

FSR Decrement and Coupling Coefficient Increment in Add-Drop Filters

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ARTICLE INFO

ARTICLE HISTORY:

Received 15 February 2015

Revised 10 April 2015

Accepted 14 April 2015

KEYWORDS:

Add-drop filter

Coupling coefficient

Free spectral range

Micro ring resonator

ABSTRACT

In this paper, effects of the structural parameters on the optical characteristics of an add-drop filter, consisting of two straight waveguides and a micro-ring resonator (MRR), have been investigated. In this research, effects of MRR radius, the width of MRR and waveguide and the gap between MRR and waveguide, on free spectral range (FSR) and coupling coefficient have been studied. It is found that by enhancing the gap and width, coupling coefficient would be increased at first but after a while it would be decreased. It is also shown that, increasing the radius and width would decrease FSR. The main goal of this research is to decrease FSR and increase the coupling coefficient of add-drop filters in a joint state, which are widely used in communication applications.

1. INTRODUCTION

Micro-ring resonators (MRRs) are important components in integrated circuits. They have been widely used in recent years due to their compactness, high quality factor and simplicity of fabrication. Add-drop filters have attracted attentions of lots of researchers in recent years such as those working on investigations of the compact parent-sub micro ring-resonator structure for highly integrated optical add-drop multiplexer (OADM); which has large FSR amounts obtainable from cascaded micro ring with relatively large diameter [1]. Currently, a channel drop filter comprised of two straight waveguides separated by an air-cavity is designed, analyzed and theoretically simulated in the hetero-woodpile-structure [2]. In the recent researches, using the practical parameters in an add-drop filter, sensing applications for the flow rate sensor, temperature sensors and medical sensors could be configured [3].

In this work, effects of structural parameters on the optical characteristics of an add-drop filter are investigated. The structural parameters are ring

radius, the width of waveguides and MRR and the gap between waveguides and MRR; while optical characteristics are FSR and coupling coefficient.

2. THEORETICAL ANALYSIS

MRR acts as a wavelength selecting filter. Propagating specific wavelength is the operating principle of an MRR. Wavelengths satisfying the following equation can be propagated in an MRR [4]:

$$nL = m\lambda \quad (1)$$

where m is an integer, $L=2\pi R$ is the circumference of the MRR, R is the ring radius λ is the resonance wavelength of the MRR and n is the mode effective refractive index of the MRR. Integrated MRRs are used in wide ranges of applications including lasers, optical switches, tunable wavelength filters, add-drop multiplexers and biosensors [4]. An add-drop filter is consisted of one input, one output waveguide and an MRR; it acts as a localizing filter with four ports. Add-drop filters can be described by certain figures of merit. One important figure is the distance between resonance peaks, which is called the free spectral

range (FSR) [5]. The simple combination consisting of unidirectional coupling between an MRR with radius R and a waveguide, is described in Fig. 1.

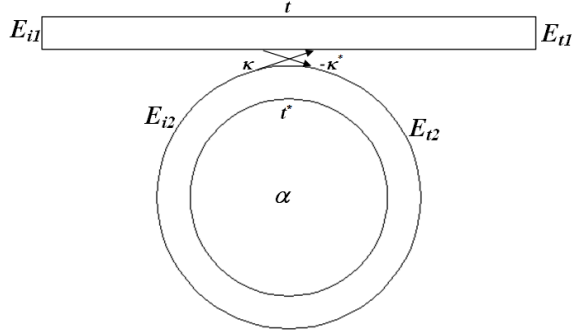


Figure 1: Model of a single MRR and a waveguide [4]

The interaction between an MRR and the waveguide can be described by the following matrix relation [4]:

$$\begin{pmatrix} E_{t1} \\ E_{i2} \end{pmatrix} = \begin{pmatrix} t & \kappa \\ -\kappa^* t^* & \alpha \end{pmatrix} \begin{pmatrix} E_{i1} \\ E_{t2} \end{pmatrix} \quad (2)$$

Where E_{i1} and E_{t1} are the input and output fields, respectively, while E_{i2} and E_{t2} are the circulating fields. The complex mode amplitudes of electric fields are normalized; t and κ are the coupler parameters. An add-drop filter is depicted in Fig. 2. The optical fields in this system can also be achieved by using (2); because this system is a combination of an input waveguide and an MRR, an MRR and an output waveguide; So desired fields can be obtained by applying Eq. (2) twice for Fig. 2 [4].

