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Research Paper

Effect of Center Wavelength on Improve FSR in MRR

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Abstract
We present the effect of the center wavelength on micro ring resonator performance via promising systems that can be used to solve many problems in communication systems. The results show that the free spectrum range (FSR) improves by increasing the center wavelengths of the soliton bands. The technological necessity of a large FSR can therefore be combined with small FWHM device requirements. The results show that a higher value of center wavelength can be used to enhance the FSR . This is obtained via the add/drop filter, which can be used to increase the channel capacity in the communication network. In this paper the best FSR and spectral width obtained are 0.598 nm and 0.03 nm, respectively. This result allows the channel capacity expanding due to the plentiful propagation spacing from the soliton collision. Thus the utilization of micro ring resonators system is possible for the expansion of the free spectrum range of light pulses.

Keywords: *Gaussian Soliton, Nonlinear Nano-ring Resonator, Free Spectrum Range, Finesse, Quality Factor*

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I. Introduction

Many research areas have shown the potential applications of the nano-ring resonators, mainly, in computer, communication, and signal processing in the nanoscale regime. Micro ring resonator (MRR) can be described as two or more waveguides. One of these waveguides is like a ring and the other is a straight waveguide, thus separated by very small gap that they interact with each other through it [1]. In the recent few years, the use of Nano ring resonator become important due to their versatile applications such as optical filters, optical delays, WDM multiplexers and on-off switches [2-4].

Light pulse passing through a nonlinear MRR device had been used by Yupapin and his group. They have reported significant results, where they derived and used the transfer functions of the output signal at the resonant condition [5-7]. They found that the broad spectrum of light pulse can be converted to the separate pulses. An optical soliton is known as a powerful laser pulse, which can be used to enlarge the optical bandwidth when propagating within the nonlinear nano ring resonator [8]. Firstly, the optimum energy is coupled into the waveguide by a larger effective core area of ring resonator device. Then the smaller one is connected to form the stopping behaviour. The filtering characteristics of the optical signal are presented within a ring resonator, where the suitable parameters can be controlled to obtain the required output energy. The soliton pulse keeps itself propagating through the ring resonator by using appropriate coupling power of MRR. Several parameters can be described the MRR performance, which are free spectrum range (FSR), full width half maximum (FWHM), quality factor (Q) and finesse (F). The high performance, low loss, high speed, low cost and simplicity in both fabrication and setup are needed in communication systems [9-11]. Optical channel filters with low insertion loss, wide FSR (high selectivity) and high stop band rejection are required in systems like dense wavelength division multiplexing (DWDM). Many theoretical and experimental designs have been proposed to optimize the filter response and other properties using various coupling coefficients and radii [8]. Yupapin and his group have shown important results by studying the influence of center wavelength on FSR using different systems. The problems of soliton-soliton interactions [12], collision [13], rectification [14] and dispersion management [15] are required to find a solution. Although the soliton interaction is elastic but interaction between solitons would affect DWDM [16]. However, this problem can be solved by designing suitable system with desirable free spectrum arrangement [17]. Therefore we are looking for a larger FSR and smaller FWHM output signal to improve the system performance. In this paper, we used different designed

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*Corresponding Author: A. Afroozeh (afroozeh@lar.ac.ir) systems to study the influence of radius, center wavelength and coupling coefficient of the multi-stage ring resonator on FSR and FWHM of the output signal.

II. Operating Principle

Optical soliton is a powerful laser pulses which can be used to expand the optical band width when propagating within the nonlinear nano ring resonator. Additionally, the large output gain is obtained by the soliton self-phase modulation. When the bright soliton pulse is injected to the multi-stage nano ring resonators, the input optical field (E_{in}) is given by

$$E_{in} = A \ \mathrm{sec}h\,[\frac{T}{T_o}]\,\exp\,[(\frac{z}{2L_D})] \tag{1}$$

