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New wavelength division multiplexing bands generated by using a Gaussian pulse in a microring resonator system

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Abstract

We propose a novel system that can be used to generate the new optical communication bandwidths (wavelength bands) using a Gaussian pulse propagating within a nonlinear microring resonator system. By using the wide range of the Gaussian input pulses, for instance, when the input pulses of the common lasers with center wavelengths from 400-1,400 nm are used. Results obtained have shown that more available wavelength bands from the different center wavelengths can be generated, which can be used to form new dense wavelength division multiplexing bands, whereas the use of the very high channel capacity for personal wavelength and network applications is plausible.

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1. Introduction

Gaussian soliton is become a very attractive tool in the area of soliton investigation, whereas the simple system arrangement can be setup to form the soliton behavior within the medium for various investigations. Many research works have reported in both theoretical and experimental works using a common Gaussian pulse for soliton study [1]. Recently, Yupapin and Suwancharoen [2] have reported the interesting results of light pulse propagating within a nonlinear microring device, whereas the transfer function of the output at resonant condition is derived and studied. They found that the broad spectrum of light pulse can be transformed to the discrete pulses. An optical soliton is recognized as a powerful laser pulse, which can be used to enlarge the optical bandwidth when propagating within the nonlinear microring resonator [3, 4]. Moreover, the superposition of self-phase modulation (**SPM**) soliton pulses, where either bright or dark [5] solitons can generate the large output power. For further reading, many earlier works of soliton applications in either theory or experimental works are found in a soliton application book by Hasegawa et

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al [6]. Many of the soliton related concepts in fiber optic are discussed by Agrawal] [7]. The problems of soliton-soliton interactions [8], collision [9], rectification [10] and dispersion management [11] are required to solve and address. Therefore, in this work we are looking for a common laser source that can be used to extend the used/installed wavelength band in the public network, especially, with the broad center wavelengths such as 400-1,400 mm are used. The use of a Gaussian pulse to form a broad wavelength bands within a microring resonator system is recommended, where the other problems such as output power and signal collision can be solved. One of the results has shown that by using the center wavelength at 1,300 with suitable parameters, the Gaussian soliton generation is plausible. Moreover, most of the results have shown that the optical signals, i.e. Gaussian pulse can be amplified within the nonlinear ring resonator system.

2. Operating Principle

Light from a monochromatic light source is launched into a ring resonator with constant light field amplitude (E_0) and random phase modulation (ϕ_0), which results in temporal coherence degradation. Hence, the time dependent input light field (E_{in}), without pumping tem, can be expressed as

$$E_{in}(t) = E_0 \exp^{j\phi_0(t)}. \tag{1}$$

We assume that the nonlinearity of the optical fiber ring is of the Kerr-type, i.e., the refractive index is given by

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

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. The effective mode core area of the device is given by A_{eff}. For the microring and nanoring resonators, the effective mode core areas range from 0.50 to 0.1 μm^2 [12]

When a Gaussian pulse is input and propagated within a fiber ring resonator, the resonant output is formed, thus, 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 expressed as[13]

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

Equation (3) indicates that a ring resonator in the particular case is very similar to a Fabry-Perot cavity, which has an input and output mirror with a field reflectivity, (1-κ), and a fully reflecting mirror. κ is the coupling coefficient, The input optical field as shown in equation (1), i.e. a Gaussian pulse, is input into a nonlinear microring resonator. By using the appropriate parameters, the chaotic signal is obtained by using equation (3). To retrieve the signals from the chaotic noise, we propose to use the add/drop device with the appropriate parameters. This is given in details as followings. The optical outputs of a ring resonator add/drop filter can be given by the equations (4) and (5) [13].

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

and

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

where E_t and E_d represents the optical fields of the throughput and drop ports respectively. Where $\beta = kn_{eff}$ represents the propagation constant, n_{eff} is the effective refractive index of the waveguide, and the circumference of the ring is $L = 2\pi R$, here R is the radius of the ring. In the following, new parameters will be used for simplification, where $\phi = \beta L$ is the phase constant. The chaotic noise cancellation can be managed by using the specific parameters of the add/drop device, which the required signals at the specific wavelength band can be filtered and retrieved. $K_1$and K_2 are coupling coefficient of add/drop filters, $k_n = 2\pi / \lambda$ is the wave propagation number for in a vacuum, and the waveguide (ring resonator) loss is α = 0.5 dBmm^{-1}. The fractional coupler intensity loss is γ = 0.1. In the case of add/drop device, the nonlinear refractive index is neglected.

and $x = \exp(-\alpha L/2)$ represents a roundtrip loss coefficient, $\phi_0 = kLn_0$ and $\phi_{NL} = kLn_2 |E_{in}|^2$ are the linear and nonlinear phase shifts, $k = 2\pi / \lambda$ is the wave propagation number in a vacuum. Where L and α are a waveguide length and linear absorption coefficient, respectively**.** In this work, the iterative method is introduced to obtain the results as shown in equation (3), similarly, when the output field is connected and input into the other ring resonators.

