Controlling Nonlinear Behavior of a SMRR for Network System Engineering

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Abstract

This research is used to control the nonlinear behavior of silicon microring resonators, MRR's such as chaos and bifurcation. Increasing of nonlinear refractive indices, coupling coefficients and radius of the SMRR leads to descend input power and round trips wherein the bifurcation occurs. As result, bifurcation or chaos behaviors are seen at lower input power of 44 W, where the nonlinear refractive index is n_2=3.2×10^{-20} m^2/W. Smallest round trips can be seen for the R=40 µm and $\kappa = 0.1$ respectively. Signals from the SMRR are passing through a polarizer beam splitter to generate quantum binary codes which are used in wireless network communication.
Keywords: Silicon microring resonator; Bifurcation; Chaos, Coupling coefficient, Nonlinear refractive index

Introduction

Nonlinear behavior of light inside a single MRR occurs when strong pulse of light is inputted into the ring system, used to many applications in signal processing and communication [1-4]. Bifurcation and chaotic signal controls are used in a great number of optical, engineering and biological designed systems [5-11].

Bifurcation can be modified via various control methods [12]. Theoretical studies of such as systems have same concepts with ring cavities, and Fabry–Perot system [13-15]. Amiri et al. have shown that chaotic signal behavior can be seen after the bifurcation was generated. Amiri et al, showed the nonlinearity behaviors of the PANDA ring resonator system [16-18]. More details of these phenomena have been explained by Afroozeh [19, 20]. One of the phenomena, known as bifurcation has been used in digital coding application [21]. Behavior of light traveling in a nonlinear ring resonator is well described by Yupapin [22]. Controlling of the bifurcation behavior can be implemented by controlling the round trip and input powers of the ring system via variation of the parameters [23-25]. Bifurcation control is not only important in its own right, but also suggests a viable and effective approach for chaos control that can be used to generation secured codes in digital information processing.

Light Propagation inside SMRR

Single MRR consists of a single coupler and a micoring resonator. Nonlinearity of the fiber ring is of the Kerr-type wherein the nonlinear refractive index is given by [26-31]

$$n = n_0 + n_2 I = n_0 + (\frac{n_2}{A_{eff}})P, \quad (1)$$

where n_0 and n_2 are the linear and nonlinear refractive indices, respectively [32-34]. I and P are the optical intensity and optical field power, respectively [35-38]. The effective mode core area of the fiber is A_{eff} [39-41]. Schematic of SMRR is illustrated in Fig.1

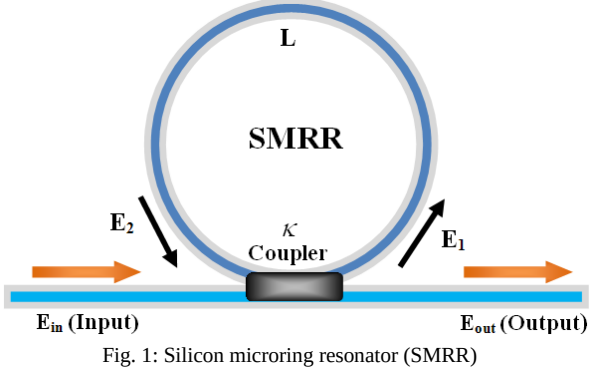

Fig. 1: Silicon microring resonator (SMRR)

The fiber has a nonlinear refractive index of n_2 and a linear absorption coefficient of α [42-44]. The intensity coupling coefficient [45-48] of the fiber coupler is κ, where γ is a coupling loss of the field amplitude [49-51]. Here the fiber coupler is considered as a point device and is reciprocal [52-54]. The relation between the electric fields E_1 and E_2, can be expressed using the nonlinear form as [55-57]:

$$E_2 = E_1 x \exp\{-j(\phi_0 + \phi_{NL})\}, \quad (2)$$

where $\phi_0 = kLn_0$ and $\phi_{NL} = kLn_2|E_1|^2$ are expressed as linear and nonlinear phase shift [58, 59], $k = 2\pi/\lambda$ is a wave number [60, 61] and L is the circumference of the ring resonator [62]. $x = \exp(-\alpha L/2)$ represents a round trip loss for the input pulse propagating inside the SMRR [63]. Mathematically, the subsequence Equations of the round trip within the system is given by Eq. (3).

$$E_{n+1} = j\sqrt{(1-\gamma)\kappa}E_{in} + \sqrt{(1-\gamma)(1-\kappa)}xE_n \exp(-j(\phi_0 + \phi_{NL})), \quad (3)$$

We consider a MRR connected to a single coupler that extracts light from the ring into the output waveguides, as schematically shown in Fig. 1. We ignore reflectivities at the coupler–waveguide interface, which is usually a good approximation due to the same structure of the output waveguides and the coupler [64-67]. Regards to steady situation of the Eq. (3), the output field can be expressed as [68-72]:

$$E_{out} = \sqrt{1-\gamma}\cdot E_{in}\left[\sqrt{1-\kappa} - \frac{\sqrt{1-\gamma}\,\kappa\, x \exp(-j(\phi_0 + \phi_{NL}))}{1-\sqrt{(1-\gamma)(1-\kappa)}\, x \exp(-j(\phi_0 + \phi_{NL}))}\right]. \quad (4)$$

Thus the output power of the light field from Eq. (4) is given by Eq. (5).

$$P_{out} = |E_{out}|\cdot|E^*{}_{out}| \quad (5)$$

Equation (5) is mathematical relation used for characterizing of nonlinear effects of the ring resonator system.

