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Full width at half maximum (FWHM) analysis of solitonic pulse applicable in optical network communication

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Abstract: In this paper, we propose a system of microring resonator (MRR). This system uses a laser diode input which can be incorporated with an optical add/drop filter system. When light from the laser diode feedbacks to the fiber ring resonator, the pulses in the form of soliton can be generated by using appropriate fiber ring resonator parameters and also the input power. The filtering process occurs during the propagation of the pulse within the ring resonators. The full width at half maximum (FWHM) or bandwidth characterization of the pulse can be performed using the proposed system. Results obtained have established particular possibilities from the application such as optical network communication. The obtained results show the effects of coupling coefficients and ring radius on the bandwidth of the soliton pulse, where the graph of the FWHM versus the variable parameters such as the radius and coupling coefficient are presented.

Keywords: Optical Network Communication, Soliton, FWHM, Pulse Bandwidth Characterization

1. Introduction

In optical communication, soliton controls within a semiconductor add/drop filter have numerous applications [1, 2]. Microring resonators (MRRs) are the types of Fabry-Pérot resonators, which can be readily integrated in array geometries for useful functions in areas such as optical communication [3, 4], signal processing in the nanoscale regime [5]. Its nonlinear phase response can also be readily incorporated into an interferometer system to produce a specific intensity output function [6, 7]. One interesting result emerges through the use of an add/drop system, which is a good candidate for nanoscale interferometer applications [8, 9]. One new feature of this specific type of ring resonator, which introduces a system of nanoscale-sensing transducers based on the add/drop ring resonator was presented by Amiri et al [10, 11]. They have shown that the multisoliton can be generated and controlled within a modified add/drop ring resonator [12, 13].

Nonlinear behaviors associated with light traveling inside a fiber optic ring resonator can be caused by the effects such as the Kerr effects, four-wave mixing, as well as the external nonlinear pumping electrical power [14, 15]. This sort of

nonlinear behaviors usually are called chaos, bistability, in addition to bifurcation. Additional information regarding these kinds of behaviors in a micro ring resonator evidently are defined by Amiri *et al* [16, 17]. Nonetheless, aside from the penalties of the nonlinear behaviors of light traveling within the fiber ring resonator, there are several benefits that can be employed by the communication methods in order to examine the obtained result. One called chaotic behavior which has been employed to make the benefit within digital or optical communications [18, 19]. In this paper we consider the characterization of soliton pulses using MRRs. The bandwidth and free spectrum range of the soliton pulses can be manipulated using suitable parameters of the system.

2. Theory of The Research

The system of the ring resonator interferometer is shown in Figure 1.

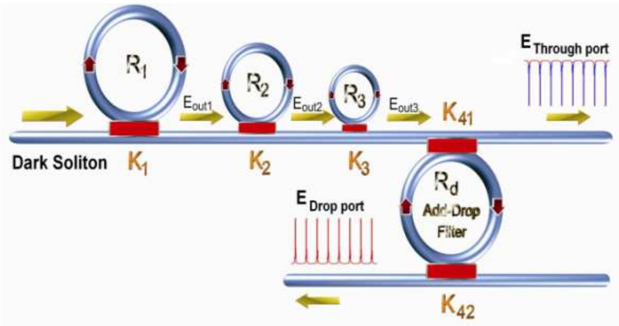

Figure 1. *A schematic of the proposed MRR's system, where R_s: ring radii, κ_s: coupling coefficients, R_d: an add/drop ring radius, A_{effs}: effective areas*

The input optical fields (E_{in}) in the form of dark soliton can be expressed by [20]

$$E_{in}(t) = A \tanh\left[\frac{T}{T_0}\right]\exp\left[\left(\frac{iz}{2L_D}\right) - i\omega_0 t\right] \quad (1)$$

