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Frequency-Wavelength Trapping by Integrated Ring Resonators For Secured Network and Communication Systems

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Abstract

Optical pulse trapping via a series of microring resonator (MRR) is presented. Large bandwidth of optical soliton is generated by input pulse propagating within the MRRs. Distinguished discrete wavelength or frequency pulses can be generated by using localized spatial pulses via a networks communication system. Quantum codes can be generated by using a polarization control unit and a beam splitter, incorporating to the MRRs. Here frequency band of 10.7 MHz and 16 MHz and wavelengths of 206.9 nm, 1448 nm, 2169 nm and 2489 nm are localized and obtained and used for quantum codes generation applicable for secured networks communication.

Keywords- *Microring Resonator (MRR); Discrete Optical Soliton, Quantum Codes, Computer networks system*

Introduction

Optical network is becoming a capable technology for secured and long distance communication [1].

The use of quantum codes with quantum router and network has been described well by Amiri *et al* [2]. Recently, Afroozeh *et al* [3] have shown that the continuous wavelength can be generated using a soliton pulse in an MRR. Kouhnavard *et al*. have proposed the use of QKD via quantum wavelength router using spatial soliton [4]. Nikoukar *et al* have proposed a system of optical tweezers generation used for secured binary codes generation applicable in network systems such as computer networks [5]. In this study, we are using MRR system to generate discrete optical soliton. Necessary frequency bands and wavelengths are selected and can be used to generate quantum codes propagating inside network communication systems [6].

Theoretical Modeling

Optical power in the form of an optical soliton pulse or a laser Gaussian beam are expressed by equations 1 and 2.

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

$$E_{in}(t) = E_0 \exp^{j\phi_0(t)} \qquad (2)$$

A and z are optical field amplitude and propagation distance, respectively. T is the time of soliton pulse propagation, where $L_D = T_0^2 / |\beta_2|$ is the dispersion length of the soliton pulse and β_2 is the propagation constant [7]. Therefore, a soliton pulse describes a pulse, which keeps its temporal or spatial width invariance while it propagates inside the MRRs system [8]. Soliton peak intensity is expressed by $\left|\beta_2 / \Gamma T_0^2\right|$, where $\Gamma = n_2 \times k_0$, is the length scale over which dispersive or nonlinear effects causes the beam to be wider or narrower. For a temporal soliton pulse in the micro ring device, a balance should be achieved between the dispersion length (L_D) and the nonlinear length ($L_{NL} = (1/\gamma\varphi_{NL})$), where γ and φ_{NL} are a coupling loss of the field amplitude and nonlinear phase shift. Here $\phi_0 = kLn_0$ is the linear phase shift [9]. Light transmits within the nonlinear medium wherein the refractive index (n) is given by [10]:

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

where n_0 and n_2 are the linear and nonlinear refractive indices, respectively. I is the optical intensity and P is the optical power. The effective mode core area of the device is shown by A_{eff}. For the micro ring and nano-ring resonators, the effective mode core area ranges from 0.50 to 0.1 μm^2 [11]. Proposed system can be connected to a rotatable polarizer and a beam splitter, which is used to generate distinct optical soliton pulses and quantum codes with greeter free spectrum range (FSR), shown by Figure (1).

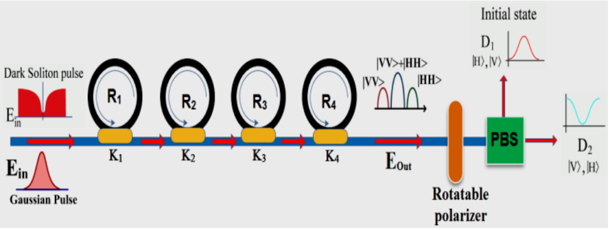

Fig.1: System of trapping, where PBS; polarizing Beam splitter; Ds, detectors; Rs, ring radii and κ_s, coupling coefficients

When the input pulse introduced into the MRRs system as shown in Fig. 1, the resonant output is built up in the series of MRRs, where equation (4) can express the normalized output of the light field [12].

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

Eq. (4) points that a ring resonator in this exacting case is comparable to a Fabry-Perot cavity which is consisting of an input and output mirror with a field reflectivity, (1-κ), and a fully reflecting mirror [13]. κ is identified as coupling coefficient, and $x=\exp(-\alpha L/2)$ represents a roundtrip loss coefficient [14]. $k=2\pi/\lambda$ is the wave propagation number, where $\phi_0 = kLn_0$ and $\phi_{NL} = kLn_2|E_{in}|^2$ are the linear and nonlinear phase shifts [15]. Equation (4) shows the output power from each ring resonator, which is realized as input power for the next ring resonator. Simulation results of the mathematical equations provide applicable optical soliton pulses to generate quantum codes, used for the secured networks communication.

