American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-10, Issue-7, pp: 90-96
www.ajer.org
Research Paper Open Access

Design and Sensitivity Investigation of Microring Resonator at Different Wavelengths and Gaps

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ABSTRACT : *A resonator is such a device that shows resonance or resonant behavior at some frequencies which are called its resonant frequencies, with greater amplitude than at other frequencies. In this paper, an attempt has been taken to design and investigate the sensitivity of a microring resonator by changing wavelengths and varying the gaps between the bus waveguide and the ring waveguide. The resonator has been designed by using numerous kinds of materials and simulated it at different wavelengths using Optiwave Finite-Difference Time-Domain (FDTD) software. This software uses an advanced boundary condition - Uniaxial Perfectly Matched Layer which solves both electric and magnetic fields in temporal and spatial domain. In this work, we also study, in details, the behavior of optical micro-ring resonator, especially when functioning as refractive index sensors.*

KEYWORDS *Resonator, Wavelength, Refractive Index, Sensor, Micro technology, Environment.*

Date of Submission: 29-06-2021 Date of acceptance: 13-07-2021

I. INTRODUCTION

Microring resonators have become a great subject now a day due to its multiple applications in various sectors. An optical ring resonator is an optical element that passes beam by total internal reflection, which can be produced by micro or nano-fabrication technology (Rajib et al., 2016). Optical microring resonators are used as frequency-selective filters (Bogaerts et al., 2012), low-threshold semiconductor lasers, and particularly for sensing applications in early-stage disease diagnosis, security, and environmental monitoring (Darius et al., 2015).

A simple ring resonator comprises of a bus waveguide and ring waveguide. Depending on the coupling techniques, the sizes of the bus waveguide and ring waveguide can vary (Darius et al., 2015). A very basic optical microring resonator is presented at fig.1.

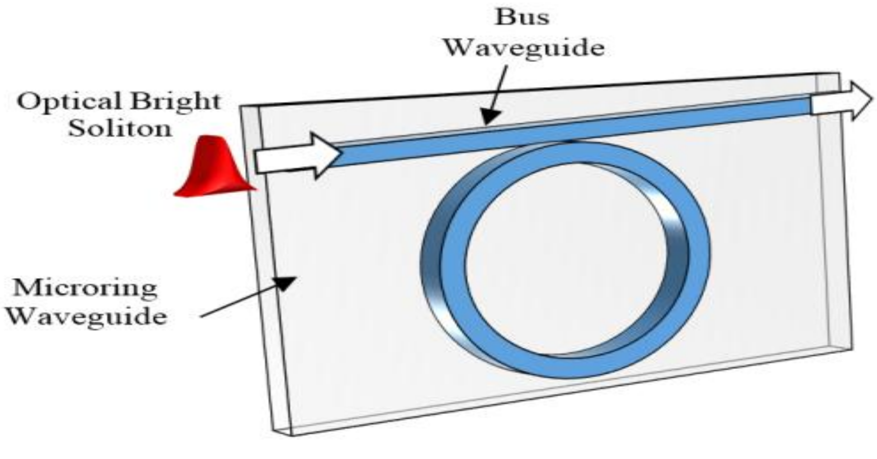

Fig.1. Basic optical microring resonator

There are various types of resonators. Among them, the simplest form of a ring resonator is an all-pass resonator. Such a device is comprised of a ring and a single straight waveguide. These resonators delay signals by storing the incoming optical energy temporarily within the ring. The phase of the transmitted light is not always the same for different frequencies of light, especially those near resonances (Konstantinas et al., 2017).

The Add-Drop Resonators are another type of resonator. This type of resonator contains a ring and two straight waveguides. Here the light with the wavelengths coinciding with the resonances of the ring comes out from the "drop" port (Gomes, 2016).