Fig. 1. A schematic of a Gaussian soliton generation system, where R_s: ring radii, κ_s: coupling coefficients, R_d: an add/drop ring radius, A_{eff}s: Effective areas.

3. Results

The schematic diagram of the proposed system is as shown in Fig. 1. An optical field in the form of Gaussian pulse with 20 ns pulse width, peak power at 2 W is input into the system. The large bandwidth signals can be seen within the second microring device, and shown in Fig. 2. 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. In order to make the system associate with the practical device [14, 15], the selected parameters of the system are fixed to λ_0 = 400 nm, n_0 = 3.34 (**InGaAsP/InP**), A_{eff} = 0.50, 0.25 μm^2 for a microring and add/drop ring resonator, respectively, α = 0.5 dBmm^{-1}, γ = 0.1. The coupling coefficient (kappa, κ) of the microring resonator ranged from 0.55 to 0.90. The nonlinear refractive index of the microring is n_2=2.2 x 10^{-17} m^2/W. In this case, the wave guided loss used is 0.5dBmm^{-1}. The input Gaussin pulse is chopped (sliced) into a smaller signal spreading over the spectrum as shown in Fig. 2 (b) and (c), which is shown that the large bandwidth signal is generated within the second ring device. The signal amplification is occurred within the second mocroring resonator, the maximum output of 500 W is obtained as shown in Fig, 2(c). In applications, the specific output wavelength range can be filter after the second ring by using the add/drop filter device. We have found that the large bandwidth signal can be selected(filtered) as shown in Fig. 2(d), the output signal with free spectrum range(FSR) and spectral width(Full Width at Half Maximum, FWHM) of 381 nm and 30 pm are obtained, respectively. Similarly, more results of the different center wavelengths are shown in Figs. 3-6.

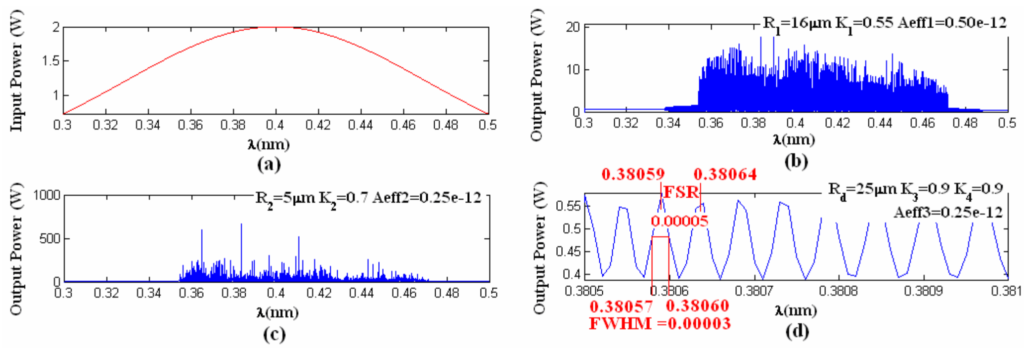

Fig. 2. Results of the spatial pulses with center wavelength at 400 nm, where (a) the input Gaussian pulse, (b) the large bandwidth signal, (c) the filtering and amplifying signals, (d) the drop port signals.

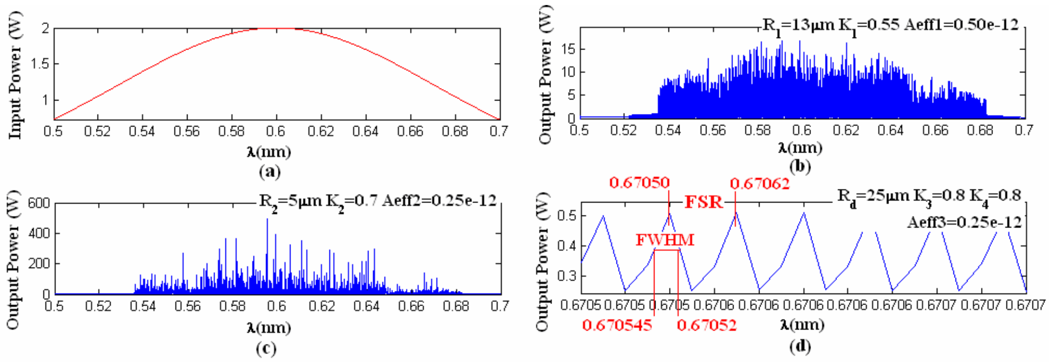

Fig. 3. Results of the spatial pulses with center wavelength at 600 nm, where (a) the input Gaussian pulse, (b) the large bandwidth signal, (c) the filtering and amplifying signals, (d) the drop port signals.

