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All-Optical Nanoscale Microring Device and System Design for Nano Communication

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Abstract

In this paper, we have shown that the two components (TE and TM waves) of polarized light are manipulated by using the orthogonal soliton pair within a PANDA ring resonator known as a dark-bright soliton pair. In operation, the orthogonal soliton sets can be generated by using the system. The optical field is fed into the ring resonator system, which is controlled by an optical switch by using a single microring. To form the initial spin states, the magnetic field is induced by an aluminum plate (Al) coupled on AlGaAs waveguides for optoelectronic spin-up and -down states. The optoelectronic spin is formed by using the TE and TM wave components. In this manipulation, the electromagnetic radiation is formed by using the orthogonal soliton pulses. In fact, they are photons, which behave like elementary particles. Hence, the spin axis of photon is always parallel to its direction of motion. Many orthogonal sets are also available and existed, in which the spin conservation of many particles is maintained for large scale system use. Therefore, for future applications, the use for high performance storage, low power magnetic logic, quantum logic, quantum gate, nano antenna, nano radio, and applications of spintronic sensing can be realized based on realistic device parameters.

Keywords: micro-ring resonators; DWDM; nano communication

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1. Introduction

Optical communication has fueled the global telecom and information technology revolution in the past two decades [1]. Nowadays, worldwide transport of huge volume of data relies on optical communication systems. Furthermore, optical signal processing technology has been aggressively pursued [2], aiming at higher operation speed and enriched functionality. This holds a great potential to diminish the need for O-E-O conversion in the data transmission links in order to upgrade system capacity, reduce latency and cost, and enable a wavelength- and data format- transparent optical network. Integrated photonics has attracted a great deal of attention in recent years not only because it allows for more cost-effective production and easier packaging but also because smaller chip size assists in realizing faster and less power-consuming photonic devices to facilitate “green” information technology. Integrated photonics also plays an increasingly important role in data com systems. Optical communication has been investigated in almost every layer of information technology infrastructure: continent-to-continent, city-to-city, server to- server, computer-to-computer, board-to-board, chip-to-chip, and finally intrachip. This has been identified to be one of bottlenecks in the future development of the integrated circuit industry, according to the International Technology Roadmap for Semiconductors (ITRS).

In general, optical communication and signal processing represent different categories of devices and subsystems, although it is hard to clearly separate them from each other. In communication, optical subsystems include, but are not limited to, signal generation, detection, amplification, filtering, and signal degrading effects’ monitoring and compensation. In signal processing, functional units would range heven more widely from pulse manipulating, data routing to optical logic, as listed Most of these functions have been demonstrated using integrated devices.

In this paper, we have shown that the two components (TE and TM waves) of polarized light are manipulated by using the orthogonal soliton pair within a PANDA ring resonator known as a dark-bright soliton pair. In operation, the orthogonal soliton sets can be generated by using the system. The optical field is fed into the ring resonator system, which is controlled by an optical switch by using a single microring. To form the initial spin states, the magnetic field is induced by an aluminum plate (Al) coupled on AlGaAs waveguides for optoelectronic spin-up and -down states. The optoelectronic spin is formed by using the TE and TM wave components. In this manipulation, the electromagnetic radiation is formed by using the orthogonal soliton pulses. In fact, they are photons, which behave like elementary particles. Hence, the spin axis of photon is always parallel to its direction of motion. Many orthogonal sets are also available and existed, in which the spin conservation of many particles is maintained for large scale system use. Therefore, for future applications, the use for high performance storage, low power magnetic logic, quantum logic, quantum gate, nano antenna, nano radio, and applications of spintronic sensing can be realized based on realistic device parameters.

2. Principles of the Microring Resonator

A dark-bright soliton conversion system using a ring resonator optical channel dropping filter is composed of two sets of coupled waveguides, as shown in Fig. 1. The relative phase of the two output light signals after coupling into the optical coupler is $\pi/2$. This means that the signals coupled into the drop and through ports have acquired a phase of π with respect to the input port signal. In application, if we engineer the coupling coefficients appropriately, the field coupled into the through port on resonance would completely extinguish the resonant wavelength, and all the power would be coupled into the drop port. The input and control fields at the input and add ports are formed by the dark and bright optical solitons and described by Equations (1) and (2), respectively [3].

$$E_{in}(t) = A_0 \tanh\left[\frac{T}{T_0}\right]\exp\left[\left(\frac{z}{2L_D}\right) - i\omega_0 t\right] \tag{1}$$

$$E_{in}(t) = A_0 \,\mathrm{sech}\left[\frac{T}{T_0}\right]\exp\left[\left(\frac{z}{2L_D}\right) - i\omega_0 t\right] \tag{2}$$

