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مطالعهٔ اثرات پارامترهای ساختاری بر بهره نوری ریزتشدیدکننده‌های حلقوی

عصمت رفیعی، فرزین امامی و نجمه نزهت

دانشکده برق و الکترونیک، دانشگاه صنعتی شیراز، شیراز، ایران

چکیده – سیستم پیشنهاد شده در مقاله شامل ریزتشدیدکننده‌های حلقوی با شعاع‌های متفاوت می‌باشد. در این مقاله، اثرات پارامترهای ساختاری مانند فاصلهٔ بین موجبرها و ریزتشدیدکننده‌های حلقوی، پهنا و ارتفاع موجبرها و ریزتشدیدکننده‌های حلقوی و شعاع ریزتشدیدکننده‌های حلقوی بر بهره نوری مطالعه شده‌اند. نشان داده خواهد شد که با افزایش شعاع ریزتشدیدکننده‌های حلقوی، بهره نوری کاهش یافته و با افزایش فاصله موجبرها وریزتشدیدکننده‌های حلقوی و همچنین پهنا و ارتفاع موجبرها و ریزتشدیدکننده‌های حلقوی، بهره نوری در ابتدا افزایش و سپس کاهش می‌یابد. ویژگی‌های این سیستم به‌صورت عددی با روش تفاضلات متناهی در حوزهٔ زمان محقق شده‌اند.

کلید واژه- ریزتشدیدکنندهٔ حلقوی، فیلتر افزایشی/کاهشی، بهره نوری.

Studying the Effects of Structural Parameters on the Optical Gain of Micro-Ring Resonators

Esmat Rafiee, Farzin Emami, Najmeh Nozhat

Electrical and Electronic Department, Shiraz University of Technology, Shiraz, Iran

Abstract-The proposed system consists of micro-ring resonators (MRRs) with different radii. In this paper, the effects of structural parameters such as gap between the waveguides and the MRRs, width and height of the waveguides and the MRRs and MRR radii on the optical gain are studied. It is shown that by increasing the MRR radius the optical gain decreases and by increasing the width and height of the MRR and the waveguide and the gap, first the optical gain increases and then decreases. The properties of this system are numerically investigated by the finite-difference time-domain (FDTD) method.

Keywords: Micro-ring resonator, Add/drop filter, Optical gain.

Studying the Effects of Structural Parameters on the Optical Gain of the System of Micro-Ring Resonators

E. Rafiee

Electrical and Electronic Department, Shiraz University of Technology, Shiraz, Iran

e.rafiee@sutech.ac.ir

F. Emami

Electrical and Electronic Department, Shiraz University of Technology, Shiraz, Iran

emami@sutech.ac.ir

N. Nozhat

Electrical and Electronic Department, Shiraz University of Technology, Shiraz, Iran

nozhat@sutech.ac.ir

1 Introduction

Micro-ring resonators (MRRs) are important components in integrated circuits. MRRs have attracted attentions in recent years due to their compactness, high quality factor and simplicity of fabrication. Propagating specific wavelength is the operating principle of an MRR. Integrated MRRs do not require facets or gratings for optical feedback, so they are particularly suited for monolithic integration with other components. An add/drop filter consists of a micro-ring resonator and two straight waveguides. Its properties are based on the MRR operating principle. MRRs have remarkable applications in optical networks, sensors, switches, biosensors and wavelength filters [1]. By tuning the response of the MRR, systems with higher channel capacities that are much faster and more secure can be achieved. Optimizing MRR structural parameters improves the optical gain of the system. These parameters also affect the frequency spectrum, the central wavelengths, the free spectral ranges (FSRs) and the coupling coefficient [2], [3].

2 Mathematical Background

The wavelengths satisfied the following equation can propagate in MRR.

$$nl = m\lambda \tag{1}$$

where m is an integer, $l=2\pi r$ is the circumference of the MRR, λ is the resonance wavelength of the MRR, and n is the refractive index of the MRR respectively.
The simple configuration, consists of unidirectional coupling between an MRR with radius r and a waveguide, is described in Figure 1.

