An Optical Filter Based on a Double Ring Resonator System

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ABSTRACT

An optical filter based on the ring resonator waveguide is proposed. In this study, a Gaussian pulse is used as the optical input signal propagates into a double ring resonator system. The simulation results have shown the filtering signal outputs that can be obtained by using the proposed system. Where the filtering characteristics can be controlled by using the specify parameters, such as the rings radii and the coupling coefficient, of the proposed system. The potential of using such a double ring resonator device for optical communication application is performed and discussed.

Keywords: Ring resonator; optical communication; optical filter.

1. INTRODUCTION

Ring resonators have been receiving intensive attention as useful components in optical communication systems. Many of the potential applications are investigated and proposed, such as optical logic gates operator [1], [2], optical switch [3], nonlinear signal processing [4], [5], and optical filters [6] – [10]. For WDM system, optical filters are used to separate an optical channel from a combined optical signal without any necessary electronic systems. The simplest optical waveguide with a single pole filter response is referred as an add/drop filter, which is a structure of a single ring resonator with two couplers. The main performance characteristics of these resonators are the transmittance, free spectral range, finesse, and group delay, which have been demonstrated both theoretically and experimentally in many investigations [11], [12]. However, it still needs further development for improving the filtering response.

In this paper, our primary aim is approach to the analytical derivation of the optical transfer functions of a modified add/drop filter as the double ring resonator system that can be useful for the filtering application in optical communication systems. The filtering characteristics of the proposed ring resonator system are demonstrated and discussed.

2. THE DOUBLE RING RESONATOR SYSTEM

Light from monochromatic light source is used to be the input optical signal that launched into a ring resonator system as shown in Fig. 1. The optical input signal is considered as a function that consists of a constant light field amplitude, E_0, and random phase modulation, which is the combination of an attenuation term, α, and phase constant term, ϕ_0, results temporal coherence degradation. The time dependent input optical field, E_{in}, can be expressed as (1), where L is a propagation distance.

$$E_{in}(t) = E_0 \exp[-\alpha L + j\phi_0(t)] \tag{1}$$

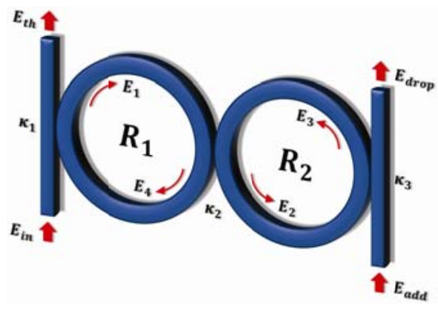

Fig. 1 *A schematic diagram of the proposed double ring resonator system.*

When a Gaussian pulse is input and propagated through the double ring resonator system as shown in

Fig. 1, the resonant outputs are formed. The relations between the output optical fields, $E_{th}(t)$ or $E_{drop}(t)$, and the input field, $E_{in}(t)$, in each roundtrip can be expressed as:

$$\left|\frac{E_{th}}{E_{in}}\right|^2 = \frac{(1-\kappa_1)y_1^2-2x_1x_2y_1\sqrt{1-\kappa_1}e^{-\frac{\alpha}{2}L_1}\cos(knL_1)+y_1y_2e^{-\alpha L_1}}{y_1^2-2x_1x_2y_1\sqrt{1-\kappa_1}e^{-\frac{\alpha}{2}L_1}\cos(knL_1)+(1-\kappa_1)y_1y_2e^{-\alpha L_1}} \quad (2)$$

$$\left|\frac{E_{drop}}{E_{in}}\right|^2 = \frac{y_1\kappa_1\kappa_2\kappa_3e^{-\frac{\alpha}{2}(L_1+L_2)}}{y_1^2-2x_1x_2y_1\sqrt{1-\kappa_1}e^{-\frac{\alpha}{2}L_1}\cos(knL_1)+(1-\kappa_1)y_1y_2e^{-\alpha L_1}} \quad (3)$$

where the optical fields, E_n, that propagate within the ring resonator system and the constant quantities of C_n, x_n and y_n are expressed as in Table 1 and Table 2.

