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SIMULATION OF SOLITON AMPLIFICATION IN MICRO RING RESONATOR FOR OPTICAL COMMUNICATION

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Abstract. A system consisting of a series of micro ring resonator (MRR) is proposed. Optical dark and bright soliton pulses propagating through the nonlinear waveguides are amplified. This system can be used in long distance communication system. The dark and bright soliton is input into the designed system. The nonlinear effect contributes to segregation of continuous soliton pulse into smaller pulses. In this way large bandwidth of optical signals can be obtained. The power amplification occurs when the soliton propagates along the MRRs systems. In this research the concern is the generation of amplified pulse of optical dark and bright soliton while propagating in the MRR device. Simulated results show the amplification of bright soliton in which the input power increases from 0.6 W to 10.9331 W and 7.684 W at the trapped wavelength of 1520.428 nm and 1519.912 nm respectively.

Keywords: Optical soliton; dark soliton; bright soliton; soliton amplification

1.0 INTRODUCTION

A number of investigations have been done on the behaviors of dark and bright soliton [1, 2]. The usage of a soliton pulse within a *MRR* for communication security and its application for long distance communication has been studied for nearly two decades [3]. Dark soliton amplitude is vanished or minimized during the propagation in a medium. Thus the detection of the dark soliton is difficult. The investigation on dark soliton behaviors has revealed that the dark soliton can be amplified and finally detected [4, 5]. This means that we can amplify dark soliton due to the low level intensity of the peak power.

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Yupapin and Suwancharoen have showed [6] that the nonlinear behavior of light pulse traveling within a *FORR* in which the nonlinear Kerr type is the major effect within the fiber ring [7-8]. They found that the broad spectrum of light pulse can be transformed into discrete pulses. When the clean dark soliton is input and sliced, the noisy signals for security purpose within the nonlinear MRR system can be transmitted into the transmission link safely [9, 10]. However, the power attenuation becomes a problem in a long distance link. For security purposes, a dark soliton pulse is recommended to overcome such a problem. In this study, we will examine the generation and utilization of amplified signal for long distance communication link. The results are based on simulation programming, using *MATLAB* software.

2.0 PROPAGATION OF SOLITON PULSE INSIDE MRR SYSTEM

The optical soliton is input into the first proposed system shown in Figure 1. The power can be amplified within this system. Here a stationary dark and bright solitons pulses are introduced into the *MRR* system [11]. The input optical fields (E_{in}) of the bright and dark soliton pulses are given by [12, 13] respectively.

$$E_{in} = A\operatorname{sech}\left[\frac{t-\beta_1 z}{T_0}\right]\exp\left[\left(\frac{\beta_2 z}{2T_0^{\,2}}\right)-i\omega_0 t\right] \tag{1}$$

$$E_{in} = A\tanh\left[\frac{t-\beta_1 z}{T_0}\right]\exp\left[\left(\frac{\beta_2 z}{2T_0^{\,2}}\right)-i\omega_0 t\right] \tag{2}$$

A is the optical field amplitude and z is propagation distance. β_1 and β_2 are the coefficients of the linear and second order terms of Taylor expansion of the propagation constant. For the soliton pulse in the micro ring device, a balance should be achieved between the dispersion length and the nonlinear length. When light propagates within the nonlinear medium, the refractive index of light within the medium is given by

$$n = n_0 + n_2 I = n_0 + \left(\frac{n_2}{A_{eff}}\right)P \tag{3}$$

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 *MRR* and *NRR*, the effective mode core areas are ranged from 0.10 to 0.50 µm^2 [13].

When a soliton pulse is input and propagated within a *MRR* as shown in Figure 1, 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

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

The close form of equation (4) 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, $(1-\kappa)$, and a fully reflecting mirror. κ is the coupling coefficient, 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. L and α are waveguide length and linear absorption coefficient, respectively.

3.0 RESULT AND DISCUSSION

The proposed system to generate amplified bright soliton in which the input bright soliton propagates inside series of MRRs is shown in Figure 1.

