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DETERMINATION OF FWHM FOR SOLITON TRAPPING

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Abstract In this study an interesting system in which a bright and dark soliton pulse can be stopped inside a nonlinear waveguide is presented. Here, we propose a system consisting of a series of ring resonators for optical trapping within a nonlinear waveguide. The bright and dark solitons can be controlled and slowed down within the waveguide. The FWHM for the output signals are calculated and used as an optical memory. Bright and dark soliton behaviors within a micro and nano ring resonator are also investigated and described. The required pulse is filtered and amplified, can be controlled and localized within the system. The localized bright and dark solitons are stopped by controlling the input power, which means that the photon stopping can be controlled by light in a ring resonator.

Keywords Dark soliton; bright soliton; nonlinear nano waveguide; stopped light

1.0 INTRODUCTION

A micro cavity can be used to stop and store light [1, 2]. However, the system is complex, which makes it difficult to implement. Yupapin and Pornsuwancharoen [3] have shown that the large bandwidth light pulses can be compressed and stored coherently within a nonlinear waveguide [4,5]. Bright and dark solitary waves are commonly induced by the nonlinear special effects and the external soliton pumping power [6]. Behaviors of dark and bright soliton in different forms of theories and experiment [7] has been presented. The use of a soliton pulse within a nonlinear waveguide for communication security has been investigated [8]. Here the tiny devices known as micro and nano ring resonators are used. In fact unexpected results of soliton in nonlinear waveguide can be used as benefit. In this study a series of ring resonators is used to trap, stop and store optical soliton [9].

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2.0 PRINCIPLE OPERATION

An optical soliton represents a pulse that travels without dispersion. It is used to enlarge the optical bandwidth during propagation within the nonlinear waveguide. Solitons are nonlinear phenomena caused by the self phase modulation (SPM). Large output power can be maintain by the superposition of SPM [10]. The optimum energy is channel into the waveguide by a larger effective core area of the ring resonator. The smaller ring connected to the system is used for soliton stopping. In this system, the interference signal has a negligible effect as compared to the losses associated with the direct passing through of the signal. Bright and dark soliton pulses are introduced into the ring resonators system as shown in Figs. 1 and 2. The input optical field (Ein) of the bright and dark soliton pulses input is given by Equations (1) and (2) [11].

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

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

Where A is the amplitude and z is propagation distance of the optical field. β_1 is the coefficient of the linear of the propagation constant. T_0 is the initial soliton pulse propagation time and β_2 is the coefficient for the second order terms in the Taylor expansion of the propagation constant. t is the soliton phase shift time, where the frequency shift of the soliton is ω_0. This is a pulse that keeps its temporal width invariance as it propagates. Therefore it is called a temporal soliton. For the soliton pulse in the micro-ring device, this means a balance is achieved between the dispersion length and the nonlinear length.

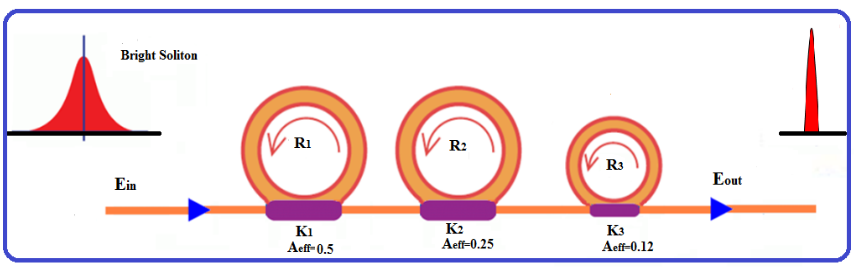


Figure 1 A schematic of optical bright soliton pulse systems, R_s: ring radii, κ_s: coupling coefficients, MRR: micro-ring resonator and NRR: nano-ring resonator

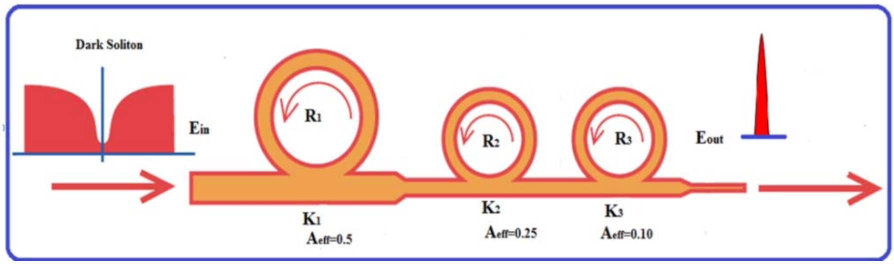


Figure 2 A schematic of optical dark soliton pulse systems, Rs: ring radii, κ_s: coupling coefficients, MRR: micro-ring resonator and NRR: nano-ring resonator

