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Conference Paper

Effect of Input Amplitude to Power Amplification in Various Orientation of Ring Resonator

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Abstract

Photonic ring waveguide resonators have great potential applications in wavelength filtering, switching, modulation and multiplexing. The response of coupled ring resonators can be designed by using various coupling configurations. Particularly, ring resonators can be used as wavelength filter when the wavelength fits a whole multiple times in the circumference of the ring. In this paper, we investigate the effect of input amplitude to power amplification in four ring resonator configurations and vary the input amplitude on five different wavelengths. With OptiFDTD Photonics Simulation Software V8.0, the results show the intensity phenomenon of filtering in optical circuit.

Keywords: Microring resonator, Side-coupled integrated space sequence of resonators, power distribution, Finite Difference Time Domain, Optical filter

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1. Introduction

Recently, optical ring resonator has become one of the most promising photonic integration platforms. The basic resonator consists of a straight waveguide coupled to a fiber ring with radius, *r* [1–5, 8]. A generic ring resonator consists of optical waveguide which is looped back on it, such that a resonance occurs when the optical path length of the resonator is exactly a whole number of wavelength [5]. The solution of Maxwell equations by Finite Difference Time Domain (FDTD) method was proved to be one of the important tools due to its simple implementation in software simulations. This mathematical method was used in a variety of photonics' studies. By using FDTD method, Hagness et. al described the design and experimental realization of a simple ring resonator. Modeling micro ring resonator is important due to the optical device offer a large free spectral range but also a narrow band [6-7]. In this study we simulated four different ring resonator configurations and vary the input amplitude on five different wavelengths. This paper studying the effect of input amplitude to power amplification for all configurations and also varies the input amplitude on five different resonant wavelengths. It is necessity to study the effect of structures on ring resonator since we discovered that power can be distributed while propagating through the structure for various performances. The output pattern of filter will varies due to particular orientation. Furthermore, we can optimize the profile of the output waves.

2. Design and Simulations of Resonators

The model is started by setting up the wafer dimensions to 60 μm in length and 20 μm in width. The 2D wafer's refractive index set to air's refractive index which is 1.00. The waveguide being used to model this simulation is to set the isotropic constant refractive index which is its real value of 1.54 and no imaginary part. The device configuration is composed by coupled up 4 double ring waveguide and a plane waveguide as shown in Fig. 1. The details of the configuration are as follows; the length of the linear waveguide has been set to 60.0 μm and the width of fiber is 1.0 μm. The waveguide is coupled to double ring waveguide with radius of 3.25 μm, both minor and major radius. The centers of the horizontal position for the upper and lower rings are located at approximately at 8 until 50 μm by difference of 22 μm between each other. While the vertical position of the upper ring is approximately 4.1 μm and the vertical position are about - 4.1 μm. The orientation angle of each ring waveguide is set to 0∘. In this model, the default setting is used for the configuration of channel thickness tapering. The width of the ring is set to 1.0 μm and the depth is set similar to profile of plane waveguide. The vertical input plane is interfaced to the device as a power source. A continuous wave with wavelength of 1.55 μm has been used as the initial properties of the input plane for the Gaussian input field transverse. The plane geometry is set and wave configuration is 0.4 μm for its Z position being transverse in positive direction with 0∘ initial phase. The input power we used is 1.0 V/m.

3. Theory

The basic relations amongst the incident field, E_1, transmitted field, E_2, and circulating fields E_3, E_4 of a single resonator are inferred by combining the relations for the coupler with that of the feedback path.

In the spectral domain the field leaving the coupling region are related to the input fields via the subsequent unitary matrix;

$$\begin{pmatrix} E_4(\omega) \\ E_2(\omega) \end{pmatrix} = \begin{pmatrix} r & it \\ it & r \end{pmatrix} \begin{pmatrix} E_3(\omega) \\ E_1(\omega) \end{pmatrix} \tag{1}$$

where the lumped self- and cross-coupling coefficient, r and t are assumed to be autonomous of frequency and fulfill the relations of $r^2 + t^2 = 1$ [8]. The feedback path (of length $2\pi R$) connects the output from port 4 backward into input port 3 where the field is conveyed as:

$$E_3 = e^{-\frac{\alpha_{ring}}{2}2\pi R} e^{ik2\pi R} E_4 \equiv a e^{i\varnothing} E_4 \tag{2}$$