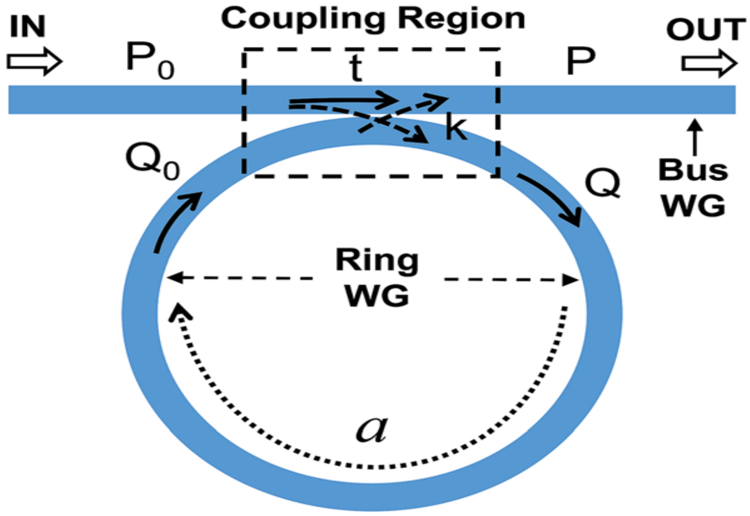

Fig.2. All pass ring resonator

The coupling efficiency of a microring resonator can be enhanced by increasing the coupling length of the ring. One such configuration with the increased coupling length is called a racetrack microring resonator. In this configuration, the coupling region is extended by placing two straight waveguides in the middle of the ring. These extensions increase the coupling efficiency (D. John, 2017).

Fig. 2 illustrates a simple all pass ring resonator. The transmission and coupled power vary with the single round trip amplitude transmission, and transmission co-efficient, variation. Moreover, the coupling length, $L_c = \pi/2k$ determines the transmission or coupling power. In critical coupling, where $a = t$ or $1 - a^2 = k^2$, the transmitted power becomes same as the loss in the ring (Darius et al., 2015). The resonance frequency can be changed by basically expanding or reducing the radius of each ring.

The authors Rajib et al. (2016) in their paper "Optical microring resonator based corrosion sensing" discussed about the theory of microring resonator. They said that a microring resonator is an optical element fabricated by by the process of micro or nano technology and it imprisons light by total internal reflection. It has a bus waveguide and a ring waveguide. Depending on the coupling technique the bus waveguide and the ring waveguide dimension may change. They also discussed that if the refractive index changes then the resonance frequency shift which permits the sensing of small amount of particles.

Bogaerts et al. (2012), in their paper "Silicon microring resonators" have discussed the fundamental theory of ring resonators, and they have applied it to the silicon photonic wire waveguides. The waveguide was small in dimensions and the radius was very tight. The theory is then quantitatively compared. Finally, various applications of ring resonators were discussed at the end.

Darius et al. (2015) have presented and mathematically verified the performance of an optical SOI microring resonator that is decorated with periodically arranged set of gold nanodisks. This resonator has an ultra wide free spectral range. They have shown that the resonator selects a single resonance frequency from a wide range of modes at a particular periodic arrangement of the gold nanodisks. They have simulated it using FDTD simulations as a proof of the concept.

Konstantinas et al. (2017) in their paper "Enhanced sensitivity and measurement range SOI microring resonator with integrated one-dimensional photonic crystal" have presented a SOI microring resonator-based refractive index sensor. The sensitivity is much enhanced and the range of the measurement is also large. They have numerically analyzed the performance of the sensor for different combinations of perforation depth and length maintaining a constant wavelength. They verified their findings both by theoretical analysis and numerical demonstration.

P. C. Gomes (2016) in his thesis paper "AlGaAs Microring Resonators for All-Optical Signal Processing"discussed about the different types of microring resonator.

Trimmer, John D. (2017) in their book "Response of Physical systems" showed a difference between properties and parameters of a system. He said that depending upon the system properties can have all types of dimensions, whereas, parameters are dimensionless, or have the dimension of time or its reciprocal.
The aim of this paper is to design and construct a better sensitive microring resonator and find the wavelength and gap between bus bar and ring at which the microring resonator works better. At first, materials for resonator were chose. Then normalized transmission spectra were simulated for different wavelengths which were then combined in a single simulation module. After that normalized transmission for different gaps were simulated and then conglomerated in a single simulation module as above to get a clear idea from the designed simulation.

II. DESIGN AND SIMULATION

Here, materials having different refractive indices were used in this paper. Such as, SiO2 (silicon dioxide), air and other materials were used. Table 1 represents refractive index of only two materials.

Table 1: List of refractive index of Air and SiO_2

Material	Refractive Index (RI)
Air	1.00
SiO_2	1.45

In this paper, a wavelength in a range between 1330 nm to 1550 nm is used for experiment purposes.
In this design, It was assumed the microring waveguide radius is 5100 (5200) nanometer, microring waveguide width is 420 nanometer, the bus waveguide width is 380 (390) nanometer, and coupling gap is 100 nanometer. The depth of the both waveguide is 1. In this design, SiO2 (Silicon di-oxide) is used as a waveguide material. The refractive index (RI) of SiO2 is 1.45. Air was used as a surrounding material whose refractive index (RI) is 1.