Table 1 *The expression of the optical fields, E_n, and the constant quantities of C_n.*

The optical fields: E_n	The constant quantities: C_n
$E_1 = E_{in}j\sqrt{\kappa_1} + E_4\sqrt{1-\kappa_1}e^{-\frac{\alpha L_1}{2\,2}-jkn\frac{L_1}{2}}$	$C_1 = 1-\sqrt{1-\kappa_2}\sqrt{1-\kappa_3}e^{-\frac{\alpha}{2}L_2-jknL_2}$
$E_2 = E_1j\sqrt{\kappa_2}e^{-\frac{\alpha L_1}{2\,2}-jkn\frac{L_1}{2}} + E_3\sqrt{1-\kappa_2}e^{-\frac{\alpha L_2}{2\,2}-jkn\frac{L_2}{2}}$	$C_2 = \sqrt{1-\kappa_2}-\sqrt{1-\kappa_3}e^{-\frac{\alpha}{2}L_2-jknL_2}$
$E_3 = E_2\sqrt{1-\kappa_3}e^{-\frac{\alpha L_2}{2\,2}-jkn\frac{L_2}{2}}$ $(E_{add}=0)$	
$E_4 = E_3j\sqrt{\kappa_2}e^{-\frac{\alpha L_2}{2\,2}-jkn\frac{L_2}{2}} + E_1\sqrt{1-\kappa_2}$	

Table 2 *The expression of the constant quantities of x_n and y_n.*

The constant quantities: $x_n = \lvert C_n\rvert$	The constant quantities: $y_n = \lvert C_n\rvert^2$
$x_1 = 1-\sqrt{1-\kappa_2}\sqrt{1-\kappa_3}e^{-\frac{\alpha}{2}L_2}\cos(knL_2)$	$y_1 = 1-2\sqrt{1-\kappa_2}\sqrt{1-\kappa_3}e^{-\frac{\alpha}{2}L_2}\cos(knL_2)+(1-\kappa_2)(1-\kappa_3)e^{-\alpha L_2}$
$x_2 = \sqrt{1-\kappa_2}-\sqrt{1-\kappa_3}e^{-\frac{\alpha}{2}L_2}\cos(knL_2)$	$y_2 = (1-\kappa_2)-2\sqrt{1-\kappa_2}\sqrt{1-\kappa_3}e^{-\frac{\alpha}{2}L_2}\cos(knL_2)+(1-\kappa_3)e^{-\alpha L_2}$

Equations (2) and (3) indicate that the ring resonator system in particular case is very similar to a Fabry–Perot cavity, which has an input and output mirror with a field reflectivity, $(1-\kappa)$, and a fully reflecting mirror, κ, where κ is the coupling coefficient. The output optical fields at the Throughput port and the Drop port of the double ring resonator system are represent by E_{th} and E_{drop}, respectively. The input optical field, E_{in}, i.e. a Gaussian pulse, is input into the double ring resonator system with the appropriate parameters. The transmitted output signals can be controlled by choosing the suitable radius of the ring resonators and the coupling ratio. The waveguide (ring resonator system) loss is considered to be $\alpha = 0.5$ dB/mm. For simplification, the intensity relation does not take into account of the coupling losses [13].

From Fig. 1, in principle, the input light pulse is divided and sliced as the discrete signal propagated within the first R_1 ring and spread to the another ring R_2 with the direction as shown in the Fig.. Finally, the required signals can be obtained via the Throughput port and the Drop port of the double ring resonator system. In operation, an optical field as Gaussian pulse from a laser source at the specified wavelength is input into the system.

3. SIMULATION RESULTS

As shown in Fig. 2(a), the Gaussian pulse with specified wavelength ranges from 1545–1555 nm (C-band), 10 nm bandwidth, with peak power at 0.2 W is input into the double ring resonator system. In order to associate the system with the practical device [14], [15], the ring radii are as R_1 = 43 μm and R_2 = 29 μm. The selected parameters of the system are fixed to n = 3.47 (Si–Crystalline silicon), α = 0.5 dB/mm. In this investigation, the coupling coefficients, κ, of the double ring resonator system are ranged from 0.10 - 0.20. The output signals from the throughput port and drop port of the system are shown in Fig. 2(b) and 2(c), respectively, where the filtering bandwidth that can be obtained from the drop port is approximately of 0.10 nm at the FWHM with a center wavelength of 1.545698 μm.

