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Mathematical simulation of light pulse propagating within a microring resonator system and applications

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ABSTRACT

This paper presents the very fascinating simulation results of light pulse traveling within a ring resonator system that have shown the unexpected results with various applications. The design system consists of a nonlinear microring/nanoring resonator system incorporating an add/drop filter. The proposed fabricated material used is InGaAsP/InP, which can provide the required output behaviors. Three different forms of input light pulses are Gaussian pulse, dark and bright soliton, whereas the suitable simulation parameters are input power, pulse width, ring radii and the material refractive indices. Three different forms of the results have been interpreted, whereas the dominants behaviors are such as Gaussian soliton, multisoliton and tunable dark soliton are described, and the potential applications for new laser sources, new communication bands and dynamic optical tweezers have been discussed.

1. Introduction

A Gaussian pulse has been recognized in the form of a laser pulse that can be used in both theoretical and experimental investigation in many subjects. However, in some ways, the limit of laser power cause a problem, especially, when the high output power or long distance link is required. Optical soliton becomes a powerful tool that can overcome such a problem, i.e. for high power laser source. Furthermore, the non-dispersion of soliton in medium is the other advantage. Optical solitons can naturally be divided into classes of dark and bright solitons, whereas a dark soliton exhibits an interesting and remarkable behavior, when it is transmitted into an optical transmission system. It has the advantage of the signal detection difficulty, when the ambiguity of signal detection becomes a problem for the un-wanted users. In principle, the soliton generations and their behaviors in media are well analyzed and described by Agarwal [1]. Many earlier theoretical and experimental works on soliton applications can be found in the soliton application book by Hasegawa [2]. However, to make such a tool more useful, the problems of soliton–soliton interactions [3], collision [4], rectification [5], and dispersion management [6–8] must be solved and addressed. Therefore, in this work, we are looking for a powerful laser source with broad spectrum that can be used in many applications.

Recently, several research works have shown that use of dark and bright soliton in various applications can be realized [9–14], where one of them has shown that the secured signals in the communication link can be retrieved by using a suitable an add/drop filter that is connected into the transmission line. The other promising application of a dark soliton signal [15] is for the large guard band of two different frequencies which can be achieved by using a dark soliton generation scheme and trapping a dark soliton pulse within a nanoring resonator [1]. Furthermore, the dark soliton pulse shows a more stable

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behavior than the bright solitons with respect to the perturbations such as amplifier noise, fiber losses, and intra-pulse stimulated Raman scattering [16]. It is found that the dark soliton pulses propagation in a lossy fiber, spreads in time at approximately half the rate of bright solitons. The dark solitons trapped in add/drop system is realized [17]. In this paper, the use of three forms of laser pulses, i.e. Gaussian soliton, dark and bright soliton propagating within the proposed ring resonator systems is investigated and described. The use of suitable simulation parameters based on the realistic device is discussed. The potential application for new laser sources, new communication bands and dynamic optical tweezers is also discussed.

2. Theory and principle

2.1. Gaussian pulse

Light from a monochromatic light source is launched into a ring resonator with constant light field amplitude (E_0) and random phase modulation as shown in Fig. 1, which is the combination of terms in attenuation (α) and phase (φ_0) constants, which results in temporal coherence degradation. Hence, the time dependent input light field (E_{in}), without pumping term, can be expressed as [18]

$$E_{in}(t) = E_0 e^{-\alpha L + j\phi_0(t)}, \tag{1}$$

where L is a propagation distance(waveguide length).

We assume that the nonlinearity of the optical ring resonator is of the Kerr-type, i.e., the refractive index is given by

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

where n_0 and n_2 are the linear and nonlinear refractive indexes, respectively. 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 microring and nanoring resonators, the effective mode core areas range from 0.10 to 0.50 μm^2 [19,20].

When a Gaussian pulse is input and propagated within a fiber ring resonator, the resonant output is formed, thus, the normalized output of the light field is the ratio between the output and input fields (E_{out} and E_{in}) in each roundtrip, which can be expressed as [21]

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

Eq. (3) indicates that a ring resonator in the particular case is very similar to a Fabry–Perot cavity, which has an input and output mirror with a field reflectivity, $(1-\kappa)$, and a fully reflecting mirror. k is the coupling coefficient, and ($x = \exp(-\alpha L/2)$ represents a roundtrip loss coefficient, $\varphi_0 = kLn_0$ and $\phi_{NL} = kL\left(\frac{n_2}{A_{eff}}\right)P$ are the linear and nonlinear phase shifts, $k = 2\pi/\lambda$ is the wave propagation number in a vacuum. Where L and α are a waveguide length and linear absorption coefficient, respectively. In this work, the iterative method is introduced to obtain the results as shown in Eq. (3), similarly, when the output field is connected and input into the other ring resonators.

The input optical field as shown in Eq. (1), i.e. a Gaussian pulse, is input into a nonlinear microring resonator. By using the appropriate parameters, the chaotic signal is obtained by using Eq. (3). To retrieve the signals from the chaotic noise, we propose to use the add/drop device with the appropriate parameters. This is given in details as followings. The optical outputs of a ring resonator add/drop filter can be given by the Eqs. (4) and (5).

$$\left|\frac{E_t}{E_{in}}\right|^2 = \frac{(1-\kappa_1) - 2\sqrt{1-\kappa_1}\cdot\sqrt{1-\kappa_2}e^{-\frac{\alpha}{2}L}\cos(k_n L) + (1-\kappa_2)e^{-\alpha L}}{1 + (1-\kappa_1)(1-\kappa_2)e^{-\alpha L} - 2\sqrt{1-\kappa_1}\cdot\sqrt{1-\kappa_2}e^{-\frac{\alpha}{2}L}\cos(k_n L)}, \tag{4}$$

and

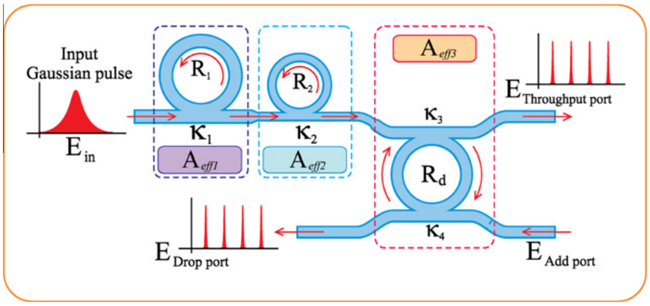

Fig. 1. A schematic of a Gaussian soliton generation system, where R_s: ring radii, κ_s: coupling coefficients, R_d: an add/drop ring radius, A_{effs}: effective areas.