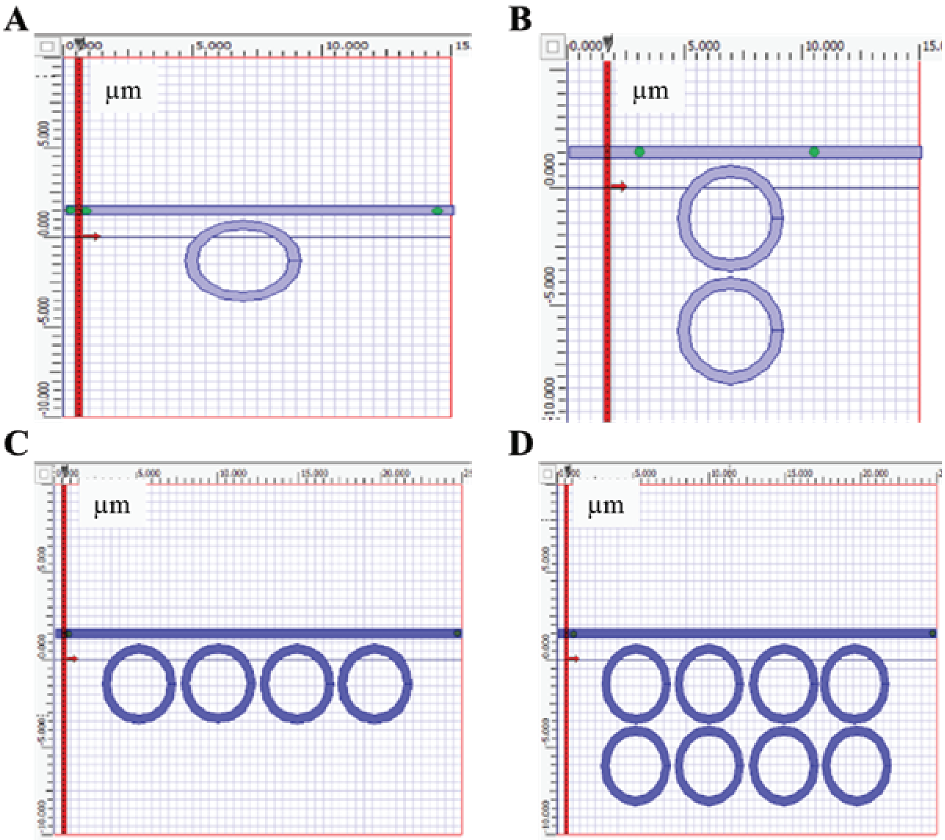

Figure 1: The schematics diagram of various configurations of ring resonators (a) single ring resonators (b) four serial-coupled single ring resonators (c) double ring resonators (d) four serial-coupled double ring resonators.

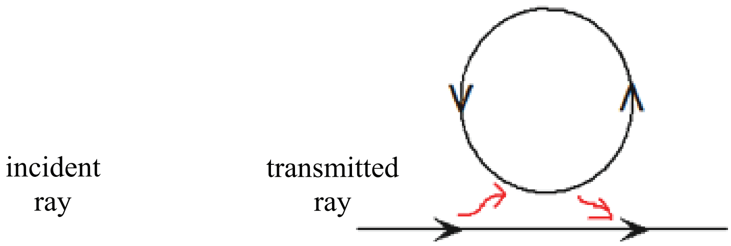

Figure 2: Electric field correlates with an all-pass ring resonator.

