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Analysis of gallium nitride-based optical microring resonator with doped polymer grafting material

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ABSTRACT

In this paper, the Gallium nitride-based optical microring resonator (OMR) filter with polymer grafting material (PMMA) coating was designed and optimized to predict its potential as a wavelength filtering device. The optimization was focused on the design parameters such as polymer thickness, gap separation variation, and the bus and ring waveguide widths. The target is to achieve the best output in terms of insertion loss (IL) and Extinction Ratio for wavelength-division multiplexing (WDM) applications, specifically for the use of the C-Band network. Upon completion, it was found that the optimized design was a ring radius of 10 μm and PMMA thickness of 0.055 μm, with the bus waveguide width of 800 nm and the output bus waveguide of 800 nm giving the observed IL of 0.07 dB and 87.3% extinction rate.

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1. INTRODUCTION

The optical microring resonator (OMR) is one of the optical telecommunication components commonly applied as a wavelength filtering function [1], [2]. Gallium nitride (GaN) is a semiconductor material with a large bandgap and is the most widely used material in the semiconductor industry after silicon. In this paper, the design of a gallium nitride-based OMR filter doped with polymer grafting material (PMMA) is reported. The design employed the research studies on the GaN and Sapphire (Al_2O_3) as the add-drop filter of an OMR through the concept of coupling between a straight bus waveguide and a ring waveguide. The waveguide is then doped with the poly(methyl) methacrylate PMMA on top of the design to enhance the device performance [3]-[5].

The material PMMA has been applied as a polymer grafting material in the design of an OMR by many researchers including in the study of synthesized and characterized Sm^{3+-} doped polymer optical waveguide amplifiers [6]-[9], the study of the effect of neutron irradiation on the optical properties of PMMA/RhB used in optical fiber amplification and the study of the effect of rare earth elements on the structural and optical properties of PMMA for possible uses in polymer optical communications [10]-[12].

It is known that Gallium nitride excels better as compared to silicon dioxide (SiO_2) due to its vast features of stunning warm properties, a moderately large bandgap, mechanical hardness, high-temperature dependability, and fantastic communicating range lucidity. GaN also has a lower energy bandgap of 3.4 eV, as compared to SiO_2 of only 1.1 eV. It will potentially serve as the key material for the next generation network of high-frequency and high-power transistors which be able to work at high temperatures, including in the form of light-emitting diodes (LEDs) and laser diodes [13]-[20].

Therefore, this study aims to propose the design of a Gallium nitride-based OMR to evaluate its performance as a wavelength filtering device in terms of insertion loss (IL) and extinction rate. To fulfill the desired application criteria, a thorough study is needed to determine the influence of those parameters. This study provides a guideline for determining the microring geometry to satisfy the desired filtering requirements.

2. RESEARCH METHOD

Figure 1 shows the 3D structure of the proposed optical microring resonator, which consists of a ring waveguide tightly coupled to two straight bus waveguides. The ring radius is represented by *R* and the gap separation is the separation distance between the straight and ring waveguides. The fully etched waveguide structure is taken into account in this study. The output power can be measured using the through and drop ports. For such a design, when the input light wave reaches resonance, it is coupled into the ring waveguide and then transferred to the drop port. On the other hand, if the resonance condition is not met, the light wave is delivered to the through port [21]. Two platforms were studied in this study; one is the conventional Si/SiO_2 platform, while the other one is the GaN/Sapphire platform.

The OMR performance was evaluated using a 3D electromagnetic simulator of the COMSOL software [22], [23]. It requires the user to configure the particular design of the waveguide by setting its length, width, depth, and radius for the waveguides. Then, another block was added as another substrate, which requires detailed attention towards its positioning and orientation, through vector values. Figure 2 depicts the graphic user interface for the component configuration settings.