When light propagates within the nonlinear material (medium), the refractive index (n) of light within the medium can be written as

$$\Delta n = n_2 I = (\frac{n_2}{A_{eff}})P, \tag{3}$$

In Equation (3) n_2 is the nonlinear refractive index. 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 micro-ring and the nano-ring resonators, the effective mode core area ranges from 0.10 to 0.50 μm^2 [4]. The normalized output of the light field is the ratio between the output and the input fields $E_{out}(t)$ and $E_{in}(t)$ in one roundtrip can be expressed as

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

In this equation, the field reflectivity is defined as $(1-\kappa)$. κ is the coupling coefficient, and $x=\exp(-\alpha L/2)$ represents a roundtrip loss coefficient, $\varphi_0=kLn_0$ and $\varphi_{NL}=kLn_2|E_{in}|^2$ are the linear and the nonlinear phase shifts, respectively, $k=2\pi/\lambda$ is the wave propagation number in vacuum and L and α are the waveguide length and linear absorption coefficient, respectively [12,13].

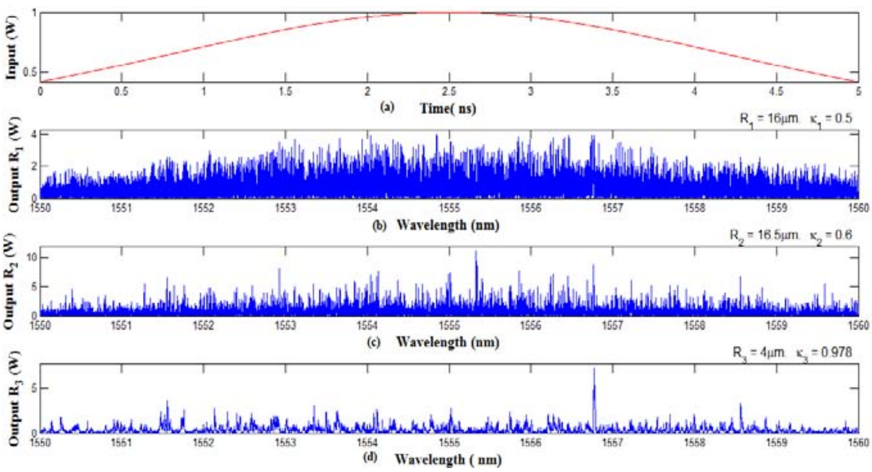
3.0 RESULTS AND DISCUSSION

The results are obtained using dark and bright solitons [7]. The bright soliton with pulse with of 50 ns and peak power of 1W is input into the system. The coupling coefficients have constant values of $\kappa_1=0.5$, $\kappa_2=0.6$, $\kappa_3=0.978$. The rings radii are $R_1=16.0$ µm, $R_2=16.5$ µm and $R_3=4$ µm. The selected parameters of the system are fixed to λ_0=1555 nm, n_0=3.34 (InGaAsP/InP), A_{eff}=0.50, 0.25 and 0.12 μm^2 for a micro-ring and nano-ring resonator, α=0.5 dB mm^{-1} and γ=0.1. The nonlinear refractive index is n_2=2.2×10^{-17} m^2/W. In this case, the wave-guided loss used is 0.5 dB mm^{-1}.

The dark soliton with pulse with of 50 ns and peak power of 800 mW also can be input into the system. Here the rings radii are R_1=10 μm, R_2=4 μm and R_3=3 μm. The selected parameters are the same as before except the Aeff has values of 0.50, 0.25 and 0.10 μm^2 and coupling coefficients of the system are 0.975, 0.3 and 0.975.

The input soliton pulse is sliced into smaller signal spreading over the spectrum as shown in Figs. 3(b) and 4(b). The first ring resonator enlarges the input signals. Figs. 3(c) and 4(c) shows the decrease in the spectral width while trapping of soliton is occurred in Figs. 3(d) and 4(d).

