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# Optical spin generated by a soliton pulse in an add–drop filter for optoelectronic and spintronic use

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ABSTRACT

A new concept of an optical spin generation using bright and dark soliton conversion behaviors within a modified optical add–drop filter known as PANDA ring resonator is proposed. The orthogonal solitons can be formed within the system and detected simultaneously at the output ports. Under the resonant condition, the dark and bright soliton pair corresponding to the left-hand and right-hand rotating solitons (photons) can be generated. When a soliton is absorbed by an object, an angular momentum of either $+\hbar$ or $-\hbar$ is imparted to the object, in which two possible spin states known as optoelectronic(soliton) spins are exhibited. Furthermore, an array of soliton spins, i.e. particles can be generated and detected by the proposed system, which can be used to form large scale spin generation.


## 1. Introduction

Optical add–drop filters have been widely investigated in many areas of applications, especially, when the use of an all-optical device which is formed by the modified add–drop optical filter known as a *PANDA* ring resonator [1–3]. Using an optical dark–bright soliton control arrangement within a semiconductor add–drop multiplexer, the promising applications have been observed [4]. In applications, one of the advantages is that the dark soliton peak signal always at low level, which is useful for secured signal communication in the transmission link. The other applications are associated to the high optical field configurations (as an optical tweezer or potential well) [5]. Spin manipulation has generated tremendous research progress in many fields, as light-shift effect in rubidium atom [6], magnetic clusters [7], semiconductors [8], GaAs/AlGaAs quantum well [9], carbon nanotubes [10], thin-film nanomagnets [11], magnetic tunnel junctions [12], and CdTe quantum dots [13]. All of them are based on pulsed magnetic resonance technique which is well developed, but to date the single spin detection still remains a challenging task. The use of photon states for spin manipulation has become a promising technique of investigation, in which photons are the ideal candidates to transmit quantum information with little de-coherency. Furthermore, spin states can be used to store and process quantum information due to their long coherence time. Therefore, the investigations of spin manipulation [14,15], spin detection, remote spin entanglement mediated by photons, quantum state transfer between photons and spins are of great importance. However, there is still need to explore the aspect of spin coupling and orbital motion of electrons in carbon nanotubes, magnetic manipulations, sidewall oxide effects on spin torque, magnetic field induced reversal characteristics of thin film nanomagnets, magnetic vortex oscillator driven by direct spin polarized current and measurement of the spin transfer torque vector in magnetic tunnel junctions [16,17].

In this paper, the use of a modified add–drop optical filter structure is analyzed within PANDA ring resonator system to form the orthogonal sets of solitons, which can be decomposed into left and right circularly rotated (polarized) waves. PANDA is a Chinese bear which is used to call a modified add–drop optical filter by the authors. This can be done relative to any orthogonal set of axes, where typical plane wave of ordinary light consists of components with all polarizations mixed together. The use of a new orthogonal set of light pulses called a dark–bright soliton pair [18] is proposed to form the two components of circularly rotated waves. In principle, the orthogonal solitons can be used to form the two components of polarized light, which are called the optoelectronic spin states. Finally, the different soliton spins are described using several pairs of the orthogonal solitons, in which the conservation of their spins is maintained and realized.

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## 2. Theoretical background

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 $\pi/2$. Thus, the signals coupled into the drop and through ports have acquired a phase of $\pi$ with respect to the input port signal. The resonant wavelength at through port on resonance can be extinguished completely by engineering the appropriate coupling coefficients and as a result all the power would be coupled into the drop port. The control fields at the input and add ports are formed by the dark and bright optical solitons and described by Eqs. (1) and (2), respectively [4,5]

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

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

Here $A_0$ and $z$ are the optical field amplitude and propagation distance, respectively. $T = t - \beta_1 z$, where $\beta_1$ and $\beta_2$ 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. $T_0$ is a soliton pulse propagation time at initial input (or soliton pulse width), where $t$ is the soliton phase shift time, and $\omega_0$ is the frequency shift of the soliton. The optical fields of the system can be expressed as follow:

$$E_1 = -j\kappa_1 E_i + \tau_1 E_4, \quad (3)$$

$$E_2 = \exp(j\omega T/2)\exp(-\alpha L/4)E_1, \quad (4)$$

$$E_3 = \tau_2 E_2 - j\kappa_2 E_a, \quad (5)$$

$$E_4 = \exp(j\omega T/2)\exp(-\alpha L/4)E_3, \quad (6)$$

$$E_t = \tau_1 E_i - j\kappa_1 E_4, \quad (7)$$

$$E_d = \tau_2 E_a - j\kappa_2 E_2, \quad (8)$$

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, $E_1 \ldots E_4$ are the fields in the ring at points 1…4, $\kappa_1$ is the field coupling coefficient between the input bus and ring, $\kappa_2$ 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 $\alpha$ is the power loss in the ring per unit length. We assume that this is the lossless coupling, i.e. $\tau_{1,2} = \sqrt{1-\kappa_{1,2}^2}$. $T = Ln_{eff}/c$.