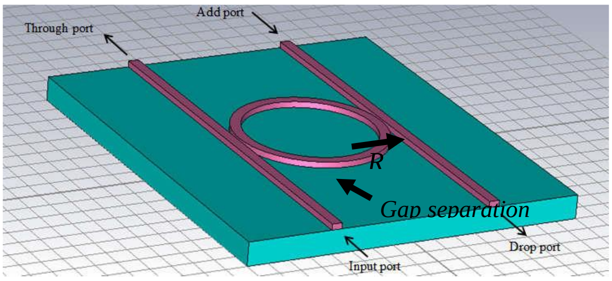
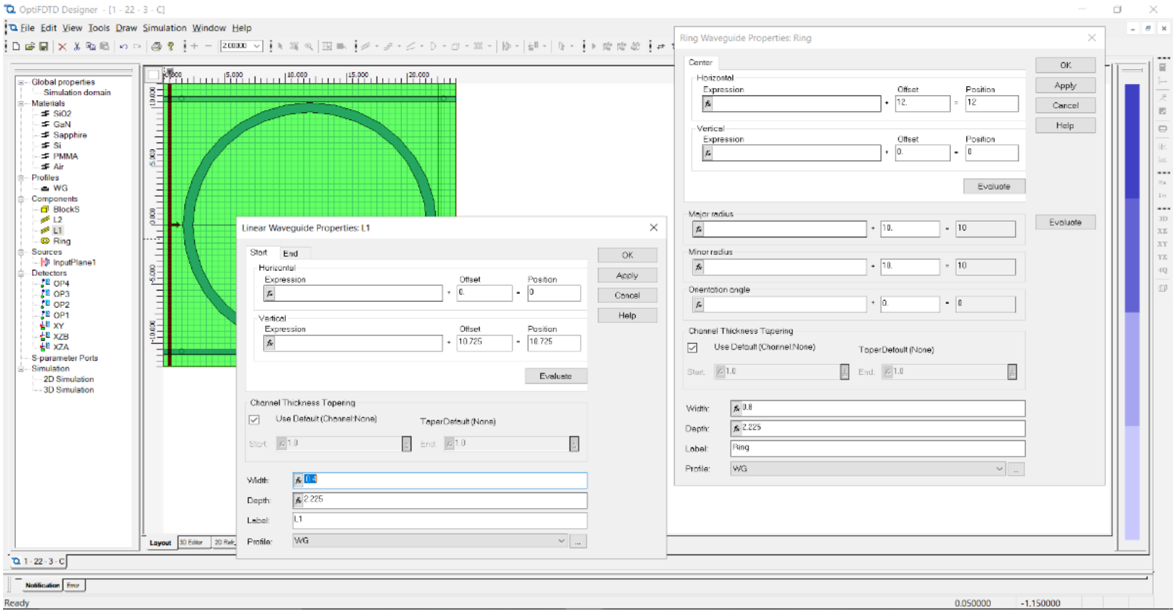


Figure 1. The 3D structure of the proposed optical microring resonator



Linear Waveguide Properties: L1

Start | End

Horizontal: Expression + Offset 0. = Position 0

Vertical: Expression + Offset 10.725 = Position 10.725

Channel Thickness Tapering

☑ Use Default (Channel:None) TaperDefault (None)

Start: 1.0 End: 1.0

Width: 0.4

Depth: 2.225

Label: L1

Profile: WG

Ring Waveguide Properties: Ring

Center

Horizontal: Expression + Offset 12. = Position 12

Vertical: Expression + Offset 0. = Position 0

Major radius: + 10. = 10

Minor radius: + 10. = 10

Orientation angle: + 0. = 0

Channel Thickness Tapering

☑ Use Default (Channel:None) TaperDefault (None)

Start: 1.0 End: 1.0

Width: 0.8

Depth: 2.225

Label: Ring

Profile: WG

Figure 2. Component configuration

The sine-modulated gaussian pulse was utilized for the wave excitation in the input plane, and the excitation will occur along the Y-axis through a complex solver on the mode of full-vector (ADI-Method). As the optical pulse excitation along the straight waveguide was ready to be coupled into the ring waveguide, the OptiMode solver would configure and analyze them. The simulated design was then executed through the OptiFDTD simulator [24].

