characteristics by applying her waveguide design variations and characterize the device performance.

Ms. Chen is a member of IEEE. Ms. Chen got her BSc degree with first class honors and received Excellent Student Award from the Ministry of education, Brunei Darussalam. Ms. Chen received UTB Scholarship Award for her programme, PhD in electrical and electronic engineering.



Dr M. Rakib Uddin was born in Bangladesh on February 18, 1978. He received his PhD degree in communication engineering from KAIST, Daejeon, Korea in 2010. He received his MSc in Electrical and Electronic Engineering from Bangladesh University of Engineering and Technology, Dhaka, Bangladesh in 2005 and BSc in Electrical and Electronic Engineering from Chittagong University of Engineering and Technology, Chittagong, Bangladesh in 2002.

He is working as ASSOCIATE PROFESSOR with Electrical and Electronic Engineering Programme Area, University Teknologi Brunei (UTB), Bandar Seri Begawan, Brunei Darussalam since December 2014. He worked for Samsung Electronics/Samsung Advanced Institute of Technology, Hwaseong/Geheung, Korea as research staff Member/Senior Engineer from 2011 to 2014. He worked as Post-doctoral fellowship with KAIST from 2010 to 2011. He has more than 60 articles in international journals and conference proceedings along with seven international patents.

Dr Rakib Uddin is a Senior member of IEEE, USA and Member of IET, UK. He got Korean government IITA full scholarship for his PhD programme from 2006 to 2010 at KAIST. He also got Korean Government Brain Korea 21 (BK21) fellowship for his post-doctoral research with KAIST, Korea. Dr Rakib Uddin received University Teaching as well as Research Excellence Awards in 2017 and 2019 at UTB, Brunei Darussalam.