Here A_0 and z are the optical field amplitude and propagation distance, respectively. $T=t-\beta_1 z$, where β_1 and β_2 are the coefficients of the linear and second-order terms of Taylor expansion of the propagation constant. $L_D = T_0^2/|\beta_2|$ is the dispersion length of the soliton pulse. T_0 in equation is a soliton pulse propagation time at initial input (or soliton pulse width), where t is the soliton phase shift time, and the frequency shift of the soliton is ω_0. The optical fields of the system in Fig. 1 are obtained and expressed in following forms

$$E_{ra} = -j\kappa_1 E_i + \tau_1 E_{rd}, \tag{3}$$

$$E_{rb} = \exp(j\omega T/2)\exp(-\alpha L/4)E_{ra}, \tag{4}$$

$$E_{rc} = \tau_2 E_{rb} - j\kappa_2 E_a, \tag{5}$$

$$E_{rd} = \exp(j\omega T/2)\exp(-\alpha L/4)E_{rc}, \tag{6}$$

$$E_t = \tau_1 E_i - j\kappa_1 E_{rd}, \tag{7}$$

$$E_d = \tau_2 E_a - j\kappa_2 E_{rb}, \tag{8}$$

Here E_i is the input field, E_a is the add(control) field, E_t is the through field, E_d is the drop field, $E_{ra}...E_{rd}$ are the fields in the ring at points $a...d$, κ_1 is the field coupling coefficient between the input bus and ring, κ_2 is the field coupling coefficient between the ring and output bus, L is the circumference of the ring, T is the time taken for one round trip(roundtrip time), and α is the power loss in the ring per unit length. We assume that this is the lossless coupling, i.e., $\tau_{1,2} = \sqrt{1-\kappa_{1,2}^2}$. $T = L n_{eff}/c$.

The output power/intensities at the drop and through ports are given by

$$|E_d|^2 = \left|\frac{-\kappa_1\kappa_2 A_{1/2}\Phi_{1/2}}{1-\tau_1\tau_2 A\Phi}E_i + \frac{\tau_2 - \tau_1 A\Phi}{1-\tau_1\tau_2 A\Phi}E_a\right|^2. \tag{9}$$

$$|E_t|^2 = \left|\frac{\tau_2 - \tau_1 A\Phi}{1-\tau_1\tau_2 A\Phi}E_i + \frac{-\kappa_1\kappa_2 A_{1/2}\Phi_{1/2}}{1-\tau_1\tau_2 A\Phi}E_a\right|^2. \tag{10}$$

Here $A_{1/2} = \exp(-\alpha L/4)$ (the half-round-trip amplitude), $A = A_{1/2}^2$, $\Phi_{1/2} = \exp(j\omega T/2)$ (the half-round-trip phase contribution), and $\Phi = \Phi_{1/2}^2$.

3. Result and Discussion

In operation, the orthogonal soliton sets can be generated by using the system in Fig. 2. The optical field is fed into the ring resonator system, which is controlled by an optical switch as shown in Fig. 2, where $R_1 = R_2 = 2.5\mu m$, $R_{ad} = 30\mu m$ by using a single microring, $R = 20\mu m$. To form the initial spin states, the magnetic field is induced by an aluminum plate (Al) coupled on AlGaAs waveguides for optoelectronic spin-up and -down states. In this simulation, the coupling coefficient ratios κ_1:κ_2 are *50:50*, *90:10*, *10: 90* acting in the following manner: (a) dark soliton is input into input and control ports, (b) dark and bright solitons are fed for input and control signals, (c) bright and dark solitons are used for input and control signals, and (d) bright soliton is used for input and control signals. The ring radii $R_{ad} = 300nm$, $A_{eff} = 0.25\mu m^2$, $n_{eff} = 3.14$(for InGaAsP/InP)[4], $\alpha = 0.1dB/mm$, $\gamma = 0.01$, $\lambda_0 = 1.55\ \mu m$. Fig. 3 shows the output intensities, for (a) spin-injected for transverse electric (TE) and transverse magnetic (TM) fields, (b) spin-up (TE) photons are resonances at 1.4671, 1.5031, 1.5403μm and spin-down (TM) photon at 1.4578, 1.4914, 1.5271μm. More output intensities are generated by using a PANDA ring resonator are as shown in Fig. 4, in which (a) spin-injected for transverse electric (TE) and transverse magnetic (TM) fields, (b) spin-up (TE) photons are at 1.2846, 1.3124, 1.3412μm and spin-down (TM) photons at 1.2888, 1.3162, 1.3427μm. Fig. **5** shows the output power at the center wavelength 1.55μm, with the output (a) through, Th (TE) port is the maximum output power -57.08dB, and drop (TM) port with the maximum output power is -48.9dB, (b) the spin-up (TE) and spin-down (TM) photons are detected.