3. RESULTS AND DISCUSSION

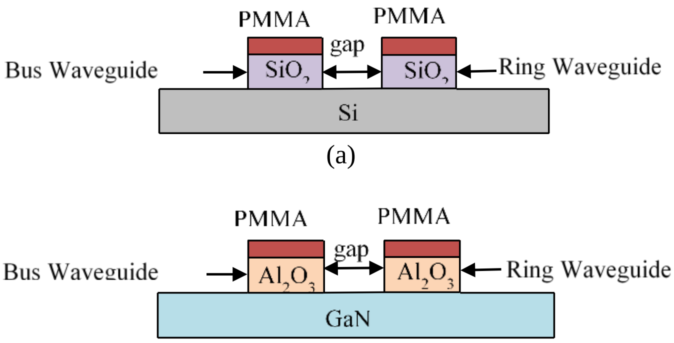
The analysis had been done with varying several design parameters to see the effect of the microring resonator performance with the PMMA being applied on top of the GaN/Sapphire (Al_2O_3). These parameters include the gap separation between the straight bus and the ring, PMMA thickness, and waveguide width.

3.1. Initial design parameters value

Table 1 shows the initial design parameter values for the microring resonator. The device was designed to be working at the C-band telecommunication wavelength or around 1550 µm. Other important parameters taken into account are the width of the straight (w_ring) and ring (w_ring) waveguides. Figure 3 depicts the side view of the proposed designs, in which the initial waveguide separation is 125 µm. The proposed design features are as shown in: a ring size of 10 µm, ring waveguide width of 800 nm, straight waveguide width of 400 nm, and gap separation of 125 µm.

Table 1. Design specifications

Parameter	Value	Description
f0	193.414 THz	Frequency
wl0	1550 (µm)	Input λ
GaN	2.279	GaN R.I
Sapphire	1.76	Al_2O_3 R.I
time_steps	$10e^{5}$	Time steps
time_size	8.339102 e^{-17}	Time size
r0	10 (µm)	Radius of ring
w_core	400 (nm)	Straight width
w_ring	800 (nm)	Ring width
dx	125 (µm)	Gap separation

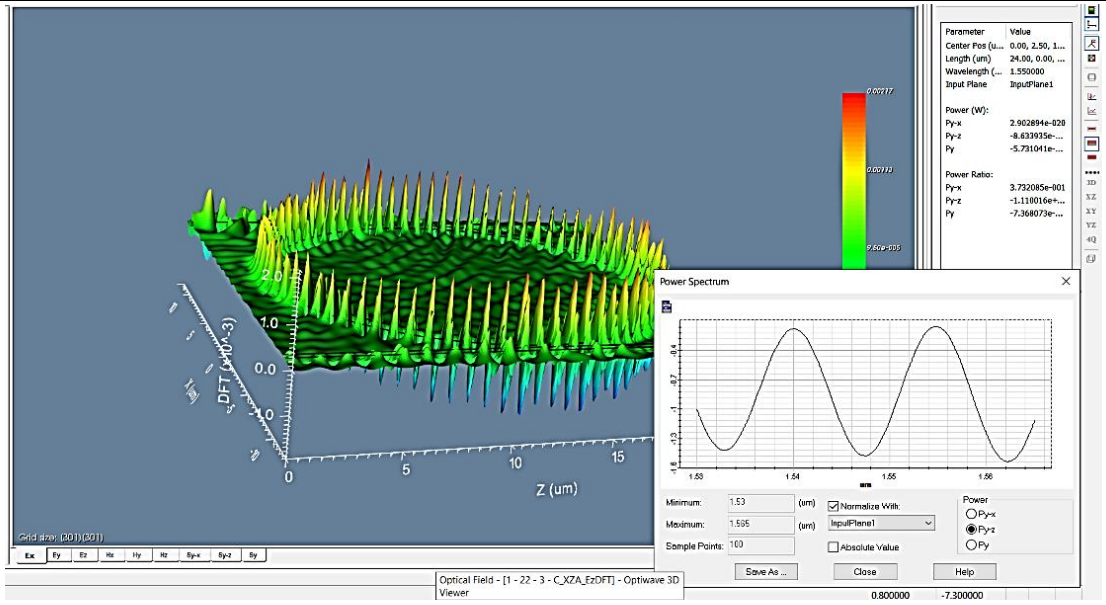


(a)