III. RESULT AND ANALYSIS

In this section, the result and the analysis of the designed ring resonator will be discussed. From the Fig. 3 it is seen that, light is coupled to ring waveguide while passing through bus waveguide. This light then rotates in the clockwise direction and then decoupled at the tip with the identical input phase of the incoming light. Here, the electric field distribution, E_y, of the ring resonator at resonance condition is clearly observed. It is clear from the figure that the intensity of light field inside the ring waveguide is lesser than that of the bus waveguide. Perhaps, the critical coupling is occurring within the bus waveguide.

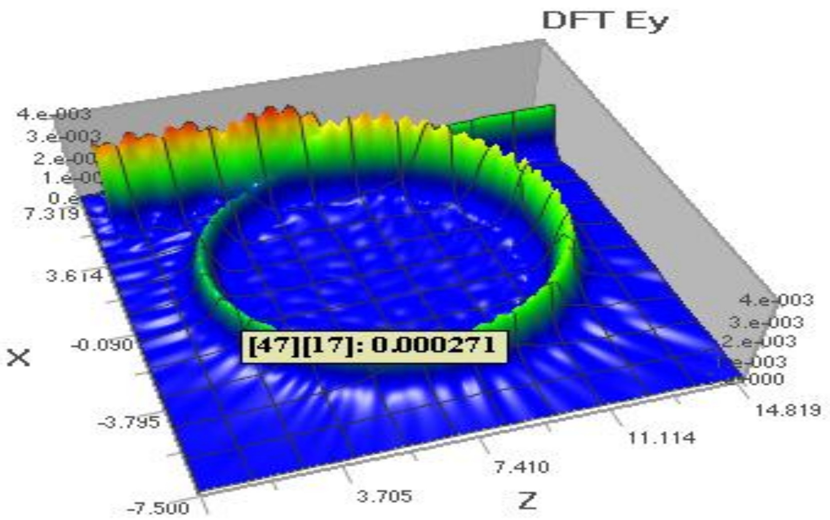

Fig. 3: The E_y field distribution for the ring resonator at resonance condition

In the following figures, the response of the normalized transmission spectra of the microring resonator for various wavelengths is shown in separate diagrams then combined in a single diagram to obtain a clear overview.