Results and Discussion

Large bandwidth of signals is generated, where the next ring resonators within the system form the chaotic filtering characteristics of the signals. Using the semiconductor material, InGaAsP/InP, the specified frequency bands are obtained based on selected ring parameters. The soliton waveform with central frequency of f_0 = 20 MHz is input into the first MRR.

The optical power is fixed to 550 mW, where n_0=3.34, n_2=2.2×10^{-17} m^2 W^{-1}, A_{eff}=0.50 μm^2, α=0.5 dB mm^{-1}, γ=0.1, with 20,000 roundtrips. The chaotic signals are generated within the first ring (R_1), where the broad frequency band is observed in ring R_2. The filtering signals are seen in rings R_3 and R_4. Fig. 2 shows the map of the simultaneous frequencies generation, for the ring parameters of R_1=10 µm, κ_1=0.9713, R_2=10 µm, κ_2=0.973, R_3=10 µm, κ_3=0.9732, R_4=15 µm, and κ_4=0.9786.

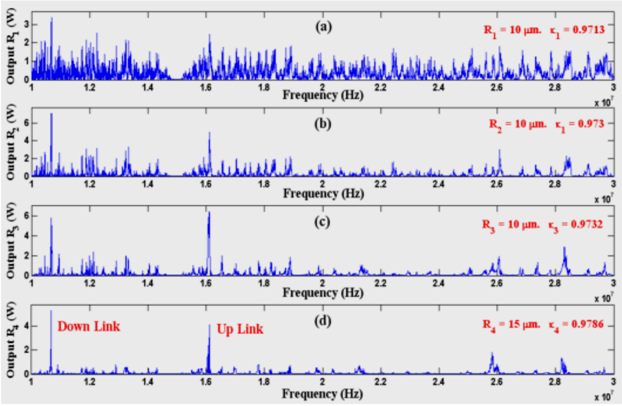

Fig. 2: Specific frequencies trapping, (a) noisy chaotic signals, (b) frequency bands, (c) filtering signals, (d) discrete signals.

Discrete frequency bands from 10 MHz to 30 MHz can be simultaneously generated, where the specified frequencies are filtered to form the required link converters. Fig. 3 shows the frequency profile generated for a down-link converter.

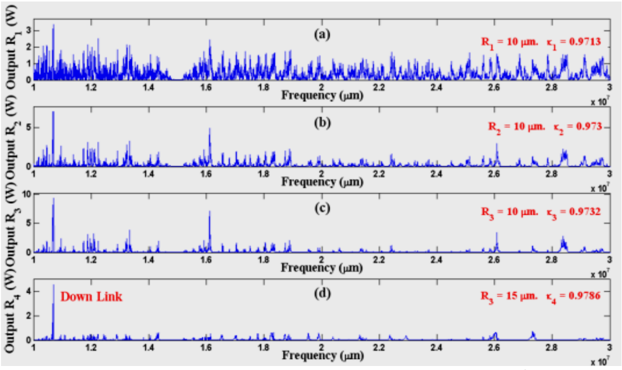

Fig. 3: Frequency band generation, (a) chaotic signals,(b) frequency bands, (c) filtering signals, (d) signal at 10.7 MHz.

Fig. 4 shows the frequency generation for an up-link converter.

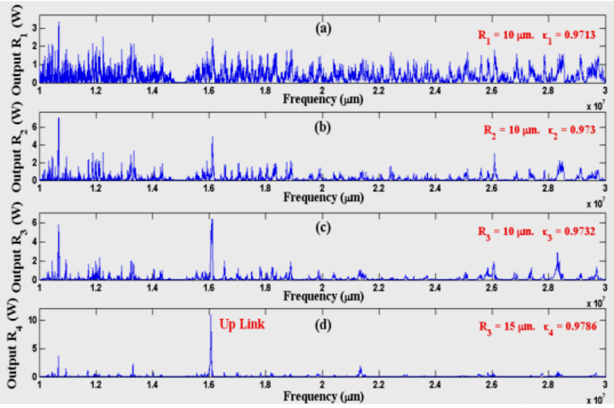

Fig. 4: Frequency band generation, (a) chaotic signals, (b) frequency bands, (c) filtering signals, (d) signal at 16 MHz.

Wide range of spread wavelength can be generated, using proposed MRRs system, where the wavelength multiplexing, dense wavelength divisions multiplexing (DWDM) can be perform via optical wireless link [16]. In principle, the specific wavelength mode is required in this technique; therefore, the chaotic signals are needed to be generated within the proposed [17]. In this case, the input power is in the form of Gaussian beam and it is given by Equation (2).

Gaussian pulse is input into the first MRR as shown in Fig.5, where light modes can be generated with smaller spectral width than the input pulse. The optical filter characteristics is perform using appropriate ring parameters such as input power and, ring material, refractive index, radius and coupling constant, etc [18]. Thus, Gaussian pulse with power of 450 mW and central wavelength of λ_0=1500 nm is input into the system, where $n_2=2.2\times10^{-15}$ m^2 W^{-1} and A_{eff} = 25 μm^2.

