Quantum Transmission of Optical Tweezers Via Fiber Optic Using Half-Panda System

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Abstract: The aim of this study is to generate nano optical tweezers to be connected to an optical transmission link in order to transmit tweezers via an optical fiber. A system of microring resonator (MRR) known as Half-Panda is proposed to generate nano optical tweezers. Optical tweezers can be used to transport molecules in a communication link. The dark soliton propagates inside nonlinear MRR. The input bright soliton is used to control the output signal at the through and drop ports of the system. Throughput nano optical tweezers can be connected to the fiber optic with a length of 100 km, where transmission of tweezers can be performed. The optical receiver will detect the signals of optical tweezers. A transmitter system can be used to transmit the tweezers via wired/wireless link to the users in a short communication link. Here the nano optical tweezers signals with width at half maximum (FWHM) of 33 nm are obtained and transmitted, where the free spectrum range (FSR) of the pulses is 50 nm.

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1. INTRODUCTION

Dark-bright soliton controls within a semiconductor add-drop multiplexer has numerous applications in optical communication (Amiri *et al.* 2010a; Ridha *et al.* 2010a; Afroozeh *et al.* 2010a; Amiri *et al.* 2012e). The nano optical tweezers technique has become a powerful tool for manipulation of micrometer-sized particles/photons in three spatial dimensions (Amiri and Ali 2014b). It has the unique ability to trap and manipulate molecules/photons at mesoscopic scales with widespread applications in biology and physical sciences (Amiri and Ali 2013b). The output is achieved when the high optical field is set up as an optical tweezers (Amiri *et al.* 2010b).

The tweezers are kept in the stable form within the add-drop system (Amiri *et al.* 2012m). Microring resonator (MRR) is a type of Fabry-Perot resonator which can be readily integrated in array geometries to implement many useful functions (Jalil *et al.* 2011; S. E. Alavi *et al.* 2013; Ali *et al.* 2011; Afroozeh *et al.* 2010d; Ali *et al.* 2010r). Its nonlinear phase response can be readily incorporated into an interferometer system to produce a specific intensity output function (Bahadoran *et al.* 2011; Ali *et al.* 2010d; Ali *et al.* 2010{; Saktioto *et al.* 2010a). Several emerging technologies, such as integrated all optical signal processing and all-optical quantum processing, require interactions between two distinct optical signals (Amiri and Ali 2014a; Shojaei and Amiri 2011a; Afroozeh *et al.* 2012d).

Internet security has become an important function in the modern internet service (Ali *et al.* 2010p; Afroozeh *et al.* 2011b; Nikoukar *et al.* 2013). However, the security technique known as quantum cryptography has been widely used and investigated in many applications (Teeka *et al.* 2011; Amiri *et al.* 2012g; Saktioto *et al.* 2010b), using optical tweezers (Amiri *et al.* 2012j). Amiri *et al*. have proposed the new design of secured packet switching (Amiri *et al.* 2012a; I. S. Amiri *et al.* 2013d; I. S. Amiri and J. Ali). This method uses nonlinear behaviors of light in MRR which can be used for high-capacity and security switching (I. S. Amiri and J. Ali 2014b; Amiri *et al.* 2011d; Ali *et al.* 2010s). Recently a quantum network shows promising usage of the perfect network security (Amiri *et al.* 2012f; Amiri *et al.* 2010-2011; Ali *et al.* 2010w). Amiri *et al.* have shown that the continuous wavelength can be generated by using a soliton pulse in an MRR (Amiri *et al.* 2012i; Afroozeh *et al.* 2011a; Kouhnavard *et al.* 2010a) . In this study, a nano transmission system based on optical soliton is developed.