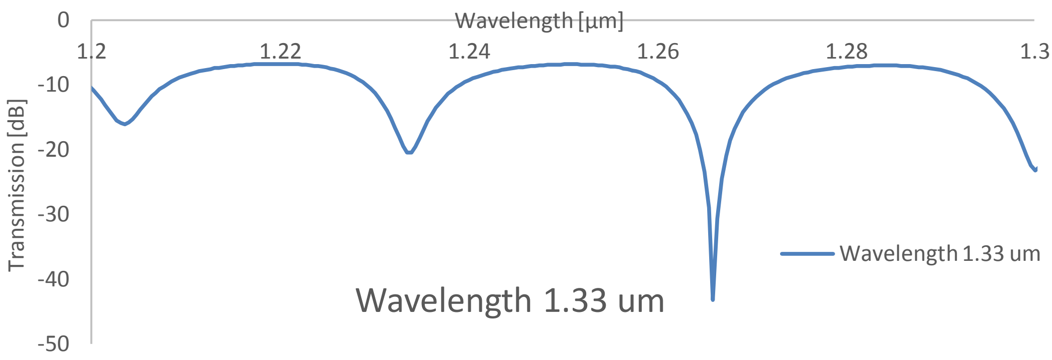

Fig.4. The normalized transmission spectra (dB) for the wavelength of 1.33 µm

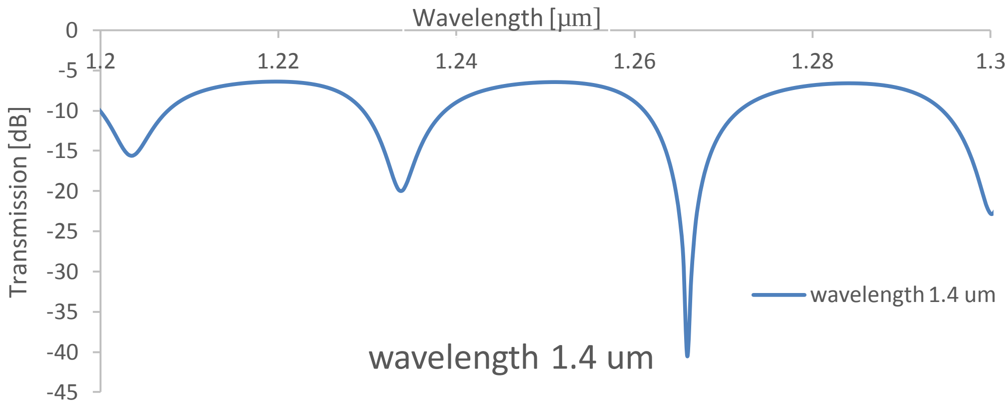

Fig.5. The normalized transmission spectra for the wavelength of 1.4 µm

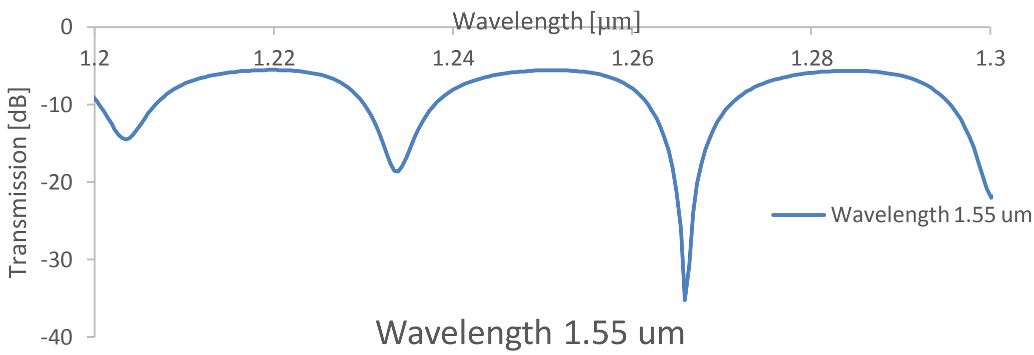

Fig.6. The normalized transmission spectra for the wavelength of 1.55 µm

The response of the normalized transmission spectra of the microring resonator for various gaps between bus waveguide and ring waveguide is shown below.