Result and Discussion

Figure (2) shows the bifurcation and chaos behavior occurred for various nonlinear refractive indices of the system. The parameters have been fixed to λ_0=1.55 μm, n_0=3.37, A_{eff}=0.30 μm^2, α=0.01 dB km^{-1} and γ=0.1. The length of the ring is L=80 μm, where the coupling coefficients is $\kappa = 0.0225$ and the linear phase shift has been kept to zero. Total round trip of the input pulse inside the ring system is 20000. An increasing of nonlinear refractive index from n_2=2.2×10^{-20} m^2/W to n_2=3.2×10^{-20} m^2/W causes the optical nonlinear phenomena to be seen at the lower range of input power shown in Fig. 2.

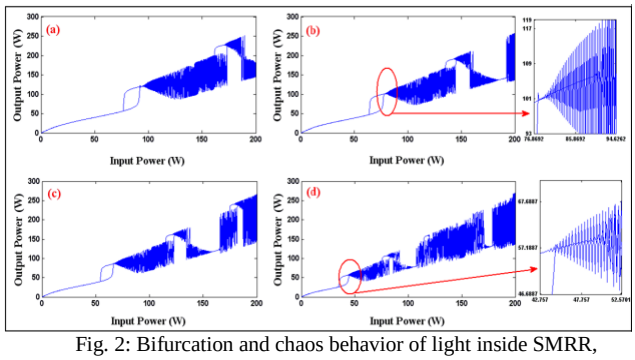

Fig. 2: Bifurcation and chaos behavior of light inside SMRR, where $\kappa = 0.0225$ and $L = 80\mu m$ for various nonlinear refractive indices: (a): n_2=2.2×10^{-20} m^2/W, (b): n_2=2.4×10^{-20} m^2/W, (c): n_2=2.6×10^{-20} m^2/W and (d): n_2=3.2×10^{-20} m^2/W.

Effects of the coupling coefficients on the bifurcation and chaos behavior, in terms of roundtrip and output powers are shown in Fig. 3. Input Gaussian pulse with power of 2W is introduced into the ring system where the radius of the ring is selected to R=15 μm. Here, the coupling coefficient is a variable parameter that varies from $\kappa = 0.01$ to $\kappa = 0.1$.

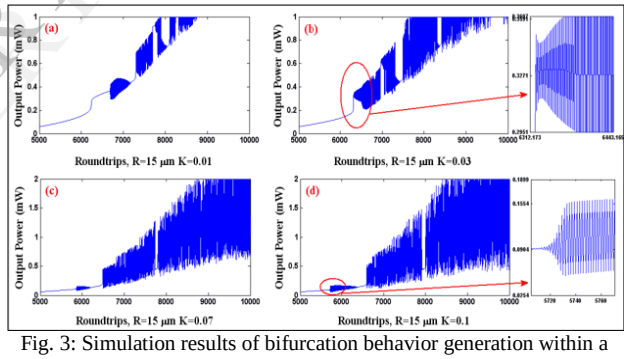

Fig. 3: Simulation results of bifurcation behavior generation within a SMRR respect to different value of couple coefficient (κ), where (a): $\kappa = 0.01$, (b): $\kappa = 0.03$, (c): $\kappa = 0.07$ and (d): $\kappa = 0.1$

Effects of ring's size are shown in Fig. (4). Here the coupling coefficient has been fixed to $\kappa = 0.0225$, where the radius of the SMRR varies from 7 μm to 40 μm.

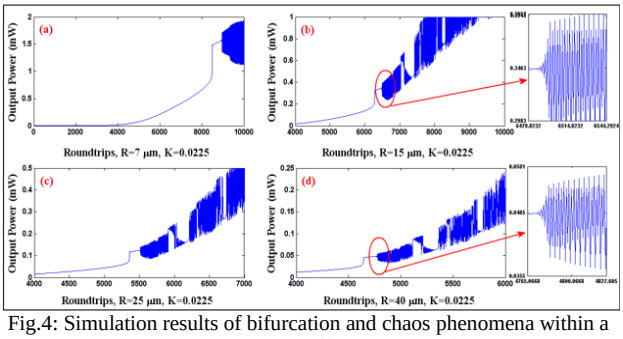

Fig.4: Simulation results of bifurcation and chaos phenomena within a micro ring resonators respect to different values of ring radius (R).