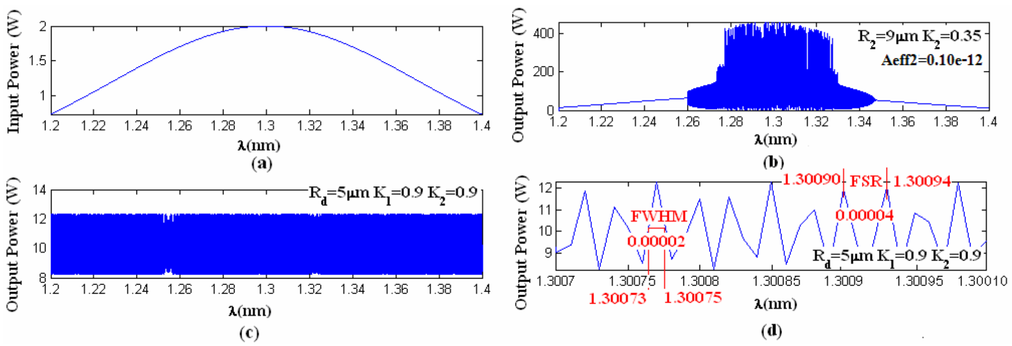

Fig. 4. Results of the spatial pulses with center wavelength at 1,300 nm, where (a) the input Gaussian pulse, (b) the large bandwidth signal, (c) the filtering and amplifying signals(soliton), (d) the drop port signals.

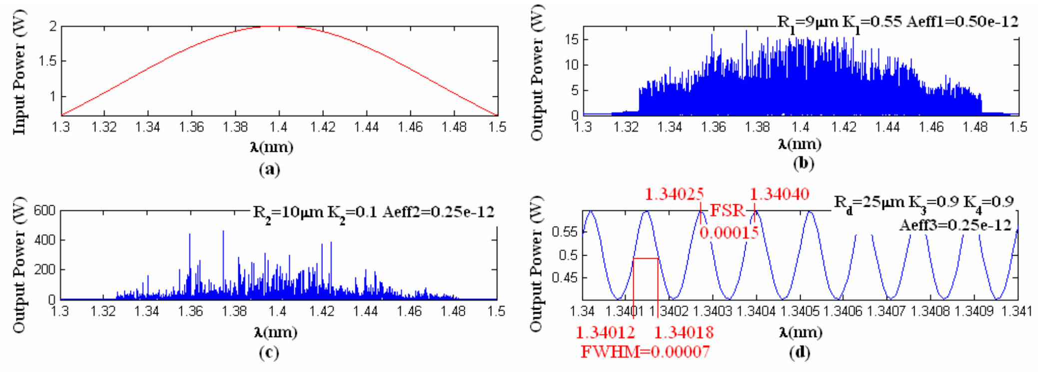

Fig. 5. Results of the spatial pulses with center wavelength at 1,400 nm, where (a) the input Gaussian pulse, (b) the large bandwidth signal, (c) the filtering and amplifying signals, (d) the drop port signals.

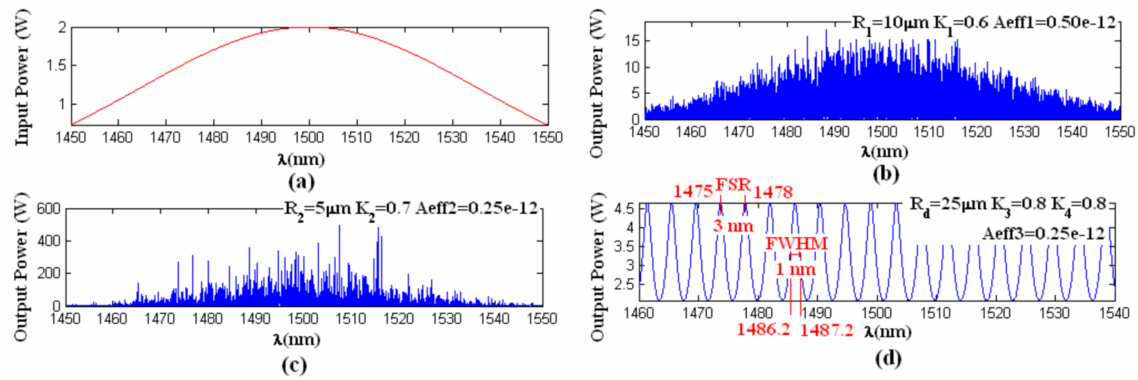

Fig. 6. Results of the spatial pulses with center wavelength at 1,500 nm, where (a) the input Gaussian pulse, (b) the large bandwidth signal, (c) the filtering and amplifying signals, (d) the drop port signals.

4. Conclusion

We have shown that the multi-wavelength bands can be generated by using a Gaussian pulse propagating within the microring resonator system, which is available for the extended DWDM with the wavelength center at 400-1,400 nm, which can be used in the existed public network. Results obtained have shown that the spatial pulses width of 30 pm and the spectrum range of 400 pm can be generated and achieved. Moreover, the problem of signal collision can be solved by using the suitable FSR design [13], while the dispersion effect is minimized when the center wavelength at 1.30 μm. Furthermore, the Gaussian pulse output power can be amplified, which can provide the power budget for long distance link. We find that the maximum power of 400 W can be obtained, however, the coupling coefficient of the add/drop filter is the major parameter of the required coupling output power, for instance, the output power of 0.5 W is obtained as shown in Fig. 5(d), where the parameters are R_d= 25.0 μm, κ_3=κ_4=0.9. This means that the use of wavelength 0.4-1.40 μm (Gaussian pulse) for DWDM via optical communication is plausible, which can be used with the existed public network installation.

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