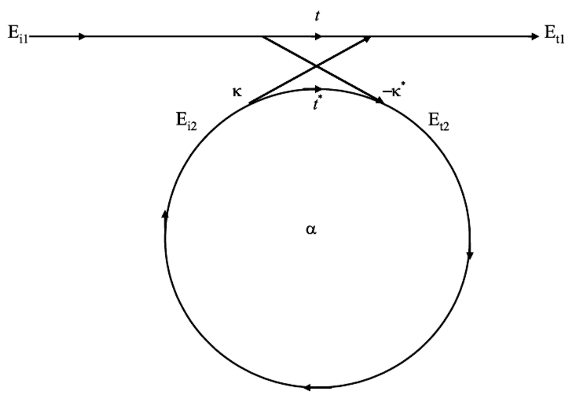

Figure 1: Model of a single micro-ring resonator with one waveguide.

It is assumed that when a single unidirectional mode of the resonator is excited, the coupling would be lossless. All kinds of losses occurring along the propagation of the light in the MRR filter are incorporated in the attenuation constant [4].
The interaction can be described by the matrix relation [1], [5]:

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

The complex mode amplitudes E are normalized; t is the self coupling coefficient and κ is the cross coupling coefficient. κ is determined by the amount of the coupling coefficient. The * denotes the complex conjugate of t and κ. It is assumed that the matrix is symmetric, so it can be written as:

$$\left|\kappa^{2}\right| + \left|t^{2}\right| = 1 \tag{3}$$

The system discussed in this paper is a combination of two MRRs with radius varying between 5 μm and 15 μm and an add/drop filter with a radius of 15 μm, as shown in Figure 2.

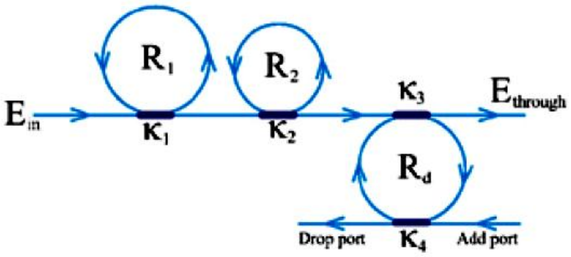

Figure 2: System of two micro-ring resonators and an add/drop filter.

The add/drop filter consists of an input waveguide, an output waveguide and an MRR as illustrated in Figure 3.

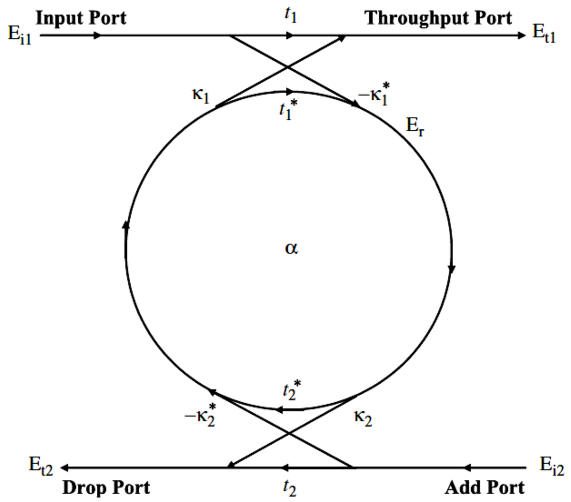

Figure 3: Model of a basic add/drop single MRR filter.

The relations of the fields in the add/drop filter are the same as Equation (2). This relation would be applied to a system of series devices; input waveguide and MRR, MRR and output waveguide. After that, the two matrices should be multiplied.
The input pulse is launched into the input port of Figure 2, propagated in the straight waveguide and coupled to the MRRs. The signal is chopped (sliced) into smaller signals spreading over the spectrum; therefore larger bandwidth signal is formed within the first ring device. The compress bandwidth with smaller group velocity is obtained within the ring R_2 and the localized signal is formed through the add/drop device. The optical gain depends on the various parameters, such as MRRs radius, width/height of the waveguides and the MRRs and the gap between the waveguides and the MRRs.
In this work the structural parameters and their effects on the optical gain are considered.

3 Simulation Results

Effects of some structural parameters on the optical gain were investigated which are simulated as follows.