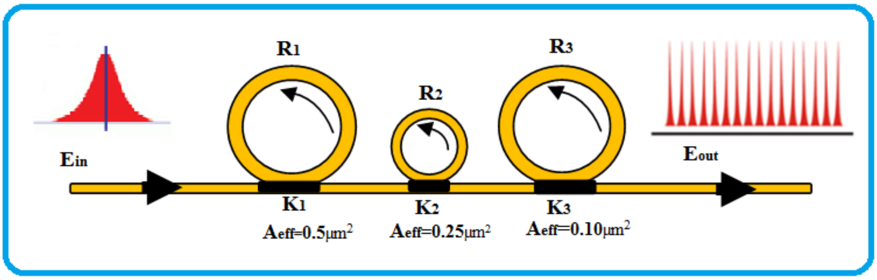

Figure 1 Schematic of bright soliton amplification system, Rs: Ring radii, κs: coupling coefficients, MRR: microring resonator

When a bright soliton pulse is input into the nonlinear Kerr effect medium (i.e. a nonlinear *MRR*), chaotic waves which known as the nonlinear behavior can be emerged as it is shown in Figure 2. The soliton pulse is separated into a broad spectrum covering the large spectrum range due to the optical soliton property and chaotic behavior. To make the system associate with the practical device [14], the selected parameters of the system are fixed to λ_0=1500 nm, n_0=3.34 (InGaAsP/InP), A_{eff}=0.50 μm^2 (for a *MRR*), α=0.02 dB mm^{-1}, γ=0.1, and R_1=20 μm. The coupling coefficient (kappa, κ) of the *MRR* is ranged from 0.5 to 0.9. The nonlinear refractive index is n_2=2.2×10^{-17} m^2/W.

In this research, the system of the amplified pulse generation consists of the multi-stage *MRRs*, where the ring radii used are selected between 5 and 35 μm. The soliton pulse is coupled into the system with the optical power of 0.6 W. The soliton input pulses with pulse widths of 50 ns is simulated. After the first *MRR*, the optical power is coupled into the second and third ring resonators, respectively. In this case, the wave-guided loss used is 0.5 dB mm^{-1}. As it is shown in Figure 2, when the input soliton pulse with pulse width of 50 ns is input into the system, chaotic behaviors occur within the *MRRs* R_1 and R_2 with ring radii 20 and 5μm, respectively. Amplified pulse is filtered and obtained within the third *MRR*, i.e. R_3, with the ring radius of 35μm. The coupling constants used are 0.9, 0.6 and 0.8 for κ_1, κ_2 and κ_3, respectively. The results show, we can amplified bright soliton from 0.6 W to 10.9331W in wavelength of 1520.428 nm or to 7.684W in wave length of 1519.912 nm .

The dark soliton can be amplified when an optical dark soliton is input to a series of *MRRs* shown in Figure 3. The superposition of self-phase modulation soliton pulse can maintain large output power. Initially, the optimum energy is coupled into the waveguide by a larger effective core area device of the *MRR*. Then the smaller one is connected to a larger *MRR* for transforming the soliton power. However, there are optical losses involved in the transferring link.