(b)

Figure 3. Schematic cross-section of the rib waveguide structures of the microring design based on the; (a) conventional Si/SiO_2 platform, (b) GaN/Al_2O_3 platform

Figure 4 portrays the initial modeling of the basic structure using the GaN/Sapphire as the core of the add-drop filter of the OMR. The simulation was carried out to observe whether the wave or optical pulses could be coupled from the straight waveguide onto the ring waveguide due to its resonance ability. It can be seen that, with the input frequency capped around 1550 nm, a clear comparison can be made due to the design's ability to transmit the data for its round trip losses and coupling coefficient within the same shape configuration of ring size (10 µm), ring waveguide width (800 nm), straight waveguide width (400 nm), and gap separation (125 µm). The light will be able to be coupled through the port to the ring and finally transmitted to the drop port.



Parameter	Value
Center Pos (u...	0.00, 2.50, 1...
Length (um)	24.00, 0.00, ...
Wavelength (...	1.550000
Input Plane	InputPlane1
Power (W):	
Py-x	2.902894e-020
Py-z	-8.633935e-...
Py	-5.731041e-...
Power Ratio:	
Py-x	3.732085e-001
Py-z	-1.110016e+...
Py	-7.368073e-...

Power Spectrum

Minimum: 1.53 (um)
Maximum: 1.565 (um)
Sample Points: 100
☑ Normalize With: InputPlane1
☐ Absolute Value
Power: ○ Py-x ● Py-z ○ Py

Optical Field - [1 - 22 - 3 - C_XZA_EzDFT] - Optiwave 3D Viewer

0.800000 -7.300000

Figure 4. Optical pulses plot of GaN/Al_2O_3 optical microring resonator

3.2. Effect of the different microring resonator platform

Figure 5 depicts the power spectrum for two different design platforms. One employs the SiO_2/Silicon (Si) platform while the other one uses GaN/Sapphire measured at the drop port. It was observed that the GaN/Sapphire design has a very low IL of 0.099728353 dB at both 1.539389 µm and 1.554220 µm wavelengths, while the Si/SiO2 platform has a 0.192454 dB loss. The output is supposedly in the ON-Resonance state where the peak of the spectrum can be observed. However, by utilizing the SiO2 design, the light was not coupled from the straight waveguide to the ring waveguide as compared to the utilization of the GaN platform. For the SiO_2/Si design, the signal will bypass the ring and exit at the through port-channel, hence, no signal arrives at the drop port.

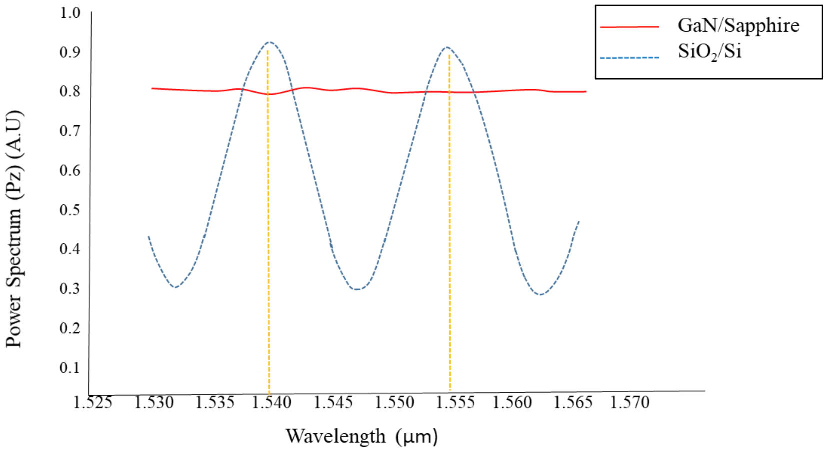


Figure 5. Power spectrum of the optical resonator based on SiO_2/Si and GaN platforms

3.3. Effect of the variation of PMMA thickness

Figure 6 shows the effect of doped PMMA thickness on top of the GaN/Al_2O_3. It can be seen that the smallest IL of 0.0675 dB was obtained with the PMMA thickness of 0.055 µm. This is due to its ability to couple much higher power from the input port through the port. The IL increases as the thickness of PMMA was increased. At 0.05 µm, due to the lack of stability, a high IL was observed. The result suggests that the lossy nature of the polymer film determines the optimum IL of the design and should be taken into account when designing an efficient microring resonator. The results can be validated by [21], where it shows that the thick PMMA guiding layer will induce large attenuation of the design devices.

