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Dark-Bright Solitons Conversion System for Secured and Long Distance Optical Communication

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Abstract: *We suggest a new purpose of a security scheme by employing the nonlinear behaviors of temporal dark and bright solitons amongst a micro-ring resonator system for signal security application. The chaotic signal is generated, where the required bright soliton pulse can be recovered and discovered by an add/drop filtering device. By using the reserve ring parameters, simulation results obtained have demonstrated that the soliton conversion can be performed. In application, the chaotic signal is generated and formed by the dark soliton inside a nonlinear micro-ring device. The different temporal soliton response time can be seen, the response times of 169 and 84 ns are mentioned for temporal dark and bright solitons, respectively, which can also be used to figure the security key. The technique of optical conversion can be use to improve the optical communication network systems.*
Keyword: *microring resonator, nonlinear medium, chaotic signals, add/drop filter, dark-bright conversion*

I. INTRODUCTION

Dark and bright soliton behaviors have been widely investigated in different forms [1]. Dark soliton is one of the soliton properties, whereas the soliton amplitude disappears or minimized throughout the propagation in media, thus, the dark soliton detection is difficult [2]. The investigation of dark soliton behaviors has been described, where one point of them has shown the interesting results, where the dark soliton can be stabilized and converted into bright soliton and eventually observed [3, 4]. This means that we can employ the dark soliton penalty because of the low level of the peak power to be the benefit, where the predicting idea is that a dark soliton can perform the communication transmission carrier where the recovery can be retrieved by the dark-bright soliton conversion [5]. A soliton pulse can be localized among a waveguide consists of micro and nanoring resonator, hence the soliton pulse can be stored within the nano-waveguide [6]. We have shown that the dark soliton can be input and chopped to the noisy signals for security use within the nonlinear ring resonator system [7]. The required users can retrieve the original signal through an add/drop filter, where they can select to retrieve in either bright or dark soliton pulses [8, 9]. The filtering feature of the optical signal is presented within an add/drop filter, where the suitable parameters can be operated to obtain the required output energy [10].

II. THEORY

The dark soliton pulse, which is introduced into the multi-stage micro-ring resonators as shown in figure1, the input optical field (E_{in}) of the dark soliton pulse input is given by [11, 12]

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

where A and z are the optical field amplitude and propagation distance, respectively [13, 14]. T is a soliton pulse propagation time in a frame moving at the group velocity [15, 16], $T=t-\beta_1\times z$, where β_1 and β_2 are the coefficients of the linear and second-order terms of Taylor expansion of the propagation constant [17]. $L_D=T_0^2/|\beta_2|$ is the dispersion length of the soliton pulse [18]. T_0 in equation (1) is a soliton pulse propagation time at initial input [19]. Where t is the soliton phase shift time, and the frequency shift of the soliton is ω_0 [20, 21].

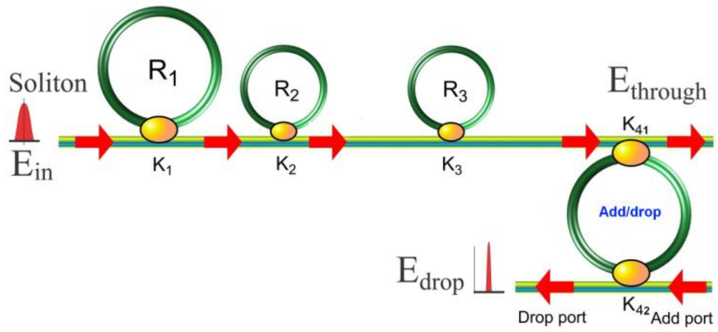

Fig. 1: Dark-bright soliton conversion system, where R_s: ring radii, κ_s: coupling coefficients, κ_{41} and κ_{42} are the add/drop coupling coefficients

The refractive index (n) of light within the medium is given by [22]

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

where n_0 and n_2 are the linear and nonlinear refractive indexes, respectively [23]. I and P are the optical intensity and optical power, respectively [24]. The effective mode core area of the device is given by A_{eff} and ranges from 0.50 to 0.10 μm^2 [25, 26]. The normalized output of the light field in each roundtrip is given by [27]