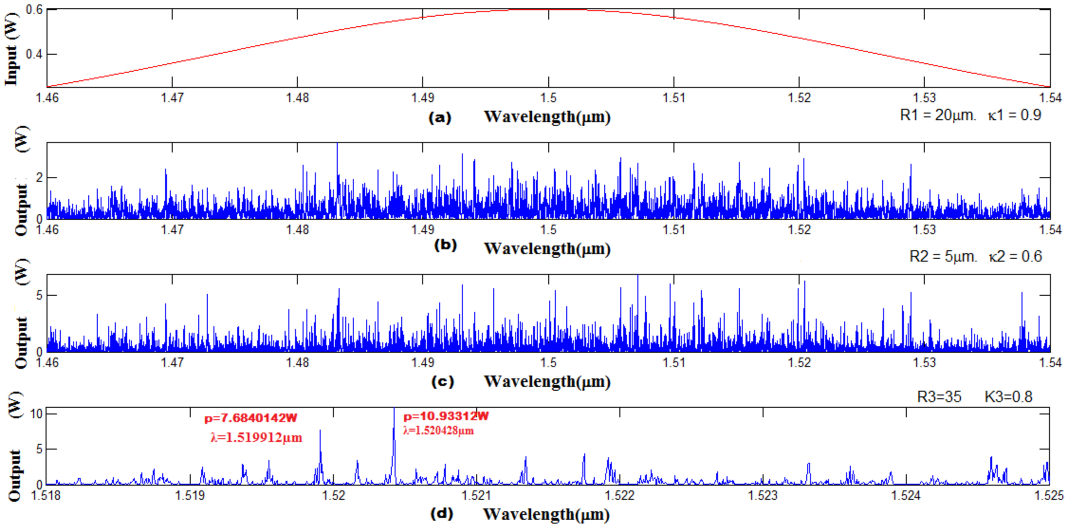

Figure 2 Results of amplified bright soliton pulse generation for the system shown in Figure 1, where a) input soliton pulse b) chaotic signals generation c) filtering of chaotic signals and d) amplified bright soliton

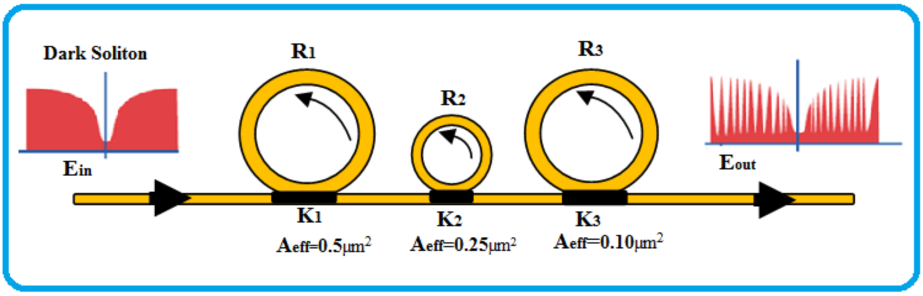

Figure 3 Schematic of an all optical dark soliton pulse system, *Rs*: ring radii, *κ*s: coupling coefficients, *MRR*: microring resonator

Large bandwidth signals within the microring device are generated when a dark soliton pulse is input into the nonlinear *MRR* as shown in Figure 4. A soliton pulse with 50 ns pulse width, maximum power at 0.5W is input into the system. The parameters used are R_1 = 18 μm, A_{eff1} = 0.50μm^2, R_2 = 5 μm, A_{eff2} = 0.25 μm^2, R_3 = 30 μm, A_{eff3} = 0.10 μm^2, κ_1 = 0.8, κ_2 =0.9 and κ_3 = 0.5. The dark soliton pulse is sliced into the smaller signals as shown in Figure 4(b). Figure 4(c) and 4(d) are the output signals of the filtering signals within the rings R_2 and R_3. The continuous spectra output are 20 times larger than the obtained input shown in Figure 4(d).

In operation, further amplification can be obtained by using a nanoring resonator. The results obtained for the amplification effect of dark soliton depends on the geometrical parameters of the ring resonators. In principle, the dark soliton amplification can be used for a number of applications in optical communications. The results indicate that the amplification can be increase to 8.22135W for an optical wavelength of 1537.628nm.