2. THEORETICAL MODELING

The dark soliton pulse is introduced into the multiplexer half-Panda system shown in figure (1) (Amiri *et al.* 2012l; Amiri and Ali 2014c; Kouhnavard *et al.* 2010c). This system consists of an add-drop ring system connected to a smaller ring resonator on the right side (Amiri *et al.* 2012p; Amiri *et al.* 2011a). The dynamic behavior of the optical tweezers is appeared when the bright soliton is input into the add port of the system (Ali *et al.* 2010|; Amiri and Ali

2012). The ring resonator with a radius (R_{ring}) of 10 μm and a coupling coefficient (κ) of κ =0.2 is connected to the add-drop system with radius (R_{ad}) of 15 μm and coupling coefficient of $\kappa_1 = \kappa_2 = 0.3$. The effective area of the coupling section is A_{eff}=25 μm^2 (Imran *et al.* 2010; Ali *et al.* 2010c; Amiri *et al.* 2013c).

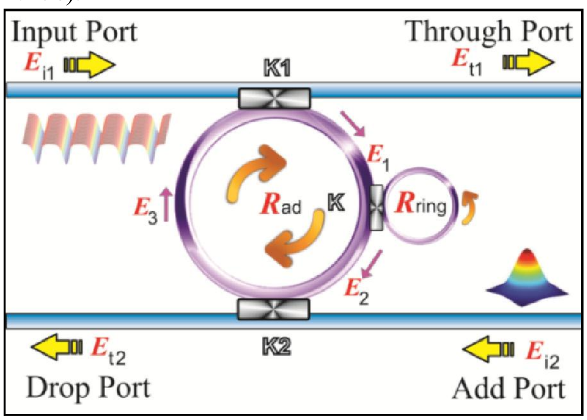

Fig.1. A schematic diagram of Half-Panda system

The input optical field (E_{i1}) of the dark soliton and add optical field (E_{i2}) of the bright soliton are given by (Mohamad *et al.* 2010b; Ali *et al.* 2010n; Ali *et al.* 2010e; Nikoukar *et al.* 2010-2011)

$$E_{i1} = A\tanh\left[\frac{T}{T_0}\right]\exp\left[\left(\frac{z}{2L_D}\right) - i\omega_0 t\right], \quad (1)$$

$$E_{i2} = A\sec h\left[\frac{T}{T_0}\right]\exp\left[\left(\frac{z}{2L_D}\right) - i\omega_0 t\right] \quad (2)$$

In equations (1) and (2), A and z are the optical field amplitude and propagation distance, respectively (Ali *et al.* 2010g; Amiri *et al.* 2013e; A. Nikoukar *et al.* 2013). T is defined as soliton pulse propagation time in a frame moving at the group velocity (Shahidinejad *et al.* 2012; Afroozeh *et al.* 2010c; A. Shahidinejad *et al.* 2014), $T = t - \beta_1 \times z$, where β_1 and β_2 are the coefficients of the linear and second order terms of the Taylor expansion of the propagation constant (Amiri *et al.* 2012k; Afroozeh *et al.* 2010b; Afroozeh *et al.* 2012b). $L_D = T_0^2/|\beta_2|$ represents the dispersion length of the soliton pulse (I. S. Amiri *et al.* 2013c; Ali *et al.* 2010t), where the carrier frequency of the soliton is ω_0 (Amiri *et al.* 2012b; Ali *et al.* 2010f; I. S. Amiri *et al.* 2013b). When a soliton pulse keeps its temporal width invariance as it propagates, it is called a temporal soliton (Ali *et al.* 2010v; Ali *et al.* 2010k). T_o is known for the intensity of soliton peak as $\left(|\beta_2/\Gamma T_0^2|\right)$. 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 the coupling loss of the field amplitude and nonlinear phase shift, thus $L_{NL} = L_D$ should be satisfied (Ali *et al.* 2010z; Shojaei and Amiri 2011b; Ali *et al.* 2010x; Ali *et al.* 2010b). Within the nonlinear medium, the refractive index (n) changes according to given following Equation (3) (I. S. Amiri and J. Ali 2014d; Ali *et al.* 2010m; Saktioto *et al.* 2010c),