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

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 nonlinear phase shifts, $k=2\pi/\lambda$ is the wave propagation number in a vacuum [28]. Where L and α are a waveguide length and linear absorption coefficient, respectively [29, 30]. To retrieve the signals from the chaotic noise, we propose to use the add/drop device with the appropriate parameters [31, 32]. Optical circuits of ring resonator add/drop filters for the throughput and drop port can be given by [33, 34, 35]

$$\left|\frac{E_t}{E_{in}}\right|^2 = \frac{(1-\kappa_{41}) - 2\sqrt{1-\kappa_{41}}\cdot\sqrt{1-\kappa_{42}}\,e^{-\frac{\alpha}{2}L}\cos(k_n L) + (1-\kappa_{42})e^{-\alpha L}}{1 + (1-\kappa_{41})(1-\kappa_{42})e^{-\alpha L} - 2\sqrt{1-\kappa_{41}}\cdot\sqrt{1-\kappa_{42}}\,e^{-\frac{\alpha}{2}L}\cos(k_n L)} \tag{4}$$

and

$$\left|\frac{E_d}{E_{in}}\right|^2 = \frac{\kappa_{41}\kappa_{42}e^{-\frac{\alpha}{2}L}}{1 + (1-\kappa_{41})(1-\kappa_{42})e^{-\alpha L} - 2\sqrt{1-\kappa_{41}}\cdot\sqrt{1-\kappa_{42}}\,e^{-\frac{\alpha}{2}L}\cos(k_n L)} \tag{5}$$

where E_t and E_d represents the optical fields of the throughput and drop ports, respectively [36]. $\beta=kn_{eff}$ is 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 [37, 38]. κ_{41} and κ_{42} are coupling coefficient of add/drop filters, $k_n=2\pi/\lambda$ is the wave propagation number for in a vacuum, and where the waveguide (ring resonator) loss is $\alpha=0.5$ dB mm^{-1} [39, 40]. The fractional coupler intensity loss is $\gamma=0.1$ [41, 42]. In the case of add/drop device, the nonlinear refractive index is neglected [43, 44].

III. Result And Discussion

Dark soliton pulse with 50 ns pulse width, the maximum power of 1.0 W is input into the dark-bright solitons conversion system as demonstrated in figure 1. The suitable ring parameters are applied, for example, ring radii R_1=10.0 μm, R_2=7.0 μm and R_3=5.0 μm. The system are prepared to λ_0=1.55 μm, n_0=3.34 (InGaAsP/InP), A_{eff}=0.50, 0.25 and 0.10 μm^2 for a micro and nanoring resonators, respectively, α=0.5 dB mm^{-1}, γ=0.1. The coupling coefficients (kappa, κ) of the micro-ring resonator are ranged from 0.05 to 0.90. The nonlinear refractive index is $n_2=1.2\times10^{-17}$ m^2/W. The input dark soliton pulse is chopped (sliced) into the smaller signals as shown in figure 2(a). Figure 2(b) and (c) are the output signals of the filtering signals within the rings R_2 and R_3. The soliton signals in R_3 is inserted into the add/drop filter, where the dark-bright solitons conversion can be performed by using equations (4) and (5).