3.4. Effect of the variations of gap separation

Using the same initial design configuration of 10 µm ring size and 0.055 µm PMMA polymer thickness, varying the gap separation to 125 µm, 155 µm and 205 µm will produce different IL performances. The gap separation was chosen based on the nearest consecutive peaks at ON resonance condition around 1550 nm wavelength. From Figure 7, it was shown that the best configuration it could offer is at the thickness of 205 µm with an IL of 0.099728352 dB. The highest IL occurs at 55 µm since its coupling ability will degrade at very small gap separation due to the high propagation loss as described in [4].

In terms of the Extinction Rate, the Extinction Ratio percentage is calculated and analyzed by the ratio of average three or two-point lowest peaks over the average of the highest peaks to the percentage calculation [25]. Increasing the gap between the bus and the ring waveguide has a limited effect in reducing the coupling efficiency, thus reducing the extinction rate (%) [26]. However, aligning the straight and ring waveguides too close will cause the coupling factor to be smaller than the scattering loss per round trip, hence high loss and low ER can be predicted. Therefore, there must be an optimized distance between both. From Figure 8, it can be seen that the ER value can be optimized when the gap separation was fixed to 255 µm with an ER of 74.1 %. Therefore, in achieving high ER, the gap separation of 255 µm is recommended.

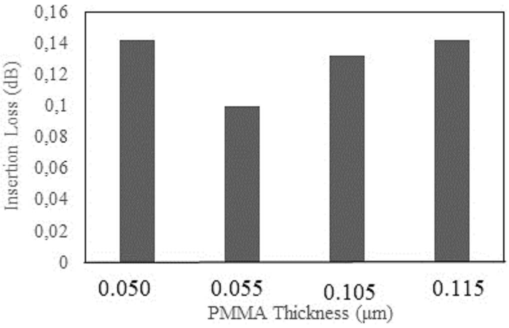


Figure 6. Insertion loss for different PMMA thicknesses

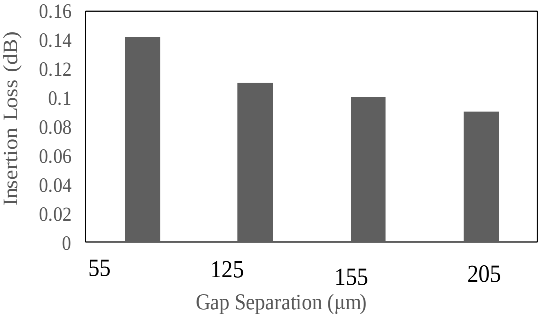


Figure 7. Gap separation effect on the insertion loss of OMR

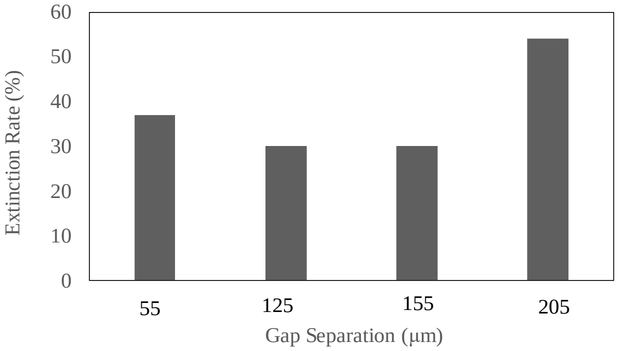


Figure 8. Gap separation effect on the extinction rate of OMR

3.5. Effect of dissimilar straight-ring wavelength width

The effect of the straight and ring waveguide sizes on the microring performance was also studied. From the power spectrum depicted in Figure 9, it is shown that the lowest IL is observed for the straight waveguide width of 600 µm and the ring waveguide of 800 µm. The IL and extinction rate observed were summarized as in Figures 10 and 11, respectively.