where *A* and *z* are the amplitude of optical field and the distance of propagation, respectively. *T* is the required time of a soliton pulse to propagate. The dispersion length of the soliton pulse is described by $L_D = T^2_0/|\beta_2|I$ where β_2 is a propagation constant. Optical beams have an internal tendency to spread as they propagate in a homogeneous medium. The temporal soliton known as a pulse that keeps its temporal width constant as it propagates. An optical waveguide is an important device to present a balance between chromatic dispersion and phase shift modulation where the medium is uniform in the direction of propagation [16]. In the nano ring device, a balance should be achieved between the dispersion length (L_D) and the nonlinear length (L_{NL}) for the soliton pulse. The nonlinear length can be described by the relation ($L_{NL} = (1/\gamma\phi_{NL})$, where γ and ϕ_{NL} are coupling loss of the field amplitude and nonlinear phase shift, respectively. The refractive index of a nonlinear optical fiber ring is following the Kerr-type, so is given by

$$n = n_o + n_2 I = n_o + (\frac{n_2}{A_{eff}})P \tag{2}$$

where n_0 and n_2 are the linear and nonlinear refractive indexes, respectively. *I* and *P* are the optical intensity and optical power, respectively. A_{eff} represents the effective mode core area of the device. The resonant output is formed when a soliton pulse is input and propagated within a nanoring resonator. Therefore, the normalized output of the light field is the ratio between the output and input fields E_{out} (*t*) and E_{in} (*t*) in each roundtrip, which can be described as [18]

$$\left|\frac{E_{out}(t)}{E_{in}(t)}\right|^2 = (1-\gamma)\left[1 - \frac{(1-(1-\gamma)\,x^2)\kappa}{(1-x\sqrt{1-\gamma}\sqrt{1-\kappa})^2 + 4x\sqrt{1-\gamma}\sqrt{1-\kappa}\,\sin^2(\frac{\phi}{2})}\right] \tag{3}$$

In fact, the approximate form of Eq. 3 shows that the precise case of a ring resonator is equivalent to a Fabry-Perot cavity [19].

An input and output mirrors of Fabry-Perot cavity have a field reflectivity (1- κ), and a fully reflecting mirror, respectively. In Eq. 3, κ is the coupling coefficient, and $x = \exp(-\alpha L / 2)$ represents a roundtrip loss coefficient. The waveguide length and linear absorption coefficient is given by L and α, respectively. $\Phi = kLn_0$ and $\Phi_{NL} = kLn_2|E_{in}|^2$ are the linear and nonlinear phase shifts. The wave propagation number in a vacuum is given by $k = 2\pi/\lambda$. In this work, the amplified constant output signals are required to verify the large bandwidth output. Hence, when the output field is launched into the other ring resonators, the iteration method is used to achieve the results as shown in Eq. 3. The soliton pulse as described in Eq. 1 is input into a nonlinear nano-ring resonator. Applying the appropriate parameters and by using Eq. 3, the chaotic signal is achieved. To retrieve the signals from the obtained chaotic noise, Chaichuay and Yupapin suggested to utilize the add/drop device with suitable parameters. The optical outputs of a ring resonator add/drop filter can be given by the Eqs. 4 and 5 [20].

$$\left|\frac{E_t}{E_{in}}\right|^2 = \frac{(1-\kappa_3) - 2\sqrt{1-\kappa_3}\cdot\sqrt{1-\kappa_4}\,e^{-\frac{\alpha}{2}L}\cos(k_n L) + (1-\kappa_4)e^{-\alpha L}}{1 + (1-\kappa_3)(1-\kappa_4)e^{-\alpha L} - 2\sqrt{1-\kappa_3}\cdot\sqrt{1-\kappa_4}\,e^{-\frac{\alpha}{2}L}\cos(k_n L)} \tag{4}$$

and

$$\left|\frac{E_d}{E_{in}}\right|^2 = \frac{\kappa_3\kappa_4 e^{-\frac{\alpha}{2}L}}{1+(1-\kappa_3)(1-\kappa_4)e^{-\alpha L} - 2\sqrt{1-\kappa_3}\cdot\sqrt{1-\kappa_4}e^{-\frac{\alpha}{2}L}\cos(k_n L)} \tag{5}$$

where E_t and E_d are the optical outputs of the throughput and drop ports, respectively. The propagation constant is given by β=k_{neff}. The effective refractive index of the waveguide is represented by n_{eff}. The circumference of the ring is L=2πR where R is the radius of the ring. When light travels in a MRR at the point where the ring becomes close to the straight waveguide, only the resonance wavelength of light is coupled into the ring. By using the particular parameters of the add/drop device, the chaotic noise cancellation can be achieved. At the resonance wavelength band λ_r, the desired signals can be filtered and reverted by achieving the chaotic cancellation. The coupling coefficient of add/drop filters are κ_3 and κ_4.The nano ring resonator loss and the fractional coupler intensity loss are α=0.5dBmm^{-1} and γ=0.1, respectively. The nonlinear refractive index is neglected for add/drop device, [21].