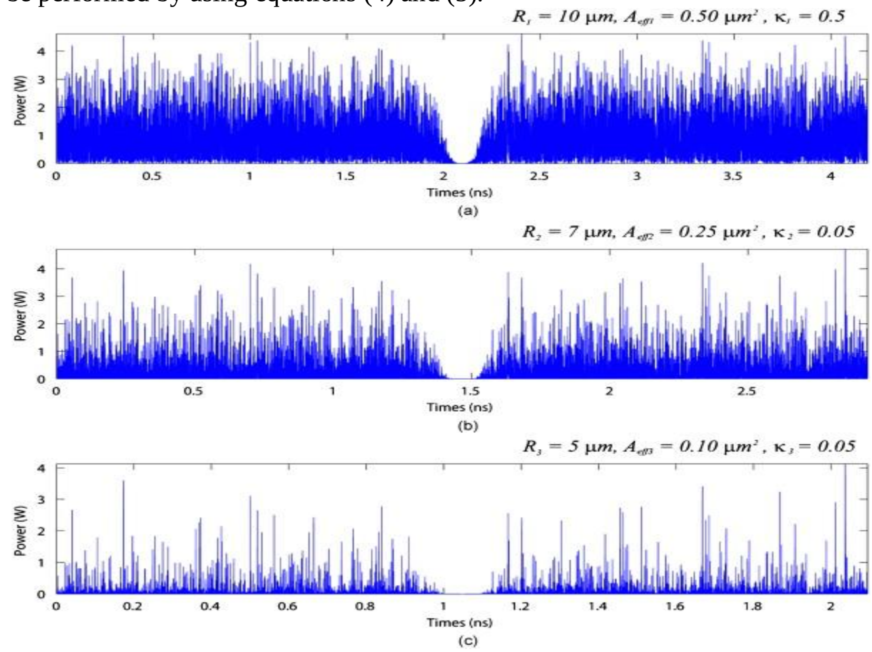

Fig. 2: Simulation results of the soliton signals within the ring resonator system, where (a): R_1 output power, (b): R_2 output power and (c): R_3 output power.

Dark soliton pulse is input into a micro and nanoring resonator systems as shown in figure 3 and figure 4. The add/drop filter is connected to two couplers where the ring radius (R_d) is 10 μm and the coupling constants (κ_{11} and κ_{12}) are the same values (0.50). When the add/drop filter is connected to the third ring (R_3), the dark-bright solitons conversion are seen. The bright soliton and dark solitons are observed by the through and drop ports as demonstrated in figure 1, respectively.

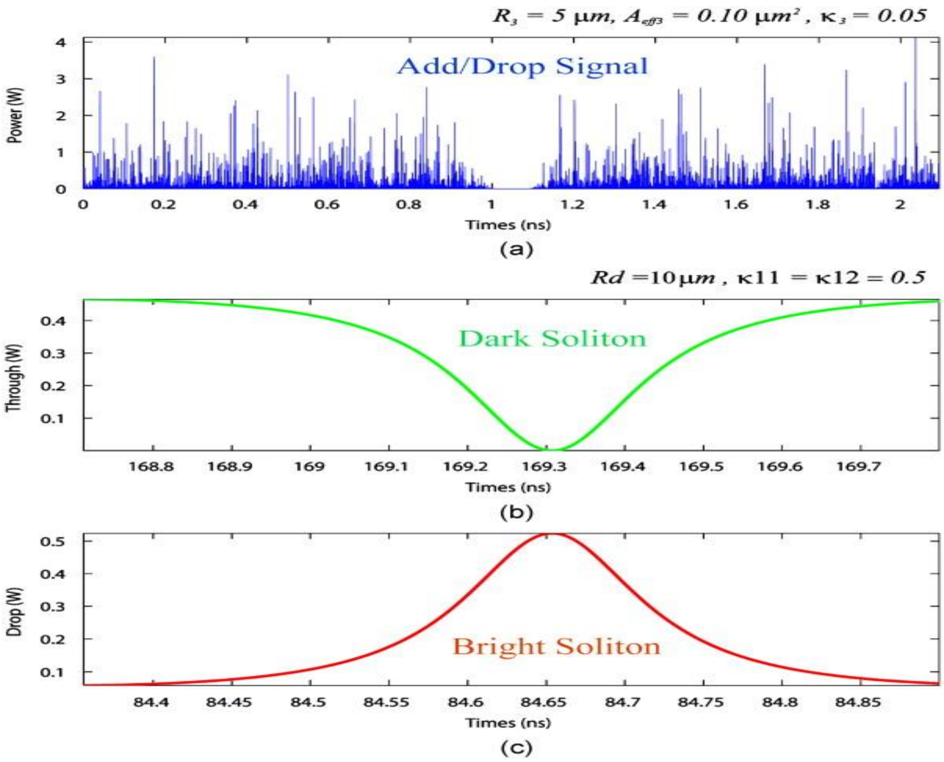

Fig. 3: Results of the optical solitons, where (a) the signals in R_3, (b) a dark soliton and (c) a bright soliton. the input dark soliton power is 1 W, κ_1=0.5, R_d=10 mm.