As a result the localized soliton can be achieved at 1556.7 and 1558.99 nm for the bright and dark solitons respectively. However, the other ring parameters are also very important for the stopping of light pulse behavior. In the proposed system, light pulse is slowed down and stopped within a ring R_3. The output energy of the bright and dark soliton in ring R_3 can be amplified to 7.2106 W and 11.76031 W respectively. Here the FWHM of trapped bright and dark soliton can be obtained as 12.5 pm and 24 pm respectively. In principle, the amplification within a nano ring device can be used for many applications in optical communication security.



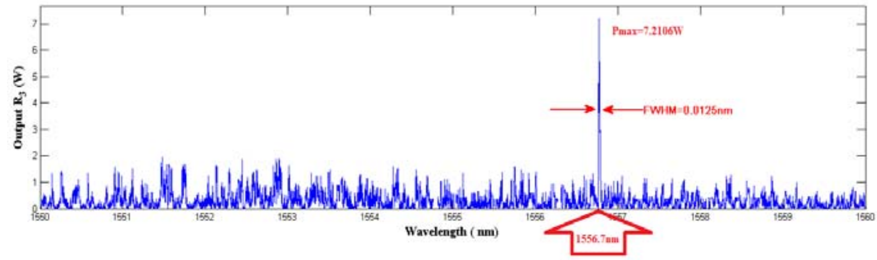


Figure 3 Simulation signals, with (a) an input bright soliton pulse, (b) large bandwidth signals, (c) decreased spectral width signals and (d) stopping of photon at 1556.7 nm and FWHM=0.0125nm

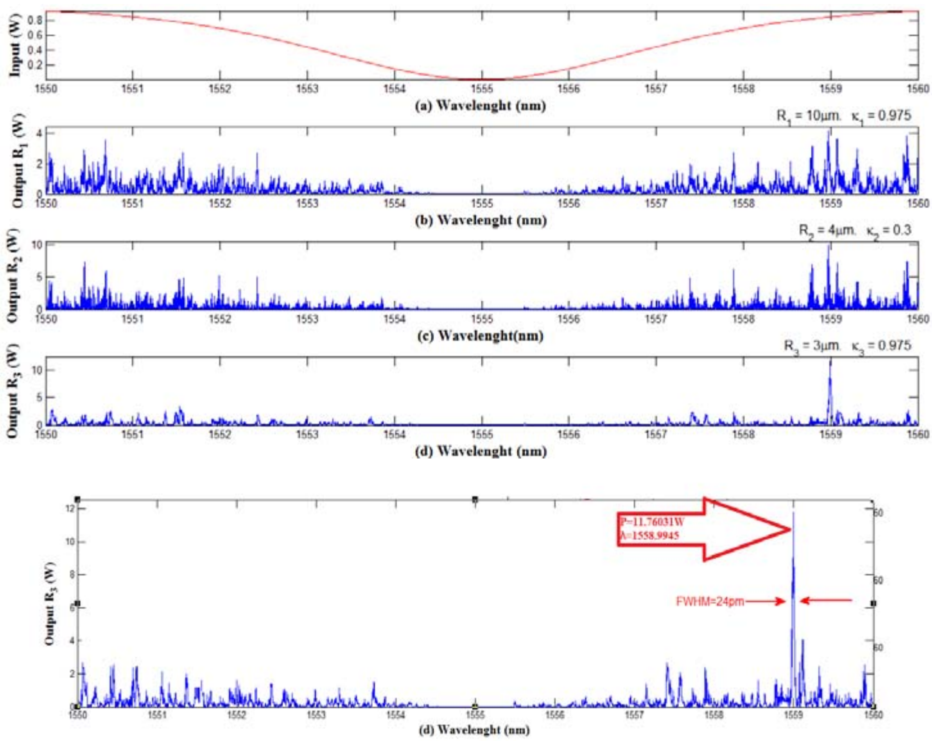


Figure 4 Simulation signals, with (a) an input dark soliton pulse, (b) large bandwidth signals, and (c) decreased spectral width signals and (d) stopping of photon at 1558.9945 nm and FWHM=24pm

4.0 CONCLUSION

As conclusion, we have shown that the large bandwidth of the random wavelength of a soliton pulse can be compressed, stopped and stored within a waveguide. There is a balance between the dispersion and nonlinear length. Results obtained show that the trapped bright and dark solitons inside the nonlinear MRR have a wavelength of 1556.7 nm (FWHM: 12.5 pm) and 15558.99 nm (FWHM: 24 pm) respectively. This has possible application as an optical memory in secured optical communication.

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