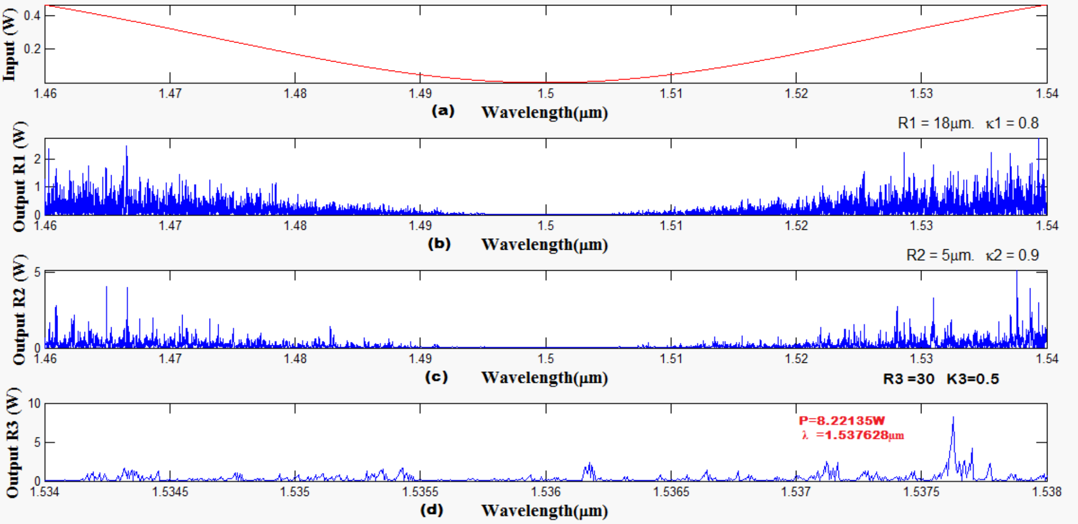

Figure 4 Simulation results of input dark soliton pulse where a) input pulse b) chaotic signals c) filtering of chaotic signals d) amplified pulse within *MRRs*

Furthermore, the large signal amplification, due to the effects of a dark soliton pulse in the nonlinear waveguide, may introduce unexpected applications for the use of signal security in long distance communication and networks. The novelty of this study is that the integrated embedded *MRR* is able to give signal amplification and secured communication.

4.0 CONCLUSION

We have shown that the large bandwidth of the optical signal can be generated and amplified within the *MRR* system. Dark and bright optical soliton signals are amplified in the proposed *MRR* system with the appropriate ring parameters and coupling coefficients. The proposed system gives an output power of 18 times larger than the input power for the bright soliton and 16 times larger for dark soliton.

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REFERENCES

[1] W. Zhao and E. Bourkoff. 1989. Propagation properties of Dark Solitons. *Opt. Lett.* 14: 703.

[2] I. V. Barashenkov. 1996. Stability Criterion for Dark Soliton. *Phys. Rev. Lett.* 77: 1193.

[3] D. N. Christodoulides, T. H. Coskun, M. Mitchell, Z. Chen and M. Segev. 1998. Theory of Incoherent Dark Solitons. *Phys. Rev. Lett.* 80: 5113.

[4] A. D. Kim, W. L. Kath and C. G. Goedde. 1996. Stabilizing Dark Solitons by Periodic Phase-Sensitive Amplification. *Opt. Lett.* 21: 465.

[5] B. A. Malomed, A. Mostofi and P. L. Chu. 2000. Transformation of a Dark Soliton into a Bright Pulse. *J. Opt. Soc. Am. B,* 17: 507.

[6] C. Fietz and G. Shvets. 2007. Nonlinear Polarization Conversion using Micro Ring Resonators. *Opt. Lett.* 32: 1683.

[7]. Ferreira, M. F. S. 2007. Nonlinear Effects in Optical Fibers: Limitations and Benefits. *Proc. SPIE,* 6793: 02.

[8]. Akhmanov, S. A. and S. Y. Nikitin. 1997. *Physical Optics.* Oxford University Press, Clarendon, Oxford. 657.

[9]. Fietz, C. and G. Shvets. 2007. Nonlinear Polarization Conversion using Microring Resonators. *Opt. Lett.* 32: 1683.

[10] Kokubun, Y., Y. Hatakeyama, M. Ogata, S. Suzuki, and N. Zaizen. 2005. Fabrication Technologies for Vertically Coupled Microring Resonator with Multilevel Crossing Busline and Ultracompact-ring Radius. *IEEE J. of Sel. Topics in Quantum Electron.* 11: 4.

[11] S. F. Hanim, J. Ali and P. P. Yupapin. 2010. Dark Soliton Generation using Dual Brillouin Fiber Laser in a Fiber Optic Ring Resonator. *Microw. & Opt. Technol. Lett.* 52: 881-883.

[12] G. P. Agrawal. 2007. *Nonlinear Fiber Optics.* Academic Press, Boston.

[13] S. Mitatha. 2009. Dark Soliton Behaviors within the Nonlinear Micro and Nanoring Resonators and Applications. *Progress in Electromagnetics Research.* 99: 383-404.

[14] P. P. Yupapin, N. Pornsuwanchroen and S. Chaiyasoonthorn. 2008. Attosecond Pulse Generation using Nonlinear Micro Ring Resonator. *Microwave Opt. Technol. Lett.* 50(12): 3108–3111.