Here, α represents the single-pass amplitude transmission and $\varnothing$ represents the single-pass phase shift. Eq. 1 and 2 are solved to acquire an interpretation for the ratio of the circulating field to the incident field;

$$\frac{E_3}{E_1} = \frac{itae^{i\varnothing}}{1 - rae^{i\varnothing}} \tag{3}$$

The ratio of the circulating intensity to incident intensity, or the buildup factor *B*, is given by the squared modulus of this outcome,

$$B = \frac{I_3}{I_1} = \left|\frac{E_3}{E_1}\right|^2 \tag{4}$$

$$= \frac{\left(1 - r^2\right) a^2}{1 - 2ra\cos\phi + r^2 a^2} \tag{5}$$

The last outcomes may allude to the circumstance in which the incident light is resonant with the ring ($\varnothing = m2\pi$) and the attenuation is not considered ($a = 1$). A passive ring resonator under these conditions achieves the maximum ratio of circulating power to incident power. For cross-coupling values of 10% ($t^2 = 0.1$), the intensity in the ring can be 40 times higher than the intensity incident on the resonator in the input waveguide. Based on the intensity in the ring that can be higher than in the bus, ring resonator can be utilized for nonlinear optics applications with moderate input intensities [8].

4. Results and Discussions

4.1. Single Ring Resonator and a Linear Waveguide

Fig. 2 describes results of light intensity before and after propagating the ring structure of single ring resonator. This study is conducted based on five different wavelength; λ = 1.0 μm, λ = 1.25 μm, λ = 1.55 μm, λ = 2.9 μm, λ = 4.25 μm and the input power is set at 1 V/m. Based on the results, from Fig. 2 (a) it is found that the trend line is nearly symmetric at wavelength 0.9 μm to 1.1 μm and a peak is found to rise at λ = 1.0 μm. There seems that the filter rise gradually and the gain is high at this range. Fig. 2 (b) depicts that the trend line is not symmetric compared in (a). The filter is slightly exponential and the gain is high but the wavelength filter is short to be used in practical application as an optical filter. Fig. 2(c) shows that the peak at wavelength 1.55 μm is sharp and this makes it as a good filter in application. Besides, it depicts a comb wave rapidly and the gain is relatively high at this range compared in (a) and (b). As we increased the value of λ to 2.9 μm and 4.25 μm, it was found that the value of output power is less compared to input power being supplied to the system. Contrary to expectation, it is assumed that the power is being reticulate as it propagates through the ring structure.

4.2. Input Amplitude of 1 V/m, 5 V/m and 10 V/m

Fig. 3 depicts that the higher input amplitude produces the narrower band wave as this one of the ideal characteristic for an optical filter for λ = 1.55 μm. However at higher input amplitude, we cannot clearly observe the gap between the input source and output source compared to lower input amplitude. It is evident from the results; the trend line for various setting of input amplitude is similar to 1 V/m, 5 V/m and 10 V/m. These findings suggest that the power gain is generally good until it reaches λ = 1.55 μm. At 2.9 μm, the output power is 90∘ to 180 ∘ phase difference due to power delays although power amplification is high. As we increased theλ, they cannot acts as a good optical filter since it has wide broadband. For lower value ofλ, it can

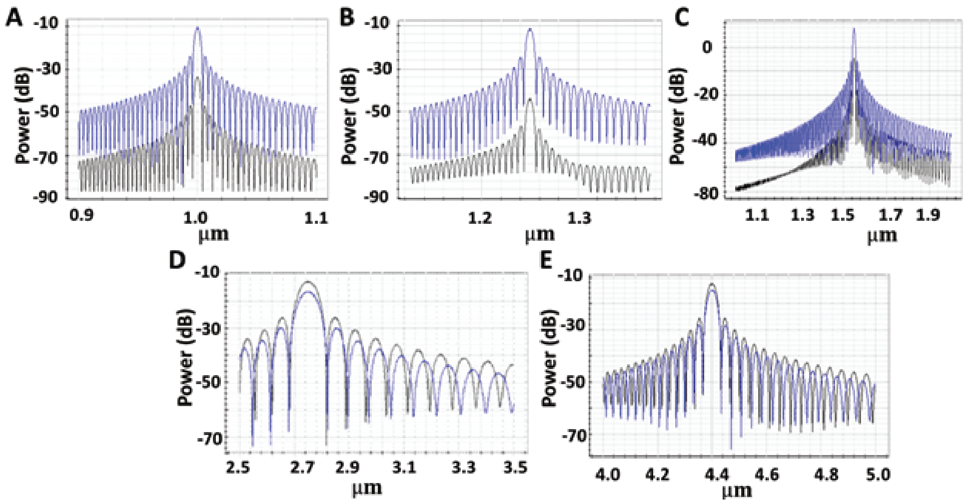

Figure 3: The transmission spectrum for single ring resonator with input amplitude of 1 V/m. (a) at λ = 1.0 μm, (b) at λ = 1.25 μm, (c) at λ = 1.55 μm, (d) at λ = 2.9 μm and (e) at λ = 4.25 μm.