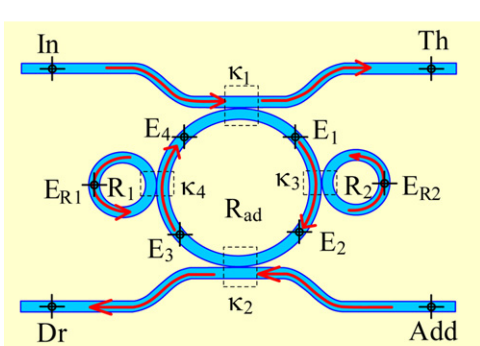


**Fig. 1.** A schematic diagram of an InGaAsP/InP PANDA ring resonator, where $R_i$: ring radii, $E_i$: electric fields, $\kappa_i$: coupling coefficients, In: input field, Th: through port, Dr: drop port, and Add: add port.

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

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

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

where $A_{1/2} = \exp(-\alpha L/4)$ (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. Simulation results

In operation, the orthogonal soliton sets can be generated by the proposed system as shown in Fig. 1. The optical field is fed into the PANDA system, where $R_1 = R_2 = 2.5\ \mu m$, $R_{ad} = 30\ \mu m$, $A_{eff} = 0.25\ \mu m^2$, $n_{eff} = 3.14$, $n_2 = 1.3 \times 10^{-13}\ cm^2/W$ (for InGaAsP/InP waveguide)[19], $\alpha = 0.1$ dB/mm, gap coefficients, $\kappa_1 = \kappa_2 = 0.5$, $\kappa_3 = \kappa_4 = 0.3$, $\gamma = 0.01$, $\lambda_0 = 1350$, 1450, 1500, 1550, and 1600 nm. It has been observed that when the dark soliton arrays are fed into a PANDA ring, the bright soliton conversion pulses are seen at $E_1$ and $E_4$ position (as shown in Fig. 2(a) and (d)), and the dark soliton conversion pulses are seen at $E_2$ and $E_3$ position ( as shown in Fig. 2(b) and (c)).

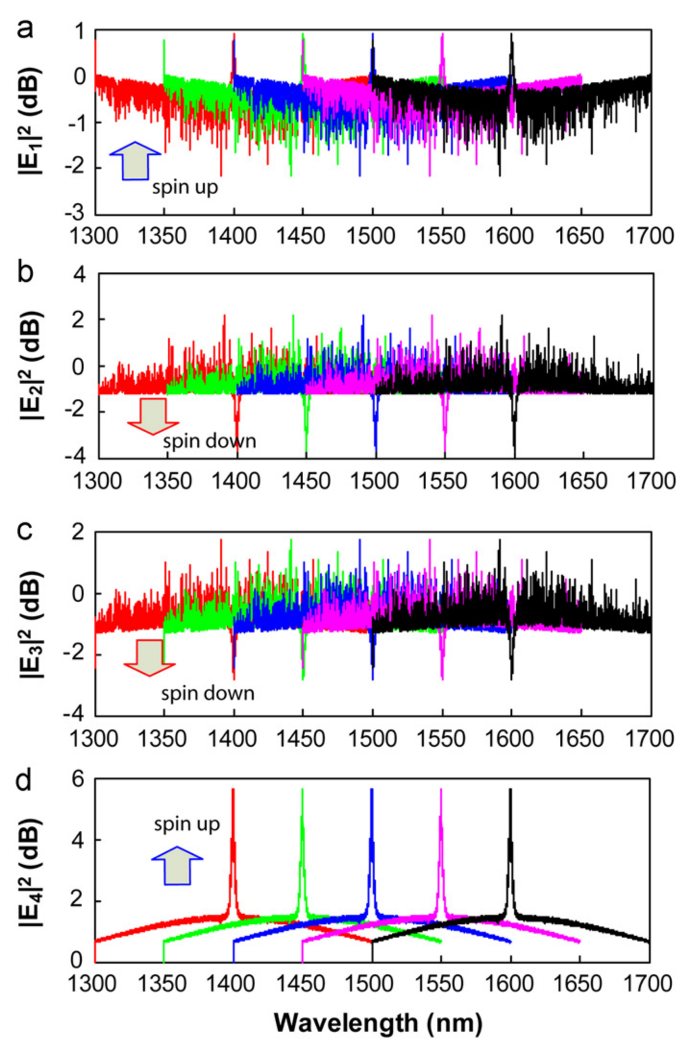


**Fig. 2.** Many soliton spins within a PANDA ring are generated using a dark-soliton pump input port (port In and where $R_1 = R_2 = 2.5\ \mu m$, $R_{ad} = 30\ \mu m$) at center wavelength 1350, 1450, 1500, 1550, and 1600 nm.