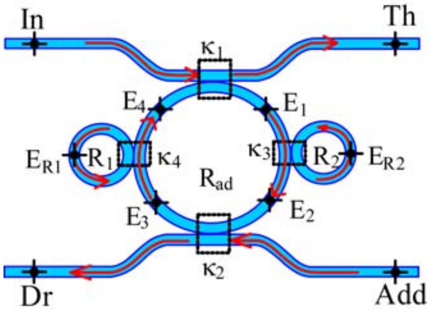

Fig. 1. A schematic diagram of a PANDA ring resonator, where R_i: ring radii, E_i: electric fields, κ_i: coupling coefficients, In: input field, Th: through port, Dr: drop port, and Add: add port

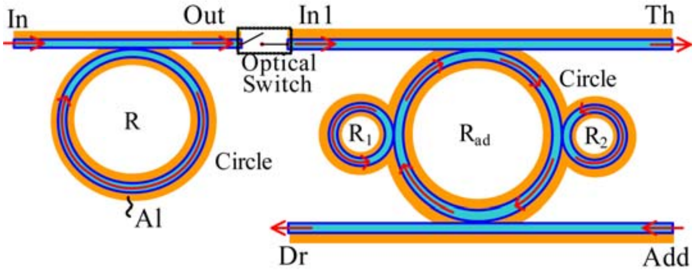

Fig. 2. Schematic of optoelectronic spin generation based-on a PANDA ring

The optoelectronic fields generated by a dark-soliton pump based-on (port In) microring resonator (R = 20μm) at center wavelength 1.45μm are as shown in Fig. 6, with (a) bright soliton at E_1, (b) dark-soliton at E_2, (c) dark soliton at E_3, (d) bright-soliton at E_4, and (e) transmittance at through (Th) and reflectance at drop (Dr) ports of a PANDA ring resonator, respectively. For a large stream of photons, the net angular momentum is essentially zero (see Fig. 6(a)), because half of photons interact in the right-handed sense and half in the left-handed sense. This corresponds to the fact that linearly polarized light can be regarded as superposition of left and right circularly polarized light. This means that spin conservation is maintained. The optoelectronic spin manipulation generated within a PANDA ring resonator is as shown in Fig. 7, where (1) input power 49.52W, 0.3226ns, (2) circulated power 0.504W, 0.5081ns, (3) reflected power 49.016W, 0.8526ns at the drop port and (4) transmitted power 0.495W, 1.0459ns at the through port. In applications, the output signals (orthogonal solitons or photons) are randomly obtained at the *Th* and *Dr* ports as shown in Fig. 6, in which the random transverse electric (TE) and transverse magnetic(TM) fields of the solitons corresponding to the left-hand and right hand photons can be generated and detected. The angular momentum of either $+\hbar$ or $-\hbar$ is imparted to the object when a photon is absorbed by an object, where two possible spin states known as optoelectronic spins are exhibited. The array of optoelectronic spins can be generated and controlled by using the proposed system as shown in Fig. 6(e), which is available for high density spin states use.