$$n = n_0 + n_2 I = n_0 + \left(\frac{n_2}{A_{eff}}\right)P, \quad (3)$$

n_0 and n_2 are the linear and nonlinear refractive indexes, respectively (Amiri and Ali 2013d; Amiri *et al.* 2010c). I and P represent the optical intensity and optical power, respectively (Kouhnavard *et al.* 2010b; Amiri *et al.* 2012h). The effective mode core area of the device is given by A_{eff} (Ali *et al.* 2010l; Ridha *et al.* 2010b). The output and input signals in each round-trip of the ring on the right side can be calculated using Equation (4) (Gifany *et al.* 2013; I. S. Amiri and J. Ali 2014c; Ali *et al.* 2010j).

$$\left|\frac{E_2}{E_1}\right|^2 = (1-\gamma)\left[1 - \frac{(1-(1-\gamma)x^2)\kappa}{(1-x\sqrt{1-\gamma}\sqrt{1-\kappa})^2 + 4x\sqrt{1-\gamma}\sqrt{1-\kappa}\sin^2(\frac{\phi}{2})}\right] \quad (4)$$

Here, the E_1(t) is the electric field inserted into the ring resonator, where the output signal is shown by E_2(t) (Nikoukar *et al.* 2012; Yupapin *et al.* 2010). Therefore ring resonator can be comparable to a Fabry-Perot cavity . It has an input and an output mirror with a field reflectivity, $(1-\kappa)$, and a fully reflecting mirror (Ali *et al.* 2010i; I. S. Amiri *et al.* 2013e). Here κ is the coupling coefficient, and $x = \exp(-\alpha L/2)$ represents a round-trip loss coefficient, $\varphi_0 = kLn_0$ and $\varphi_{NL} = kLn_2|E_{in}|^2$ are the linear and nonlinear phase shifts, $k = 2\pi/\lambda$ is the wave propagation number in a vacuum (I. S. Amiri *et al.* ; I. S. Amiri *et al.* 2014; Afroozeh *et al.* 2012c). L and α are a waveguide length and linear absorption coefficient, respectively (Amiri *et al.* 2013f; Ali *et al.* 2010y). In this work, the iterative method is inserted to obtain the required results using Equation (4). The electric field of the left side of the add-drop ring resonator can be expressed by Equation (5) (I. S. Amiri *et al.* 2013a):

$$E_3 = \sqrt{1-\gamma_2} \times [E_2 \times \sqrt{1-\kappa_2} + j\sqrt{\kappa_2} \times E_{i2}] \quad (5)$$

Here we define the E_0 which can be expressed by,

$$E_0 = E_1 \frac{\sqrt{(1-\gamma)(1-\kappa)} - (1-\gamma)e^{-\frac{\alpha}{2}L_{ring} - jk_n L_{ring}}}{1 - \sqrt{1-\gamma}\sqrt{1-\kappa}e^{-\frac{\alpha}{2}L_{ring} - jk_n L_{ring}}}, \quad (6)$$

and it is the electric field of the small ring on the right side of the Half-Panda system (Amiri *et al.* 2012d).

The output fields, E_{t1} and E_{t2} at the throughput and drop parts of the Half-Panda are expressed by

$$E_{t1} = -x_1x_2y_2\sqrt{\kappa_1}E_{i2}e^{-\frac{\alpha L_{ad}}{2}} - jk_n\frac{L_{ad}}{2} + \left[\frac{x_2x_3\kappa_1\sqrt{\kappa_2}E_0E_{i1}(e^{-\frac{\alpha L_{ad}}{2}} - jk_n\frac{L_{ad}}{2})^2 + x_3x_4y_1y_2\sqrt{\kappa_1}\sqrt{\kappa_2}E_0E_{i2}(e^{-\frac{\alpha L_{ad}}{2}} - jk_n\frac{L_{ad}}{2})^3}{1 - x_1x_2y_1y_2E_0(e^{-\frac{\alpha L_{ad}}{2}} - jk_n\frac{L_{ad}}{2})^2}\right] \quad (7)$$