2.1 FSR Expansion

Several important parameters must be selected carefully for the purpose of improvement the MRR systems. One of the key specifications of the ring resonator is the free spectrum range (FSR). The separation between two consecutive resonant peaks at the drop port is known as FSR. It is an important parameter when MRRs are used as filters or sensors [22]. The best performance of MRR is required higher FSR, where its mathematical expression can be given by terms of frequency (*f*) or wavelength (λ) by Eqs. 6 and 7, respectively [23].

$$\mathrm{FSR} = \Delta f = \frac{c}{n_g L} \tag{6}$$

$$\mathrm{FSR} = \Delta\lambda = \frac{\lambda^2}{n_g L} \tag{7}$$

The relationship in Eq. 7 indicates that to improve the FSR a higher value of λ is desired. In order to achieve high FSR, the ring must be small, because the FSR is inversely proportional to the ring radius, where L=2πR.

2.2 FWHM Reducing

Another key specification is the full width at half maximum (FWHM) which can be reducing at lower coupling, wavelength and larger ring radii [24]. The sensitivity of the MRR filter improves, at lower values of FWHM. By decreasing κ, both FWHM and attenuation is reduced [25].

III. Results and Discussion

The first proposed system consists of two ring resonators and add drop device as shown in Fig. 1. An optical field in the form of soliton pulse with 20 ns pulse width and peak power at 2 W is input into the system. The suitable ring parameters are used, for instance, ring radii R_1= 16.0 µm, R_2= 5.0 µm, and R_d= 25.0 µm. For practical device, the suitable system achieved by fixing the selected system parameters to; n_o = 3.34 (**InGaAsP/InP**), A_{eff} = 0.50, 0.25 µm ^{2} for a nano ring and add/drop ring resonator, respectively, α = 0.5 dBmm^{-1} and γ = 0.1. The nonlinear refractive index of the nano ring is n_2=2.2 x 10^{-17} m^2/W. The coupling coefficient (κ) of the nano ring resonator increases from 0.55 to 0.90 [18].

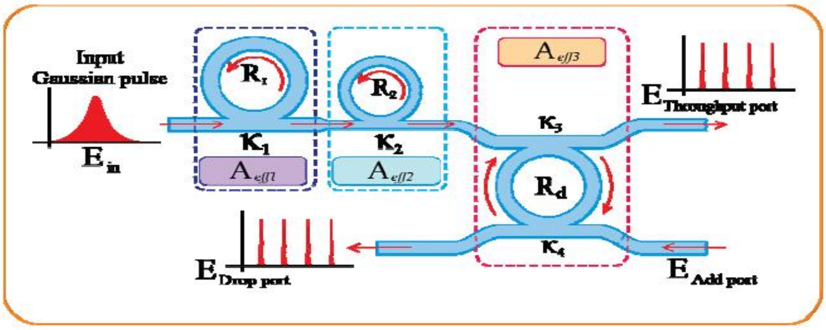

Fig. 1. A schematic of a MRR filter system, where R_s: ring radii, κ_s: coupling coefficients, R_d: an add/drop ring radius, A_{effs}: Effective areas.

In applications, the specific output wavelength range can be filtered after the second ring by using the add/drop filter device. We found that the output signal with FSR and FWHM of 0.05 nm and 0.03 nm are obtained, respectively when κ_3 and κ_4 are fixed to 0.9. The enhancement of the FSR achieved in this system when κ_3 and κ_4 are fixed to 0.8. By increasing the center wavelength from 0.6 to 1.5 µm, the FSR and FWHM is increased from 0.12 to 3 nm and 0.07 to 1 nm, respectively [15]. The second system consists of three rings and add/drop device, where R_1=15, R_2= 10, R_3=5 µm, and for add/drop filter R_d=155 µm and κ_3= κ_4=0.1 as shown in Fig. 2. An important result can be obtained by varying the center wavelength from 1.3 to 1.5 µm. This increasing raises FSR and FWHM from 0.535 to 0.598 nm and 0.02 to 0.03 nm respectively as shown in Fig. 3 [26].