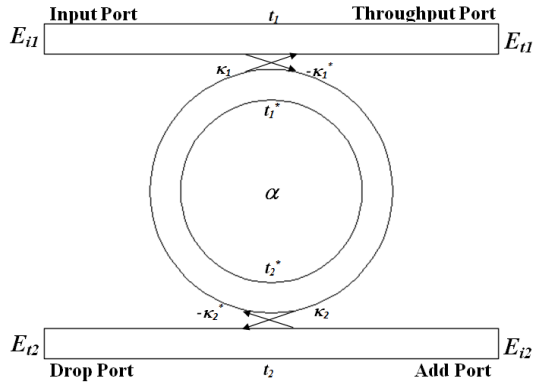


Figure 2: Model of a basic add-drop filter [4]

Input pulse is applied into the input ports (E_{i1} and E_{i2}), then it is propagated toward the throughput (E_{t1}) and it would drop (E_{t2}) ports meanwhile it is coupled to MRR through the directional coupler. Input pulse is sliced into smaller signals spreading over the spectrum while passing through MRR; localized signals can be obtained from drop and throughput ports [4]-[7].

3. DISCUSSIONS AND RESULTS

The selected parameters are $n_0=3.34$ (InGaAsP/InP), $A_{eff}=0.25\mu m^2$ and $\kappa=0.7$. A Gaussian pulse with the central wavelength of $2\mu m$, bandwidth of $2\mu m$ and peak power of 1W is input to the add-drop filter.

A. Effects of the Width of MRR and Waveguides on the Coupling Coefficient

Coupling coefficients versus width for different values of radii are depicted in Fig. 3.

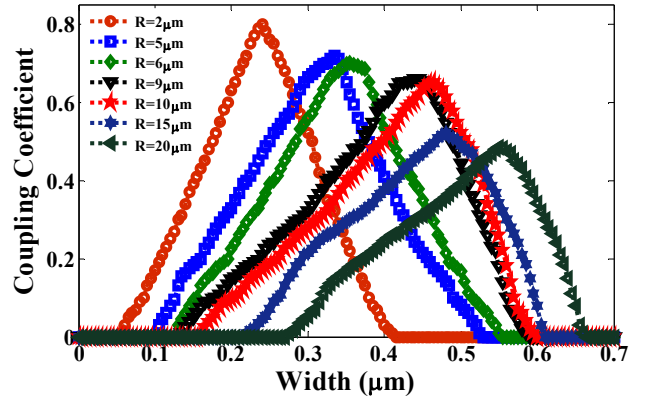


Figure 3: Coupling coefficient vs. width variation

It is understood that, as the width is decreased, the transmission and coupling losses are increased; which in turn causes the coupling coefficient to be decreased. In another case, as the width is increased, the confinement of the trapped signal is also increased; which also leads to a decrease in the coupling coefficient [8]- [10].

B. Effects of the Gap between MRR and Waveguides on the Coupling Coefficient

Coupling coefficients versus gap between MRR and waveguides for different values of radii have been demonstrated in Fig. 4.

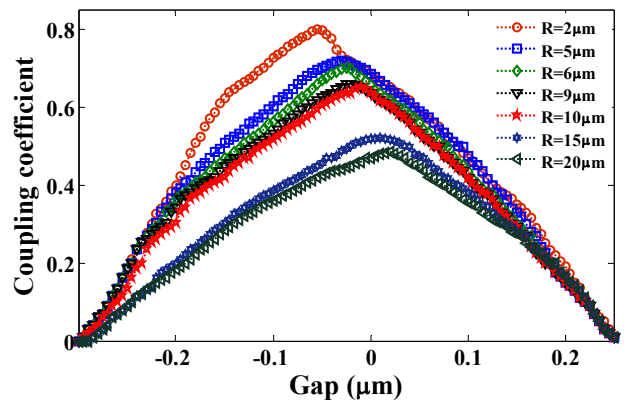


Figure 4: Coupling coefficient vs. gap variation

It's realized that by increasing the gap, coupling and transmission losses are also increased; which lowers the coupling coefficient. On the other hand, decreasing the gap also increases the internal and transmission losses which also eliminate the coupling coefficient [8], [9].

C. Effects of MRR Radius on FSR

In this part, effects of MRR radius on FSR are investigated. FSR is obtained according to (3) by changing ring radius [8]-[10].

$$FSR = \Delta f \frac{\pi(\alpha A \sqrt{1-\kappa})^2}{1 - \alpha A \sqrt{1-\kappa}} \quad (3)$$

where Δf , α , $A=e^{-\alpha L}$ and κ are respectively full-width at half maximum (FWHM), transmission loss, amplitude loss in one turn and coupling coefficient. From (3), it can be concluded that by increasing the ring radius, FSR would be decreased. FSR vs. MRR radius is depicted in Fig. 5 [10].

