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 selected 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.

\[ E_m = A \tan \left[ \frac{T}{T_0} \right] \exp \left[ \left( \frac{z}{2L_0} \right) - i\alpha \beta \right] \]  

\[ E_{a}(t) = E_0 \exp^{i\beta(t)} \]  

\[ A \text{ and } z \text{ are optical field amplitude and propagation distance, respectively. } T \text{ is the time of soliton pulse propagation, where } L_0 = T_0^2 / |\beta_2| \text{ is the dispersion length of the soliton pulse and } \beta_2 \text{ is the propagation constant [7]. Therefore, a soliton pulse describes a pulse, which keeps its temporal or spatial width invariance while it propagates inside the MRRs system [8]. Soliton peak intensity is expressed by } \left( \beta_2 / |\Gamma T_0^2| \right) \text{, where } \Gamma = n_s \times k_0 \text{ is the length scale over which dispersive or nonlinear effects causes the beam to be wider or narrower. For a temporal soliton pulse in the micro ring device, a balance should be achieved between the dispersion length (} L_0 \text{) and the nonlinear length (} L_{NL} = (1 / \gamma \phi_{NL}) \text{, where } \gamma \text{ and } \phi_{NL} \text{ are a coupling loss of the field amplitude and nonlinear phase shift. Here } \phi_0 = k L_t \text{ is the linear phase shift [9]. Light transmits within the nonlinear medium wherein the refractive index (} n \text{) is given by [10]:} \right[ \frac{\beta_2}{\Gamma T_0^2} \right] \]  

\[ n = n_0 + n_z I = n_0 + \left[ \frac{\beta_2}{\Gamma T_0^2} \right] P, \]
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 $\mu m^2$ [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 greater free spectrum range (FSR), shown by Figure (1).

The optical power is fixed to 550 mW, where $n_0=3.34$, $n_2=2.2 \times 10^{-17}$ m$^2$ W$^{-1}$, $A_{eff}=0.50 \mu m^2$, $a=0.5$ dB mm$^{-1}$, $\gamma=0.1$, 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 $R_1=10 \mu m$, $\kappa_1=0.9713$, $R_3=10 \mu m$, $\kappa_3=0.9732$, $R_4=15 \mu m$, and $\kappa_4=0.9786$.

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

**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.
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 $\lambda_0=1500$ nm is input into the system, where $n_2=2.2\times10^{-15}$ m$^2$ W$^{-1}$ and $\Lambda_{eff}=25$ $\mu$m$^2$.

Figure (5) shows the trapping of wavelength pulses, obtained by using the MRRs system. Discrete wavelengths of $\lambda_{01}=1448$ nm and $\lambda_{02}=2169$ 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 $\mu$m respectively. The coupling constants $\kappa_1$, $\kappa_2$, $\kappa_3$, $\kappa_4$ are selected to 0.995, 0.9831, 0.985 and 0.9826, respectively.

Figure (6) shows the filtering of chaotic signal, where the discrete wavelengths of $\lambda_{D1}=206.9$ nm and $\lambda_{U1}=2489$ nm with powers of 760.5 mW and 962.3 mW are generated respectively. Here, the coupling constants $\kappa_1$, $\kappa_2$, $\kappa_3$ and $\kappa_4$ of the rings have been selected to 0.9895, 0.9858, 0.9858 and 0.9713, 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].
The security code can be formed by the spatial soliton pulses generation using an analog to digital electronic converter 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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**References**


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