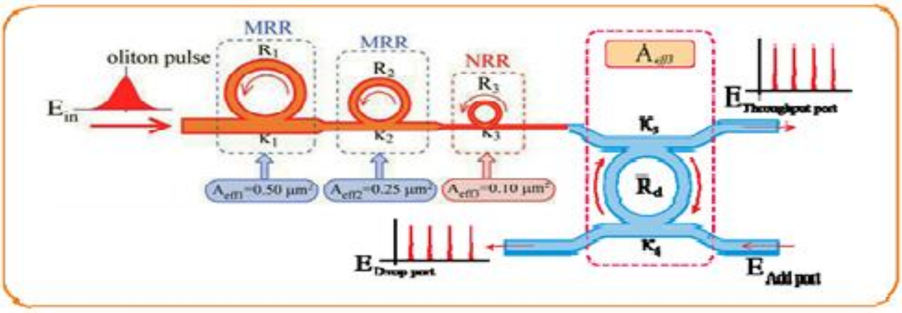

Fig. 2. A schematic of a MRR filter system, where R_s: ring radii, κ_s: coupling coefficients, R_d: an add/drop ring radius, A_{effs}: Effective areas.

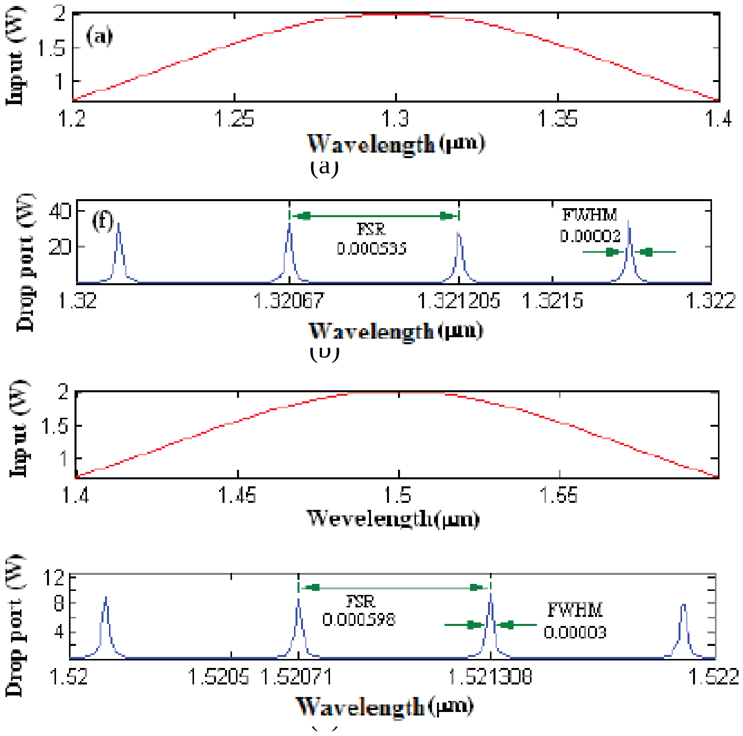

Fig. 3. Results of the spatial pulses, where (a) the input soliton with center wavelength at 1,300 nm, (b) the drop port signals (c) the input soliton with center wavelength at 1,500 nm, (d) the drop port signals.

IV. Conclusion

When the soliton pulse is propagated within the nonlinear microring and nanoring resonators, many promising results can be obtained. The technological necessity of a large FSR can therefore be combined with small FWHM device requirements. The results show that a higher value of center wavelength can be used to enhance the FSR. The enhanced FSR and FWHM that achieved are 0.598 nm and 0.03, respectively. This fits the communications design requirements to have the largest FSR possible for the system. Practically to avoid and control the soliton collision, the values of FSR and FWHM must be enhanced. Thus the utilization of MRR system is possible for the expansion of the free spectrum range of light pulses.

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