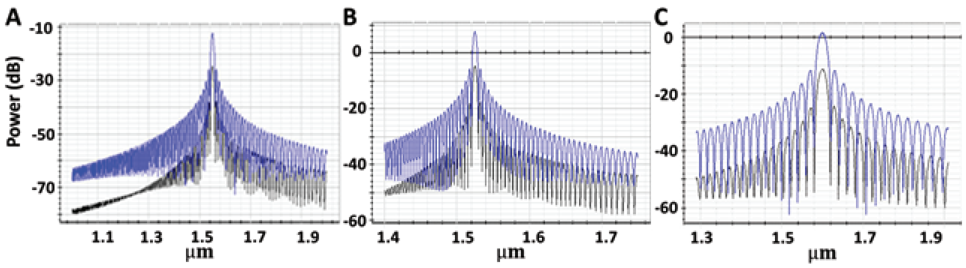

Figure 4: The transmission spectrum for single ring resonator for λ = 1.55 μm with (a) input amplitude of 1 V/m, (b) input amplitude of 5 V/m and (c) input amplitude of 10 V/m.

filter certain required wavelength since the peak is steep at certain range compared to biggerλ. These are due to the factor of higher wavelength carries high power energy. Four serial-single ring resonators is a good filter compared to single ring resonator. However the double ring resonator showing the sharp peak results. For increasing input amplitude 1 - 10 V/m, the effect of phase difference and group velocity affect the filter wave mainly at high wavelength source. The gain is sharp but for high input voltage the wave seems not sinusoidal, it suspects due to the effects of ring do not completely acts as resonator since some geometrical parameter is changed. It is the effect of nonlinear phenomenon occurs in the light wave as it propagates through the bus and ring structure.

4.3. Power Amplification of Light Intensity for Four-Coupled Double Ring Resonator

Fig. 4 shows the power amplification for optical light intensity in double ring resonator if varies the input amplitude from 1 – 10 V/m for wavelength range from 1 – 4.25 μm. This phenomenon occurs is expected due to time delay when the light is propogate in the ring. It is expected due to energy loss as it circulates in the ring. Furthermore, during the circulating, there are phase difference due to time delay between the first