Optical soliton can be used to generate chaotic filter characteristics when propagating within the SMRR [73-75]. When the input pulse is introduced into the SMRR as shown in Fig.1, the input optical field (E_{in}) can be expressed by [76, 77]

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

$$E_{add}(t) = E_0 \exp\left[\left(\frac{z}{2L_D}\right) - i\omega_0 t\right] \quad (2)$$

Here A and z are the optical field amplitude and propagation distance, respectively [78]. T is the soliton pulse propagation time, and $L_D = T_0^2/|\beta_2|$ is the dispersion length of the soliton pulse [79]. β_2 is the propagation constant. This soliton describes a pulse that keeps its temporal or spatial width invariance as it propagates along the MRR system [80]. When soliton peak intensity $\left(|\beta_2/\Gamma T_0^2|\right)$ is given, then T_0 is known, where $\Gamma = n_2 \times k_0$, is the length scale over which dispersive or nonlinear effects makes the beam become wider or narrower [81]. For the 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 [82]. Here $\phi_0 = kLn_0$ si the linear phase shifts [83].

The optical power of the dark soliton 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 ring (R), where R=10 μm, κ=0.9713, shown in Figure 5(a). Gaussian pulse with power of 450 mW and central wavelength of λ_0=1500 nm is input into the system, where n_2=2.2×10^{-15} m^2 W^{-1} and A_{eff} = 25 μm^2. In this case R=17 μm, κ =0.995 and R=17 μm, κ =0.9895 shown in Figure 5(b) and 5(c) respectively.

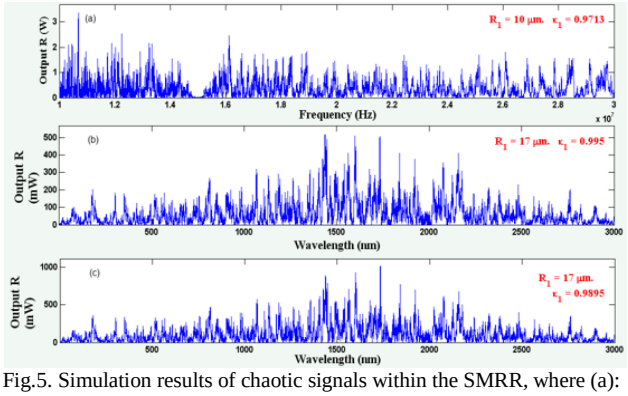

Fig.5. Simulation results of chaotic signals within the SMRR, where (a): simulated frequency chaotic band, (b) and (c): spatial chaotic signals.

Obtained results of the chaotic signals from the SMRR pass through a PBS as shown in Figure (6). In application, the variable quantum binary codes can be generated using the PBS [84]. It means that the localized wavelength or frequency can be used to generate variable codes [85]. Binary codes via chaotic signals can be connected into a network communication system shown in Fig. 6 [86]. Therefore, generated secured quantum binary codes can be transmitted to different users via a wireless networks transmitter system [87].

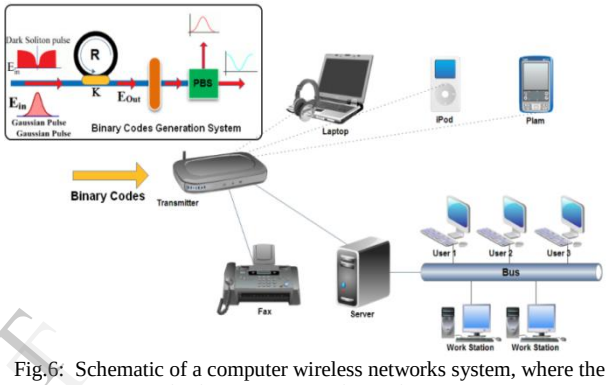

Fig.6: Schematic of a computer wireless networks system, where the transmission of information in the form of binary codes can be implemented using SMRR

Therefore, chaotic signals are generated, whereas the required signals including specific wavelengths or frequencies can be used to perform the secure wireless communication network [88, 89]. In order to increase the capacity of micro ring systems [90-92], more sharp optical pulses with smaller free spectrum range (FSR) are recommended [93-104].

Conclusion

We have presented nonlinear effects of the single ring resonator as optical bifurcation and chaos. Traveling of light inside the proposed ring system is analyzed by manipulating of nonlinear refractive index, coupling coefficient and the radius of the ring resonator. Results have shown that the bifurcation and chaos can be occurred in different roundtrip times and input power. Occurrence of bifurcation at lower input power or smaller round trip is a beneficial effect in order to improve the nonlinear microring system. Therefore, controlling the round trip times and the input power of the system can be used to deal with and control the bifurcation and chaotic signals, where it is used in many applications in photonics communication such as security processing or digital coding implementations. In this study generation of quantum binary codes was perform using chaotic signals which are transmitted via wireless networks and information transmission system.

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