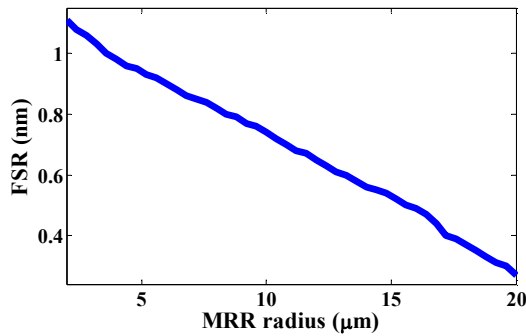


Figure 5: FSR vs. MRR radius variation

D. Effects of the width of MRR and waveguide on FSR

FSR relation can be theoretically written as follows by changing MRR width (for rings having the same perimeter L) [9], [10].

$$FSR = \frac{C}{n_g L} \quad (4)$$

$$n_g = n_{eff} + f_0 \left(\frac{dn_{eff}}{df} \right) \quad (5)$$

where n_g , n_{eff} , C and f_0 are group index of the waveguides, effective index of the waveguides, speed of the light and resonant frequency, respectively.

It is known that, as the width increases, attenuation coefficient of the waveguide becomes smaller, so this would lead to a decrease in the amount of FSR. This conclusion is consistent with (4), (5); also it is consistent with the results depicted in Fig.6 for different values of radii; so increasing the width of MRR would decrease FSR.

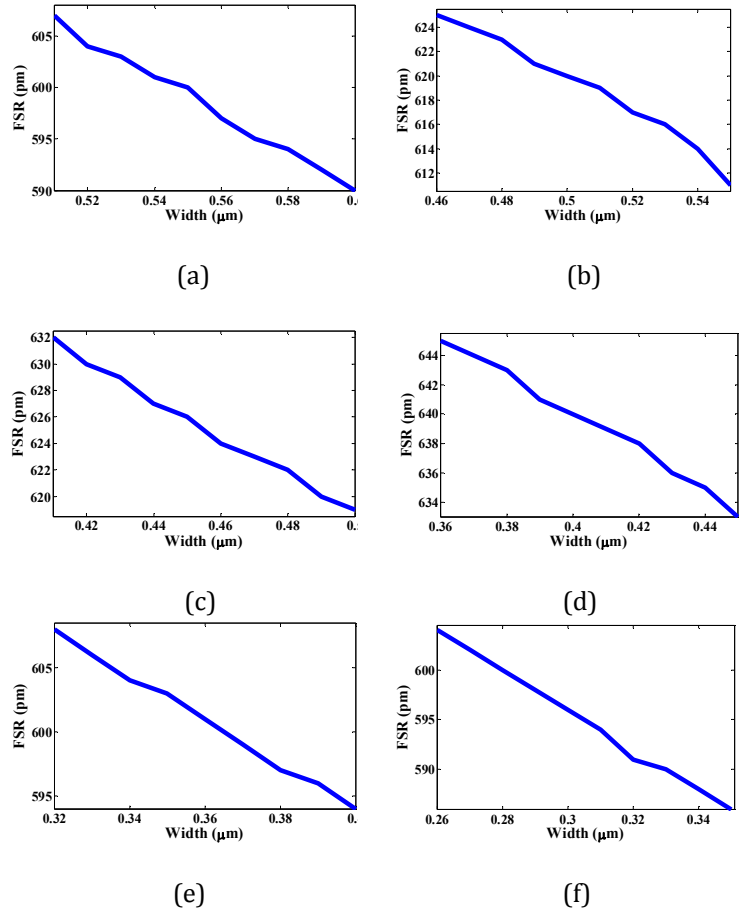


Figure 6: FSR vs. width variation for $R=$ (a) 20 μm , (b) 16 μm , (c) 15 μm , (d) 10 μm , (e) 9 μm , (f) 6 μm

As it is shown, MRR width has less significant effect on FSR than MRR radius.

4. CONCLUSION

In this research, effects of the structural parameters such as ring radius, width and gap between MRR and waveguides on the coupling coefficient and FSR had been investigated. It was investigated that, increasing the width and gap, would at first enhance the coupling coefficient but then diminish it. It was also indicated that, increasing the ring radius and width would decrease FSR.

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BIOGRAPHIES



Esmat Rafiee was born in Shiraz, Iran in 1988. She received her B.Sc. degree in Electronic Engineering from Kerman University in 2010, M.Sc. degree in Optoelectronics Engineering from Shiraz University of Technology in 2013. She is currently a Ph.D. student in Optoelectronics Engineering, Faculty of electrical engineering, Shiraz University of Technology, Shiraz, Iran.

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Farzin Emami was born in Shiraz, Iran in 1967. He received his Ph.D. degrees in laser optic from Tarbiyat Modares University of Tehran-Iran in 2002. In 2003 he was the Head of the Electronic Department of Shiraz university of technology, where he worked on a variety of optoelectronic devices including optical modulators, optical detectors, semiconductor optical amplifiers, Raman amplifiers, photonic crystals, neutron

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