Here A and z are the optical field amplitude and propagation distance, respectively [21]. T represents the soliton pulse propagation time in a frame moving at the group velocity, $(T = t - \beta_1 \times z)$, where β_1 and β_2 are the coefficients of the linear and second order terms of the Taylor expansion of the propagation constant [22-24]. The dispersion length of the soliton pulse can be defined as $L_D = T_0^2/|\beta_2|$, where the frequency carrier of the soliton is ω_0 [25]. The intensity of soliton peak is $(|\beta_2/\Gamma T_0^2|)$, where T_o is representing the initial soliton pulse propagation time [26, 27]. A balance should be achieved between the dispersion length (L_D) and the nonlinear length ($L_{NL} = 1/\Gamma\phi_{NL}$), where $\Gamma = n_2 \times k_0$, is the length scale over which disperse or nonlinear effects causes the beam becomes wider or narrower. Here, $L_D = L_{NL}$ [28]. The total index (n) of the system is given by [29, 30].

$$n = n_0 + n_2 I = n_0 + \left(\frac{n_2}{A_{eff}}\right)P, \quad (2)$$

where n_0 and n_2 are the linear and nonlinear refractive indices, respectively. I and P are the optical intensity and optical power, respectively [31, 32]. A_{eff} represents the effective mode core area of the device, where in the case of MRRs, the effective mode core areas range from 0.50 to 0.1 µm2. The normalized output of the light field is defined as [33, 34].

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

Here, κ is the coupling coefficient, $x = \exp(-\alpha L/2)$ represents a round-trip loss coefficient, $\phi = \phi_0 + \phi_{NL}$, $\phi_0 = kLn_0$ and $\phi_{NL} = kLn_2|E_{in}|^2$ are the linear and nonlinear phase shifts and $k = 2\pi/\lambda$ is the wave propagation number and γ is the fractional coupler intensity loss [35, 36]. Here L and α are the waveguide length and linear absorption coefficient, respectively [37, 38]. The input power insert into the input port of the add/drop filter system. E_{th} and E_{drop} represent the optical electric fields of the through and drop ports, respectively expressed by equations (4) and (5) [39, 40],

$$|E_{th}|^2/|E_{out3}|^2 = \frac{(1-\kappa_{41}) - 2\sqrt{1-\kappa_{41}}\cdot\sqrt{1-\kappa_{42}}\,e^{-\frac{\alpha}{2}L_d}\cos(k_n L_d) + (1-\kappa_{42})e^{-\alpha L_d}}{1 + (1-\kappa_{41})(1-\kappa_{42})e^{-\alpha L_d} - 2\sqrt{1-\kappa_{41}}\cdot\sqrt{1-\kappa_{42}}\,e^{-\frac{\alpha}{2}L_d}\cos(k_n L_d)}$$

$$|E_{drop}|^2/|E_{out3}|^2 = \frac{\kappa_{41}\kappa_{42}e^{-\frac{\alpha}{2}L_d}}{1 + (1-\kappa_{41})(1-\kappa_{42})e^{-\alpha L_d} - 2\sqrt{1-\kappa_{41}}\cdot\sqrt{1-\kappa_{42}}\,e^{-\frac{\alpha}{2}L_d}\cos(k_n L_d)}$$

where $|E_{th}|^2$ and $|E_{drop}|^2$ are the output intensities of the through and drop ports respectively [41, 42].

3. Results and Discussion

Temporal profile of the input dark soliton pulse can be seen from Figure 2, where the input of the pulse is 350 mW with central wavelength of 1.3 µm. The ring radii of the rings are selected to R_1=30µm, R_2=12µm and R_3=5µm, where κ_1=0.7, κ_2=0.9 and κ_3=0.93.

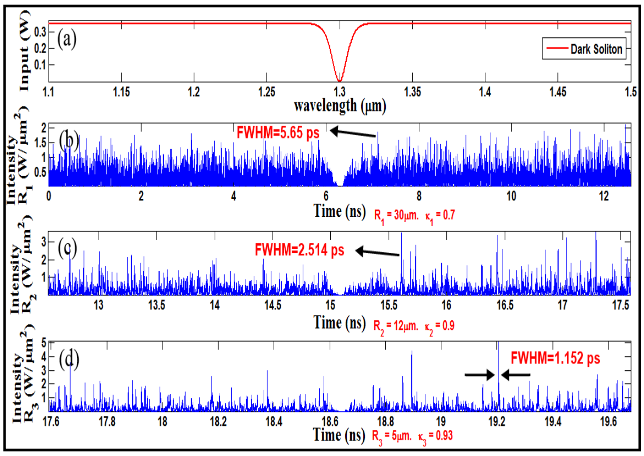

Figure 2. *Results of temporal chaotic signals generation within a series of MRRs with dark soliton input*