A. The effect of the MRR radius on the optical gain

In this part, the effect of the MRR radii is being considered in Figure 4.

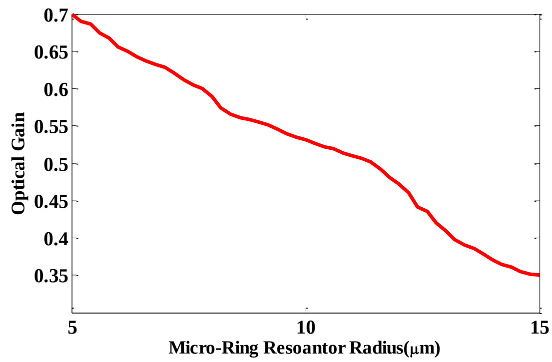

Figure 4: Micro-Ring Resonator radius variation vs. the optical gain

It is obvious from Figure 4 that by increasing the MRR radius the optical gain decreases. This happens due to the increase of the coupling and waveguide losses for MRRs with higher radius. In other words, by increasing the radius, the losses increase and the gain decreases. Therefore, for having higher optical gains, the radius of R_2 should be lower than R_1 in Figure 2.

B. The effect of width/height of the MRR and the waveguide on the optical gain

We consider the same value for the width and height of the MRRs and the waveguides. The width and height of the MRRs and the waveguides greatly affect the optical gain. As shown in Figure 5, optical gain is greater than zero only for specific amounts.
As the width/height decreases, the transmission and coupling losses increase and the optical gain decreases. In another case, as the width/height

increases the optical gain also increases; but as the width approaches to the higher values, the confinement of the trapped light increases and the optical gain decreases [7],[8]. In Figure 5, the plots for MRRs of radius 5 μm, 10 μm and 15 μm are shown. According to this figure we can choose the best MRR that is available for our application.

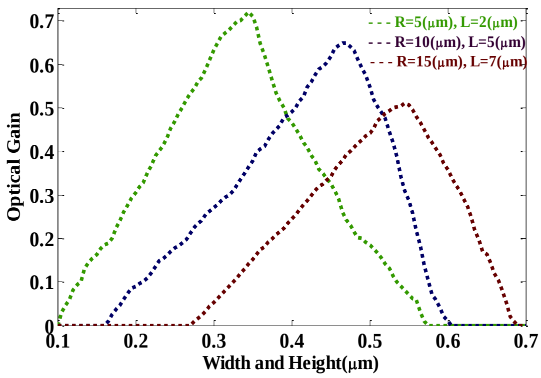

Figure 5: MRR and waveguide width and height variation vs. the optical gain

C. The effect of the gap between the MRR and the waveguide on the optical gain

Tuning the gap between the MRRs and the waveguides is of great importance. Its optimum value is around zero. As shown in Figure 6, the gap can get negative or positive values. By increasing the radius, the optimized gap increases as well. This means the gap for MRR with 15 μm radius is greater than the one with 10 μm, but the differences are too small [8].

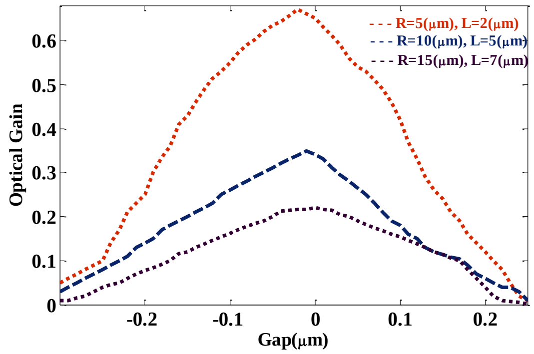

Figure 6: The gap between the MRR and the waveguide variation vs. the optical gain

4 Conclusion

In this research the combination of MRRs with an add/drop filter was studied. It is found that, When the MRR radius increases, the optical gap decreases as a result of the coupling and waveguide losses. By increasing the width/height and gap the amount of the optical gain increases firstly and then decreases. Generally, the characteristics of the systems made of MRRs can be changed and adjusted by structural parameters like radius, gap and width.

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