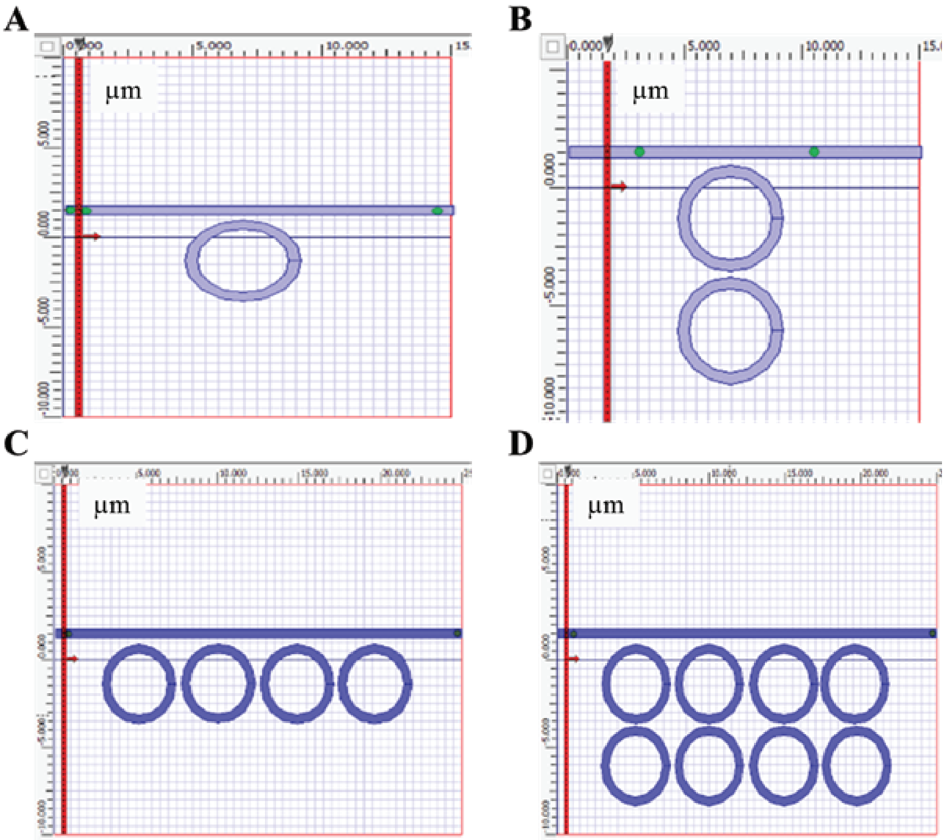

Figure 5: The power amplification of light intensity for double ring resonator. (a) at λ = 1.0 μm, (b) at λ = 1.25 μm, (c) at λ = 1.55 μm, (d) at λ = 2.9 μm and (e) at λ = 4.25 μm.

and the next wave. For larger wavelength, it carries low energy and it requires longer period to circulate in the ring.

5. Conclusion

In summary, we successfully designed and studied the effect of input amplitude to power amplification in four various ring resonator configuration. We began our analysis with a single bus waveguide coupled with single ring resonators. It shows that the peak at wavelength of 1.55 μm, the transmission spectrum from the output port at this specific wavelength is sharp and this makes it a good filter in optical application. In next section, we analyse the effect if we varies value of input amplitude of 1 V/m, 5 V/m and 10 V/m. It reveals for λ = 1.55 μm, the higher input amplitude produces the narrower band wave, as this one of the important characteristics for an optical filter. However, if we increase the input energy, it is uneasy see the gap between input and output optical spectrum. These also compared the transmission spectrum between four configurations to identify the optimum that match to fulfill the ideal optical filter.

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References

[1] R. Orta, P. Savi, R. Tascone, and D. Trinchero, Synthesis of multiple-ring-resonator filters for optical sytem, *IEEE Photon Tech. Lett.*, **7**, 1447–1449, (1995).

[2] D. G. Rabus, in *Integrated Ring Resonator: The Compendium*, **127**, Springer Series in Optical Sciences, 2007.

[3] W. Bogaerts, P. Dumon, D. Van Thourhout, D. Taillaert, P. Jaenen, J. Wouters, S. Beckx, V. Wiaux, and R. Baets, Compact wavelength-selective functions in silicon-on-insulator photonics wires, *IEEE J Sel Top Quantum Electron*, **12**, 1394–1401, (2006).

[4] P. Dumon, W. Bogaerts, V. Wiaux, J. Wouters, S. Becks, J. Van Campenhout, D. Taillaert, B. Luyssaeert, P. Bientsman, D. Van Thourhout, and R. Beats, Low-loss SOI photonics wires and ring resonators fabricated with deep UV lithography, *IEEE Photonics Technol Lett*, **16**, 1328–1330, (2004).

[5] W. Bogaerts, P. D. Heyn, T. V. Vaerenbergh, K. D. Vos, S. K. Selvaraja, T. Claes, P. Dumon, P. Bientsman, D. V. Thourhout, and R. Baets, Silicon microring resonator, *Laser Photonics Rev*, **6**, 47–73, (2012).

[6] S. C. Hagness, D. Rafizadeh, S. T. Ho, and A. Taflove, FDTD Microcavity Simulations: Design and Experimental Realization of Waveguide-Coupled Single Mode Ring and Whispering-Gallery-Mode Disk Resonators, *J Lightwave Technol*, **15**, 2154–2165, (2007).

[7] H. M. Hairi, T. Saktioto, Dedi Irawan and J. Ali, "A Design of Twisted Double Channel SCISSORs for Optical Filter," Komunikasi Fisika Indonesia, 10(6), 2013.

[8] J. Heebner, R. Grover, and T. Ibrahim, Optical Microresonator: Theory, Fabrication and Application Springer Series in Optical Sciences 138, 2008.