In Figure 2(a), the dark soliton is input and propagates within the ring system. In Figure 2(b), the input pulse is split to many noisy and chaotic signals in the form of temporal signals with FWHM=5.65 ps, where Figures 2(c) and 2(d) show the temporal signals seen within the range of 12.5-17.5 ns and 17.6-19.6 ns with FWHM of 2.514 and 1.152 ps respectively. The shorter bandwidth of the chaotic signals can be obtained by adding more ring resonators. The effects of the ring's radius and coupling coefficients of the ring resonators on the FWHM of the chaotic pulses are shown by Figure 3.

Therefore, the chaotic signals can be generated using the input dark soliton pulse. In order to use the chaotic signals for long distance communication, the use of input bright soliton is recommended, where the security of soliton signals can be performed when the input dark soliton is inserted into the system and split into chaotic signals.

Optical field of the Gaussian pulse can be inserted into the input port of the multi-stage MRR's system shown in Figure 4. Considering the proposed system, the radii of the rings have been selected as $R_1 = 15\mu m$, $R_2 = 9\mu m$, $R_3 = 7\mu m$, and $\kappa_1 = 0.96$, $\kappa_2 = 0.94$, $\kappa_3 = 0.92$, where the add/drop filter has a radius of $R_d = 78\mu m$ and coupling coefficients of $\kappa_4 = \kappa_5 = 0.1$. Some parameters of the system are fixed such as n_0=3.34 (InGaAsP/InP), A_{eff}=0.50, 0.25 and 0.10μm^2 for the microrings, α=0.5dBmm^{-1}, γ=0.1. The nonlinear refractive index of the MRRs is n_2=2.2 x 10^{-17} m^2/W.

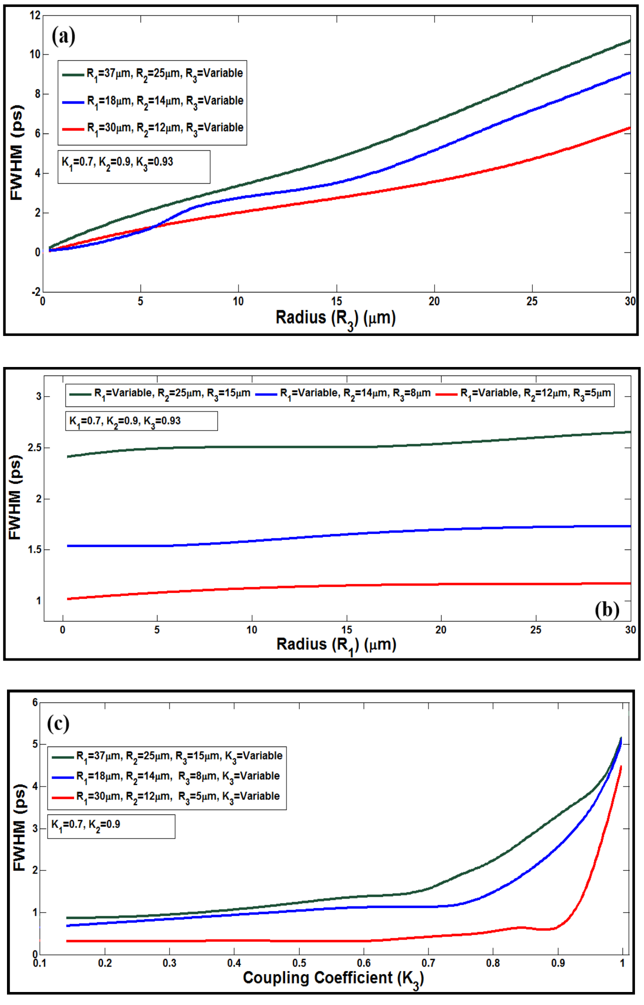

Figure 3. *Results of FWHM, where (a): radius of the third ring varies, (b): radius of the first ring varies, (c): coupling coefficient of the third ring varies*