Figure (5) shows the trapping of wavelength pulses, obtained by using the MRRs system. Discrete wavelengths of λ_D=1448 nm and λ_U=2169 nm with powers of 592.6 mW and 394.6 mW are generated respectively. Here, the ring radii, R_1, R_2, R_3 and R_4 are 17, 13, 14 and 14 µm respectively. The coupling constants κ_1, κ_2, κ_3, κ_4 are selected to 0.995, 0.9831, 0.985 and 0.9826, respectively.

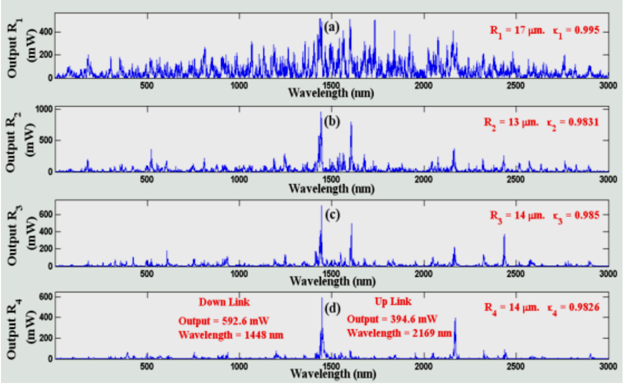

Fig.5: Wavelengths trapping, where (a): chaotic signals from R_1, (b): filtering by R_2, (c): wavelength trapping by R_3, (d) localized wavelengths at λ_D=1448 nm and λ_U=2169 nm with powers of 592.6 mW and 394.6 mW respectively.

Figure (6) shows the filtering of chaotic signal, where the discrete wavelengths of λ_D=206.9 nm and λ_U=2489 nm with powers of 760.5 mW and 962.3 mW are generated respectively. Here, the coupling constants κ_1, κ_2, κ_3 and κ_4 of the rings have been selected to 0.9895, 0.9858, 0.9858 and 0.9713, respectively.

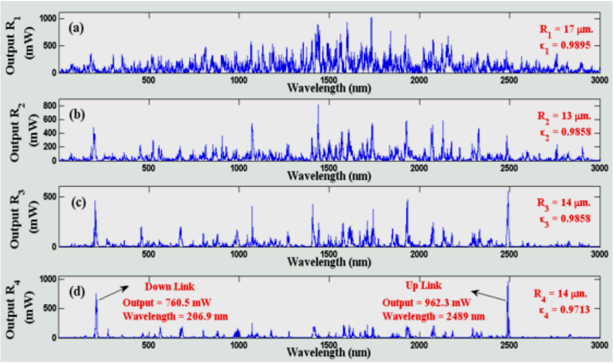

Fig.6: Wavelengths trapping, where (a): chaotic signals from R_1, (b): filtering by R_2, (c): wavelength trapping by R_3, (d) localized wavelengths at λ_D=206.9 nm and λ_U=2489 nm with powers of 760.5 mW and 962.3 mW respectively.

Obtained results of discrete wavelengths or frequencies from MRRs system can be passed through a PBS as shown in Figure (1). In application, the variable quantum codes can be generated using the PBS. Localized wavelength or frequency can be used to generate variable quantum codes. In this concept, we assume that the polarized photon can be performed by using the proposed arrangement. Optical codes via localized optical solitons can be connected into a network communication system shown in Fig.7. Therefore, generated secured optical codes can be transmitted to the different users via a networks transmitter system [19].

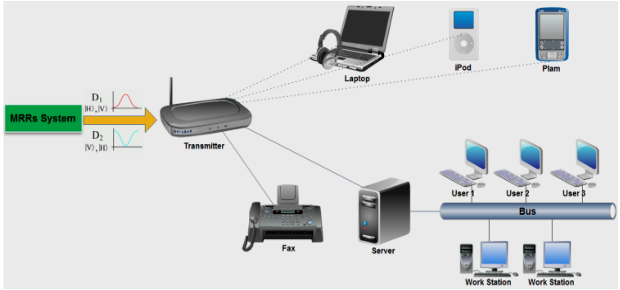

Fig.7: Networks communication system, where the transmission of information can be implemented using generated optical codes

The security code can be formed by the spatial soliton pulses generation using an analog to digital electronic convertor system. Furthermore, the applications such as quantum repeater, quantum entangled photon source are available, which can complete the concept of quantum optical communication networks.

Conclusion

A system of MRRs was presented in which, secured optical codes can be performed and transmit via a network system. MRR system is connected to a rotatable polarizer and a beam splitter, where this system can be used to generate localized optical soliton pulses applicable in public network systems. In this study, localized optical pulse with frequencies of 10.7 MHz and 16 MHz and wavelengths of 206.9 nm, 1448 nm, 2169 nm and 2489 nm are simulated. Further, more frequency and wavelength bands are available for many applications in networks communication.

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