The lowest IL was observed for the 600/800 nm straight/ring waveguide combination with 0.02 dB and was slightly increased to 0.07 dB for the 800/800 nm waveguide combination. The highest extinction rate yields at around 87.3203 % for the dissimilar combination of 800/800 nm waveguide width combination. These results can be predicted since larger waveguide width will cause better optical confinement as explained theoretically in [4]. From both Figures 10 and 11, the waveguide width of 800 nm was suggested for both straight and ring waveguides since low insertion and extinction were obtained.

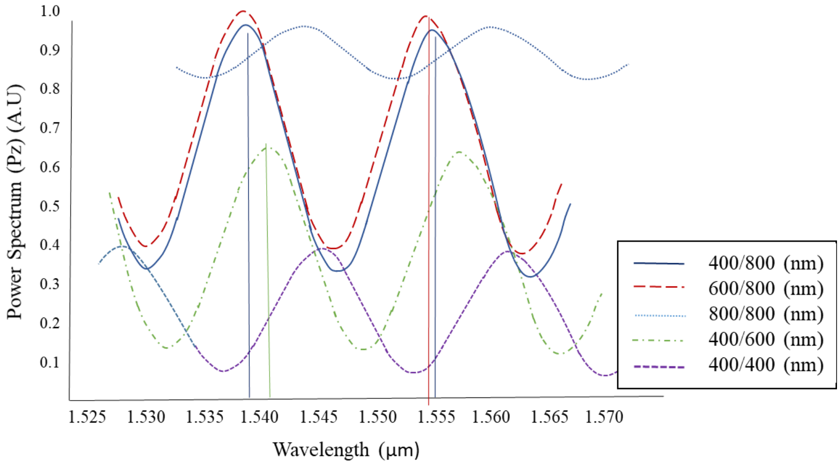


Figure 9. Power spectrum of different waveguide width designs

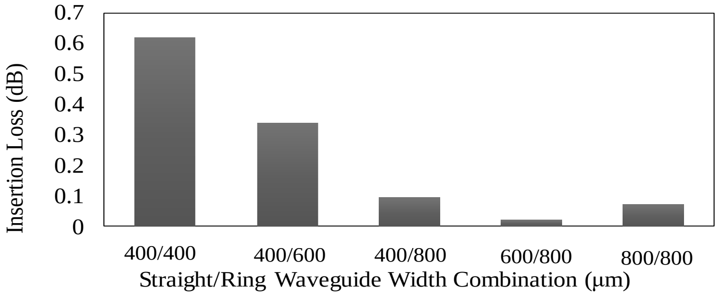


Figure 10. Insertion loss of dissimilar combination of straight-ring widths

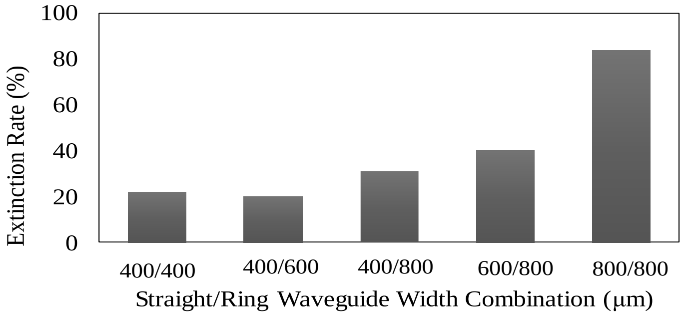


Figure 11. Extinction Rate of different waveguide width combination

4. CONCLUSION

The design of a gallium nitride-based optical microring resonator was studied. It can be concluded that the optimized configuration for the GaN optical microring with PMMA material coating is polymer grafting material PMMA thickness of 0.055 µm, gap separation of 125 µm, straight and ring waveguide length of 800 nm, and ring radius of 10 µm. This study provides a guideline for determining the microring geometry to satisfy the desired filtering requirements.

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