The input Gaussian laser pulse with power of 2W is introduced into the MRR's system shown in Figure 4(a). The output powers from three ring resonators are shown in Figures 4(b-d), where Figures 4(e-f) show the output power from the throughput port in terms of wavelength. The FWHM and FSR of the spatial soliton pulses are 50 pm and 1440 pm respectively. Figures 4(g-h) show the output power from the drop port of the system with the same FWHM and FSR.

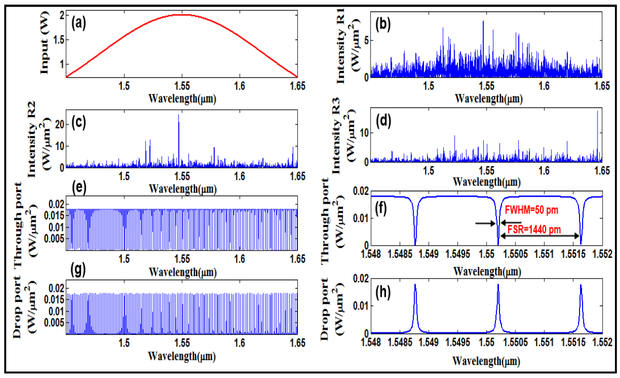

Figure 4. *Results of spatial dark and bright soliton generation, where (a): input Gaussian beam, (b-d): large bandwidth signals, (e-f): dark soliton at the through port with FWHM and FSR of 50 pm and 1440 pm respectively, (g-h): bright soliton at the drop port with FWHM and FSR of 50 pm and 1440 pm respectively*

The advantage of this technique is its ability to operate on the trains of low-power picometer optical pulses. In order to improve the system, narrower soliton pulses are recommended, where the attenuation of such signals during transmission lessens when compared to the conventional peaks of micrometre laser pulses. Therefore, the bandwidth varies with respect to the variation of the coupling coefficients of the add/drop filter system shown in Figure 5.

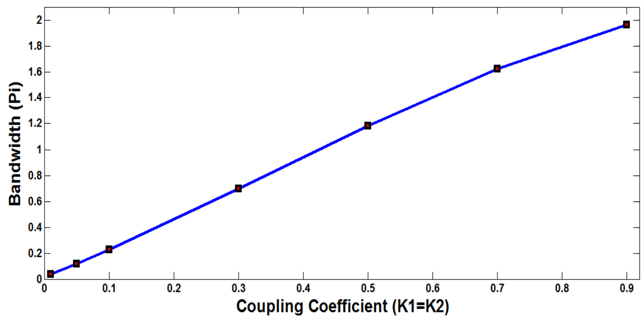

Figure 5. *Result of the single bandwidth manipulation respect to variation of the coupling coefficients of the add/drop filter system*

As it can be seen from the Figure 5, the increase of the coupling coefficients of the add/drop filter system leads to increase of the bandwidth of the soliton pulse. Thus in order to use ultra-short soliton pulses applied in optical communication, lower coupling coefficient is recommended where, the power control can be performed within the system [43-45].

Using this method, the output power of the system can be simulated successfully. This system act as a passive filter system which can be used to split the input power and generate chaotic signals using suitable parameters of the system [46-48]. Therefore input power of Gaussian beam can be sliced to smaller peaks as chaotic signals. The chaotic signals have many applications in optical communications.

4. Conclusion

Soliton signals can be generated using the input laser power propagating within a nonlinear ring resonator, where the required signals can be recovered and manipulated by using appropriate parameters of the system such as the ring radius and coupling coefficients. Results obtained have shown that the FWHM of the generated soliton pulses can be affected by vary the parameters. Here, the effects of coupling coefficients and radius on the bandwidth of the soliton pulse have been presented.

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