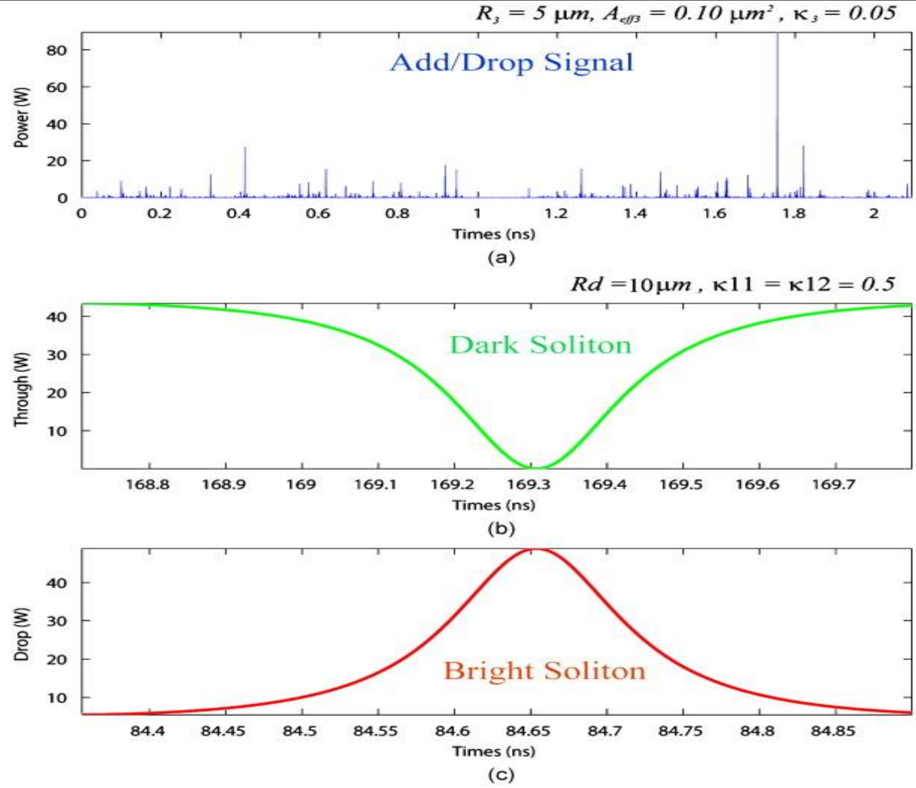

Fig. 4: Results of the optical solitons, where (a): the signals in R_3, (b): a dark soliton and (c): a bright soliton, where input dark soliton power is 1 W, κ_1=0.9, R_d=10 mm.

The system of conversion optical soliton pulses can be used in optical communication network where the security can be performed by use of dark soliton. The bright soliton is used for long distance optical communication where the optical conversion system allows the different users to receive suitable type of optical solitons depending of the required application. Schematic of an optical communication network system is shown in figure 5 where the system of conversion can be seen along the link.

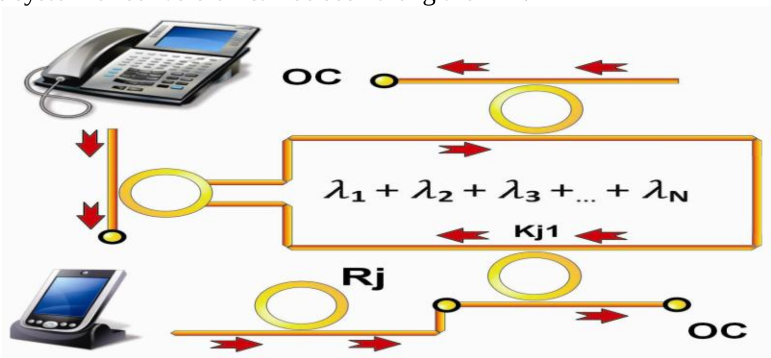

Fig. 5: Schematic of an optical communication network system where R_j: ring's radius, λ_i: transmitting wavelength, κ_j: coupling coefficient, OC: optical conversion system

IV. Conclusion

In conclusion, dark soliton in the optical microring resonator can be converted to be a bright soliton incorporating the add/drop system. By using the reasonable dark soliton input power, the output bright soliton power obtained can be used to perform the common soliton for long-distance link, for instance, the output power of bright solitons of 0.5 and 40 W are obtained. The advantage is that the detection of the dark soliton along the through port is difficult, while the detection of the bright one can be performed by the standard form. This means the use of dark soliton to form the signal security or communication security is plausible, which is also available for network security application.

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