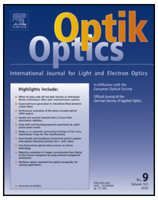
Optik 127 (2016) 1690–1694

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo



Investigating the effects of structural parameters on the optical characteristics of add-drop filters

Esmat Rafiee*, Farzin Emami

Optoelectronic Research Center, Electronic Department, Shiraz University of Technology, Shiraz, Iran

ARTICLE INFO

Article history:
Received 17 February 2015
Accepted 30 October 2015

Keywords:
Add-drop filter
Central wavelength
Coupling coefficient
Free spectral range
Micro ring resonator

ABSTRACT

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 the central wavelength of the signal, free spectral range (FSR) and coupling coefficient have been studied. It is shown that, increasing the radius of MRR would decrease the central wavelength of the input signal; while increasing the width of MRR and waveguide and the gap between MRR and waveguide would increase it. It is found that, by enhancing the gap and width, coupling coefficient would increase at first but after a while it would diminish. It is also concluded that, increasing the radius and width would decrease FSR. The main goal of this research is to study the effects of structural parameters on the functionality of add-drop filters.

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 lots of attentions in recent years; as can be mentioned, investigations on the performance of an optical network in terms of crosstalk, based on optical add-drop multiplexer with Mach–Zehnder interferometer had been done [1]; also polymer MRRs with novel materials which are fascinating materials for electro-optic application had been proposed [2]. A compact parent-sub microring-resonator structure for highly integrated optical add-drop multiplexer (OADM) which has large FSR amounts that can be obtained by cascaded microring with relatively large diameter is suggested [3]. 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 [4]. In recent researches, in an add-drop filter by using the practical parameters sensing applications for the flow rate sensor, temperature sensors and medical sensors can be configured and used [5].

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 central wavelength of the signal, FSR and coupling coefficient. By changing these structural parameters in MRRs, add-drop filters can be used for different applications.

2. Theoretical analysis

2.1. Micro-ring resonator (MRR) and add-drop filter descriptions

MRRs act as wavelength selecting filters. Propagating specific wavelength is the operating principle of MRRs. Wavelengths satisfying the following equation can propagate in an MRR [6]:

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

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.

MRRs do not require facets or gratings for optical feedback. Integrated MRRs are used in wide ranges of applications including lasers, optical switches, tunable wavelength filters, add-drop multiplexers and biosensors [6]. An add-drop filter is consisted of one input, one output waveguide and an MRR; which acts as a localizing filter with four ports. The four ports are referred as input port, throughput port, drop port and add port; Usually, optical fields are

---

* Corresponding author. Tel.: +98 713 8349262; fax: +98 711 7353 502.
E-mail addresses: e.rafiee@sutech.ac.ir (E. Rafiee), emami@sutech.ac.ir (F. Emami).

http://dx.doi.org/10.1016/j.ijleo.2015.10.232

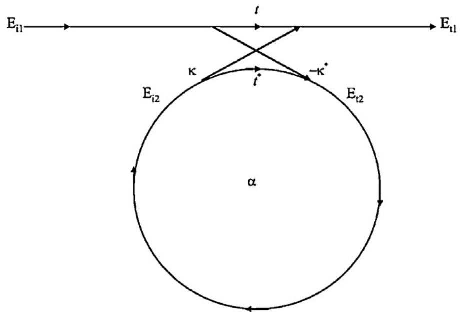


Fig. 1. Model of a single MRR and a waveguide [6].

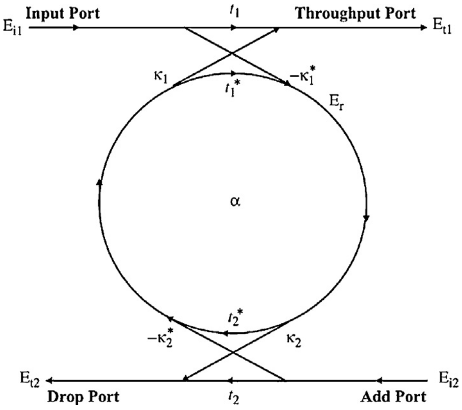


Fig. 2. Model of a basic add-drop filter [6].

launched to the filter through input and add ports, while outputs are obtained from drop and throughput ports. In operation, the large bandwidth signals can be generated within MRR devices if the Linear and nonlinear effects which are known respectively as group velocity dispersion (GVD) and self phase modulation (SPM) eliminate each other; In effect, there should be a balance between the nonlinear and dispersion lengths. Add-drop filters can be described by certain figures of merit which are also generally used to describe optical filters. One important figure is the distance between resonance peaks, which is called the free spectral range (FSR) [7].