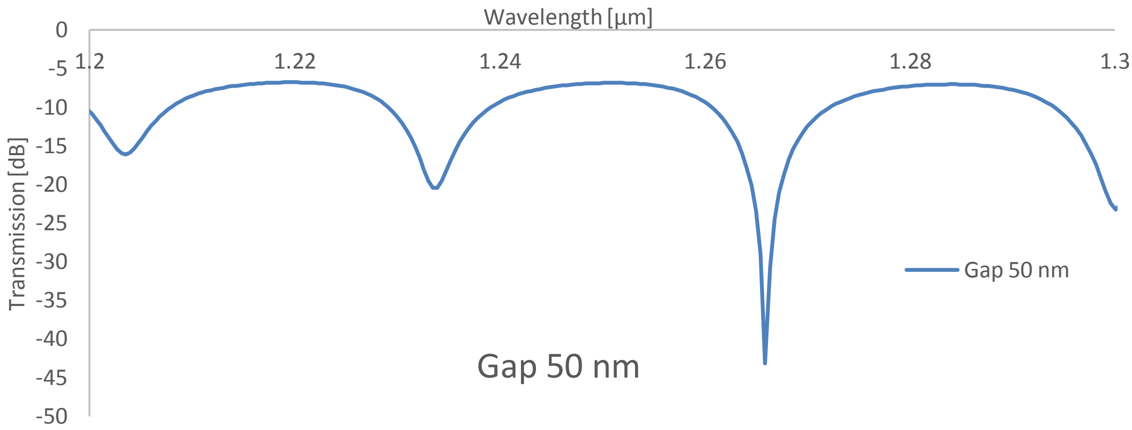

Fig.7. The normalized transmission spectra at the wavelength 1.33µm on 50 nm gap

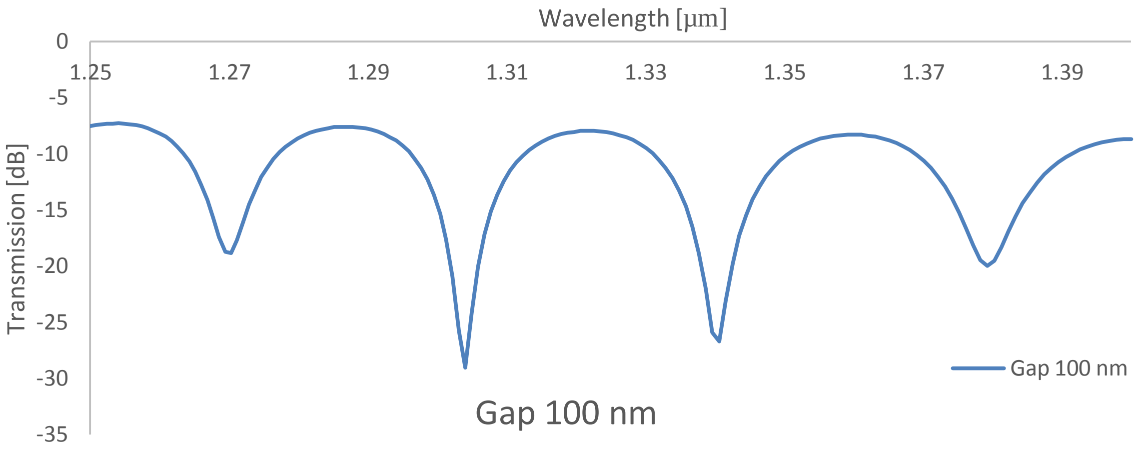

Fig.8. The normalized transmission spectra at the wavelength 1.33µm on 100 nm gap

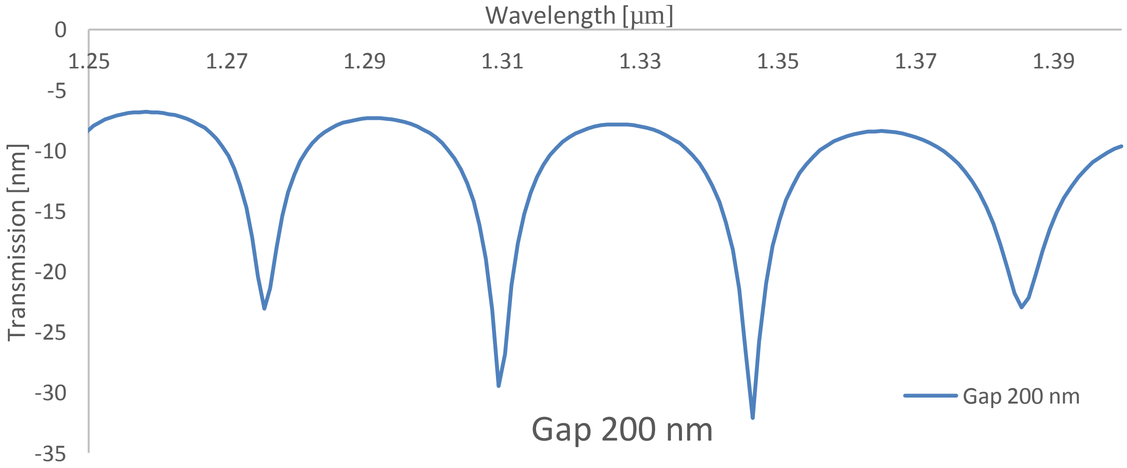

Fig.9. The normalized transmission spectra at the wavelength 1.33µm on 200 nm gap

The response of the normalized transmission spectra of this microring resonator on different wavelengths is shown in Fig.10.