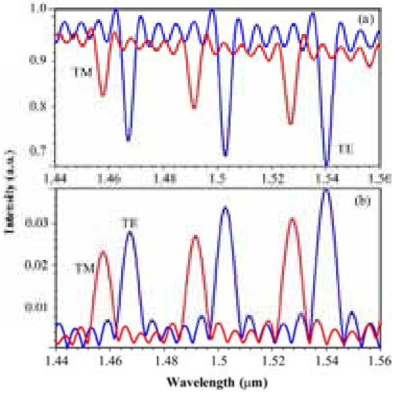

Fig. 3. Output intensities are generated by using a single microring resonator

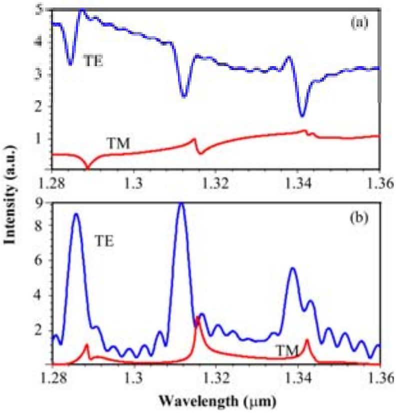

Fig. 4. Output intensities are generated by using a PANDA ring resonator

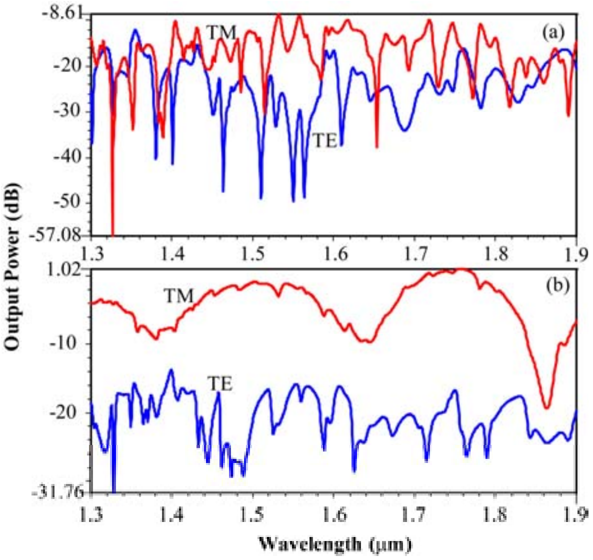

Fig. 5. Output power generated at the center wavelength 1.55µm

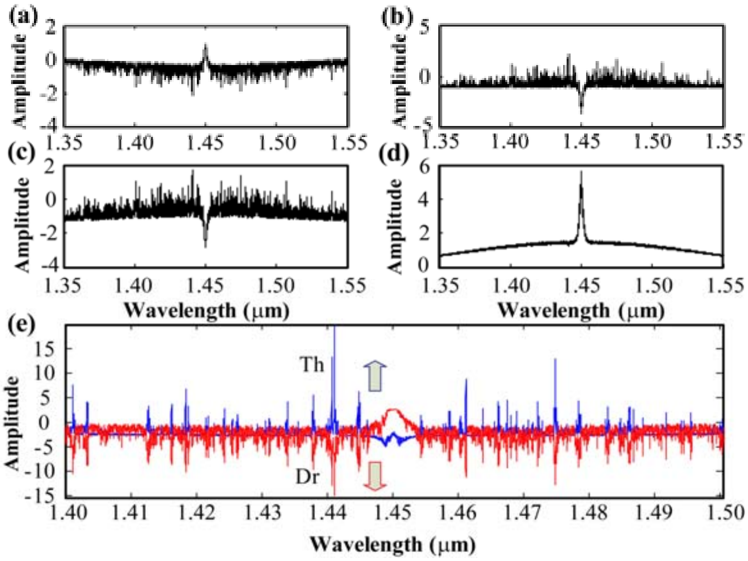

Fig. 6. Optoelectronic fields generated by a dark-soliton pump based-on (port In) microring resonator (R = 20µm) at center wavelength 1.45µm

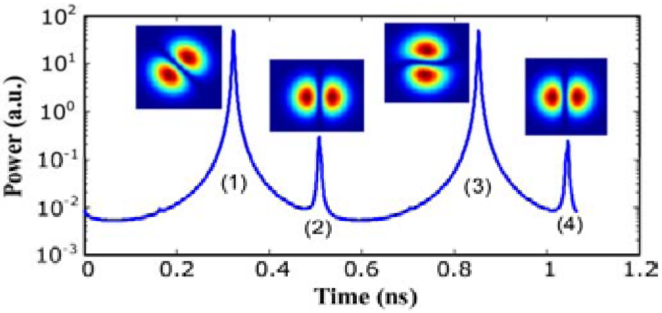

Fig. 7. Optoelectronic spin manipulation generated within a PANDA ring resonator

4. Conclusion

In this paper, we have shown that the two components (TE and TM waves) of polarized light are manipulated by using the orthogonal soliton pair within a PANDA ring resonator known as a dark-bright soliton pair. The optoelectronic spin is formed by using the TE and TM wave components. In this manipulation, the electromagnetic radiation is formed by using the orthogonal soliton pulses. In fact, they are photons, which behave like elementary particles. Hence, the spin axis of photon is always parallel to its direction of motion. Many orthogonal sets are also available and existed, in which the spin conservation of many particles is maintained for large scale system use. Therefore, for future applications, the use for high performance storage, low power magnetic logic, quantum logic, quantum gate, nano antenna, nano radio, and applications of spintronic sensing can be realized based on realistic device parameters.

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