The simple combination consisting of unidirectional coupling between an MRR with radius R and a waveguide, is described in Fig. 1. It should be assumed that a single unidirectional mode of the resonator is excited, the coupling is lossless and various kinds of losses occurring along the propagation of signal in the MRR are incorporated in the attenuation constant (α) [6].

The interaction between an MRR and the waveguide can be described by the following matrix relation [6]:

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

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. As shown in Eq. (3), the system of Fig. 1 would be reciprocal, if matrix of Eq. (2) is symmetric [6].

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

An add-drop filter is depicted in Fig. 2. The optical fields in this system can also be achieved by using Eq. (2); cause this system is a combination of an input waveguide and an MRR, an MRR and an output waveguide. So by applying Eq. (2) twice for Fig. 2, desired fields can be obtained [6].

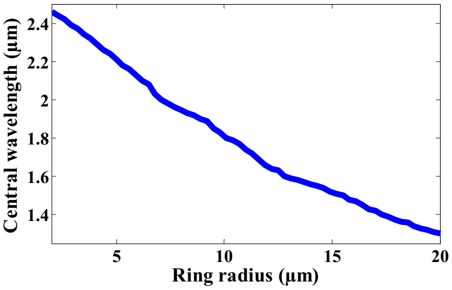


Fig. 3. Central wavelength of the signal vs. MRR radius variation.

2.2. Optical pulse propagating in the add-drop filter

Input pulse is applied into the input port (E_{i1} and E_{i2}) and then propagated toward the throughput (E_{t1}) and drop (E_{t2}) ports meanwhile it is coupled to MRR through the directional coupler; coupling coefficient (κ) is dependent to various parameters such as MRR radius, the width of MRR and waveguides and the gap between waveguides and MRR. Input pulse is sliced into smaller signals spreading over the spectrum while passing through MRR and localized signals can be obtained from drop and throughput ports [6,8].

Output fields which are obtained from drop and throughput ports, are given vs. input field by Eqs. (4) and (5) [6].

$$\left|\frac{E_{t1}}{E_{in}}\right|^2 = \frac{(1-\kappa_1) - 2\sqrt{1-\kappa_1}\sqrt{1-\kappa_2}e^{-(\alpha/2)L}\cos(k_n L) + (1-\kappa_2)e^{-\alpha L}}{1 + (1-\kappa_1)(1-\kappa_2)e^{-\alpha L} - 2\sqrt{1-\kappa_1}\sqrt{1-\kappa_2}e^{-(\alpha/2)L}\cos(k_n L)} \tag{4}$$

$$\left|\frac{E_{t2}}{E_{in}}\right|^2 = \frac{\kappa_1\kappa_2 e^{-(\alpha/2)L}}{1 + (1-\kappa_1)(1-\kappa_2)e^{-\alpha L} - 2\sqrt{1-\kappa_1}\sqrt{1-\kappa_2}e^{-(\alpha/2)L}\cos(k_n L)} \tag{5}$$

where $E_{\text{in}}, L = 2\pi R, \alpha, \kappa_1$ and κ_2 are the input fields, circumference of MRR, absorption coefficient and coupling coefficients, respectively. This structure allows specific wavelengths to pass and also localizes the output signal [6].

3. Results and discussions

The equations describing the optical pulse propagating in an add-drop filter are generally Maxwell's equations that can't be solved by any analytic solutions. Therefore, a numerical approach is often necessary to solve them. Finite-Difference and Split-Step Fourier method can be used as numerical methods. Split-Step Fourier method obtains an approximate solution by assuming that in propagating the optical field over a small distance (h), the dispersive and nonlinear effects can be assumed to act independently. Although the Split-Step Fourier method is commonly used for analyzing nonlinear effects in optical fibers, its use becomes quite time-consuming for an optical pulse propagating in an MRR. As Finite-Difference methods analyze the nonlinear effects much faster, they attract more attentions. Several Finite-Difference schemes have been used to solve the pulse propagating in an MRR; in which Finite-Difference-Time-Domain (FDTD) method is the most efficient one. The FDTD method is certainly more accurate because it solves Maxwell's equations directly with a minimum number of approximations. However, improvement inaccuracy is