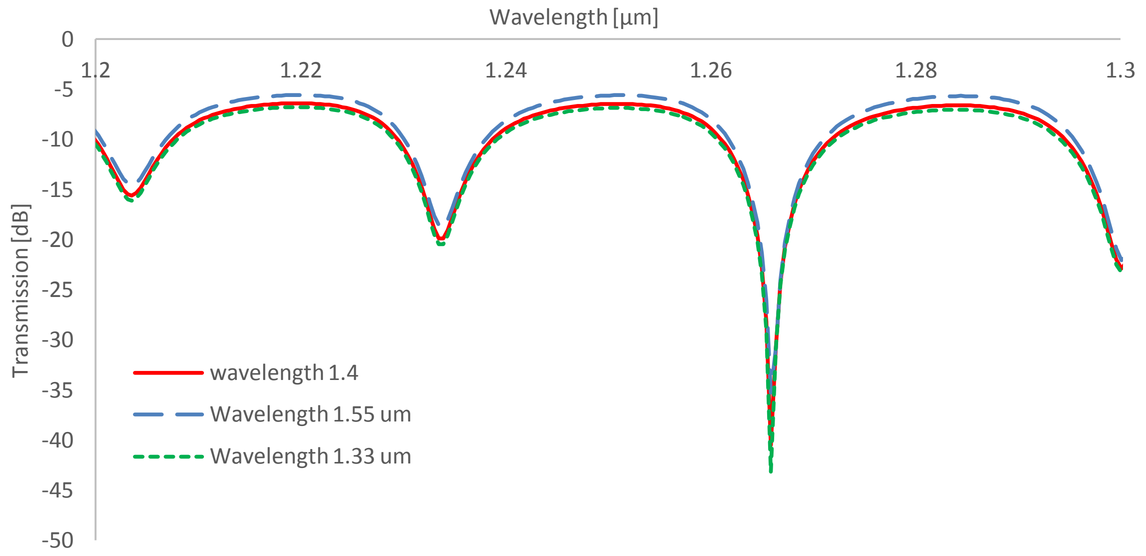

Fig.10. Normalized transmission spectra on different wavelength

Table 2: Normalized transmission spectra on different wavelength

Operating wavelength (µm)	Normalized amplitude (dB)
1.33	-42.04
1.4	-40.70
1.55	-35.60

Here, it is found that the resonance of the microring resonator is better at 1.33 µm than other wavelengths. As the wavelength increases, sensitivity of the resonator decreases.

It is also observed that the microring resonator has different resonances at the same wavelength for different gaps between bus waveguide and ring waveguide. The response of the normalized transmission spectra for the different gaps between bus and ring waveguide is shown in Fig. 11 which is then summarized in Table 3.

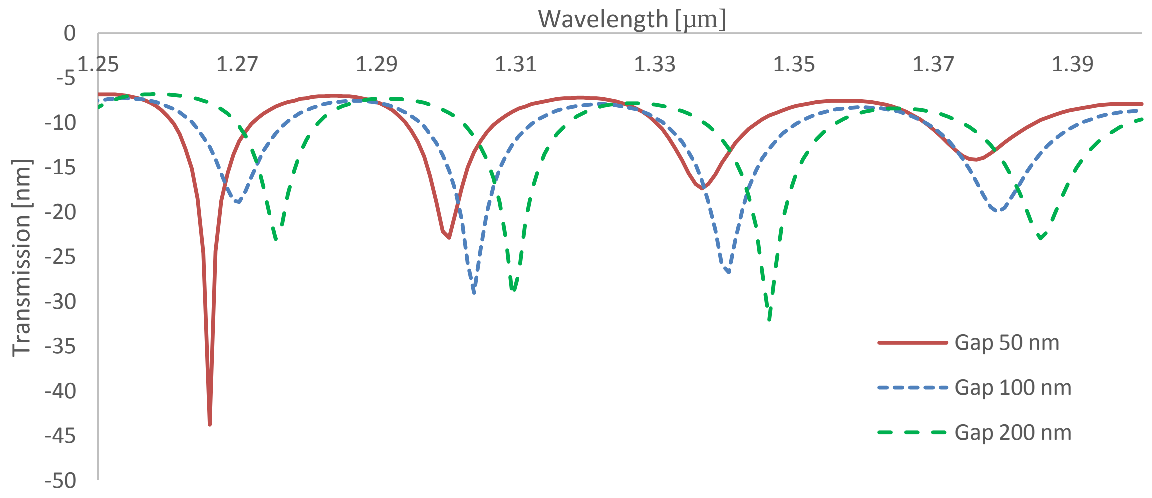

Fig. 11: **Normalized transmission spectra for different gaps between bus and ring waveguide**

Table 3: Normalized transmission spectra for different gaps between bus and ring waveguide

Gap (nm)	Normalized amplitude (dB)
50	-44.04
100	-29.18
200	-32.05

From the table, it is clear that the smaller the gap between the bus waveguide and ring waveguide the higher is the sensitivity of the ring resonator.

IV. CONCLUSION AND FUTURE WORK

The gap between the bus waveguide and ring waveguide plays an important role in measuring the sensitivity. At the end, It can be said that for a specific waveguide materials the sensitivity of the microring resonator strongly depends on the choice of wavelengths of the optical source and the selection of gaps between bus waveguide and ring waveguide. It is found that the lesser is the gap, the better is the sensitivity of the resonator. In this paper, the gap between bus bar and ring waveguide was 50nm. Moreover, the designed resonator performs best at the wavelength of 1.33µ. Future work would be on how to further enhance the sensitivities of the resonator.

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Md. Mahmudul Hasan, et. al. "Design and Sensitivity Investigation of Microring Resonator at Different Wavelengths and Gaps."*American Journal of Engineering Research (AJER)*, vol. 10(7), 2021, pp. 90-96.