Fig. 2(c) and 2(d) show the simulation results of the same an input signal with the appropriate ring parameters change for five sets as shown in the Fig.. The output signals from the throughput port and drop port of the system are superimposed in Fig. 2(c) and 2(d), respectively. The filtering center wavelengths that can be obtained from the drop port of each ring parameter set are approximately of 1.549425 µm, 1.549698 µm, 1.549950 µm, 1.550189 µm and 1.550410 µm, respectively, with 0.10 nm bandwidth at the FWHM and the mean value of a free spectral range between the two adjacent channels is approximately of 0.246 nm.

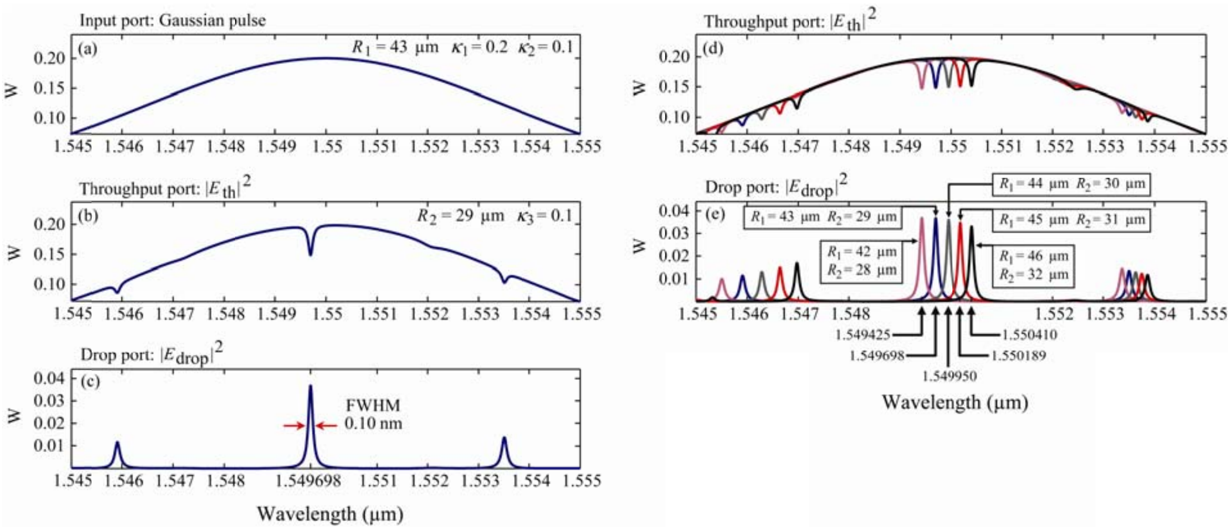

***Fig. 2** The simulation results for Gaussian input at wavelength ranges from 1.545 µm to 1.555 µm.*

4. Discussion

In practice, the appropriated system parameters, such as the ring radius and the coupling coefficients that are used in the simulation, might have unavoidable errors in the fabrication process for the practical device and result in the filtering characteristics of the designing system. However, the resonant response of a micro-ring resonator can be tuned by several methods. The most typical and straightforward approach for tuning the resonant response is to change the refractive index of the waveguide material, such as the thermo-optic effect method, which applies the heat to the material [16], the electro-optic effect method, which applies the electrical field to the waveguide [17]. The carrier injection, which changes the loss parameter of the system using optical pumping to create some free carriers (single photon or two-photon absorption) is also useful for tuning the optical waveguides [18]. Therefore, in order to function properly, the waveguide tuning techniques must be considered in the fabrication work, which are not considered in this investigation.

5. CONCLUSION

In this paper, an optical filter based on the double ring resonator system is presented. By using a Gaussian pulse inputs into the proposed system, the filtering bandwidth that can be obtained from the drop port of the system is approximately of 0.10 nm at the FWHM. The filtering characteristics can be controlled by using the specify parameters, such as the rings radii and the coupling coefficient, of the system. From the simulation results, the proposed ring resonator system can be useful as an effective optical filter for optical communication application.

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