$$E_{t2} = x_2y_2E_{i2} + \left[\frac{x_1x_2\kappa_1\sqrt{\kappa_1}\sqrt{\kappa_2}E_0E_{i1}e^{-\frac{\alpha L_{ad}}{2} - jkn\frac{L_{ad}}{2}} + x_1x_3y_1y_2\sqrt{\kappa_2}E_0E_{i2}(e^{-\alpha\frac{L_{ad}}{2} - jk_n\frac{L_{ad}}{2}})^2}{1 - x_1x_2y_1y_2E_0(e^{-\frac{\alpha L_{ad}}{2} - jk_n\frac{L_{ad}}{2}})^2}\right]. \quad (8)$$

Here, we define $x_1 = \sqrt{1-\gamma_1}$, $x_2 = \sqrt{1-\gamma_2}$, $x_3 = 1-\gamma_1$, $x_4 = 1-\gamma_2$, $y_1 = \sqrt{1-\kappa_1}$ and $y_2 = \sqrt{1-\kappa_2}$. E_{t1} and E_{t2} represent the optical fields of the throughput and drop ports respectively (Amiri and Ali 2013a; Jalil *et al.* 2010). $L_{ad}=2\pi R_{ad}$, where R_{ad} is the radius of the ring. The waveguide (ring resonator) loss is α=0.1 dBmm^{-1} (Amiri *et al.* 2012o; Mohamad *et al.* 2010a; Ali *et al.* 2010h). The fractional coupler intensity loss is γ=0.1, where $L_{ring} = 2\pi R_{ring}$ and R_{ring} is the radius of the ring (Amiri *et al.* 2012c; Amiri *et al.* 2013a; Afroozeh *et al.* 2012a). The chaotic noise cancellation can be managed by using the specific parameters of the add-drop system in which required signals can be retrieved by the specific users (Amiri *et al.* 2012n; Amiri *et al.* 2011b).

3. RESULT AND DISCUSSION

The fixed and variable parameters of the system are listed in Table 1.

Input optical dark and bright solitons with powers 500mW and 320mW respectively are inserted into the Half-Panda system. The add-drop system has a radius of R_{ad}=15 µm where the coupling coefficients are κ_1=κ_2=0.3. The dark solitons are propagating inside the Half-Panda system with central wavelengths of λ_0=1.4µm, 1.45µm, 1.5µm, 1.55µm, 1.6µm. In order to increase the capacity of the output optical tweezers, input dark soliton pulses with four different central wavelengths are introduced into the input port of the Half-Panda system. Figure 2(a), shows the optical inputs in the form of dark and bright soliton pulses. The nonlinear condition forms the interior signals as chaotic signals respect to 20,000 round-trip of the input power. In order to make the system associate with the practical device (InGaAsP/InP) (Ali *et al.* 2010q; I. S. Amiri and J. Ali 2014a; Ali *et al.* 2010u), the selected parameters of the system are fixed to $n_0 = 3.34$, $n_2 = 2.5\times10^{-17}$ and $A_{eff} = 25$ µm^2. By adjusting the parameters such as the dark and bright powers at the input and add ports and the coupling coefficients, the tweezers depth would be controlled and tuned as shown in figure 2(b-d).

Table 1: Fixed and variable parameters of proposed microring resonator system

Fixed Parameters:
R_{ring} = ring's radius
R_{ad} = Add/drop ring's radius
κ_1 = Add/drop coupling coefficients
κ_2 = Add/drop coupling coefficients
κ = ring's coupling coefficient
L_{ring} = Circumference of the ring resonator
L_{ad} = Circumference of the add-drop ring
n_0 = Linear refractive index
n_2 = Nonlinear refractive index
α = Ring resonator loss
β_1 = Propagation constant
β_2 = Propagation constant
γ = Coupler intensity loss
A_{eff} = Effective core area
E_{i1} = Input electric field at input port
E_{i2} = Input electric field at drop port
ω_0 = Frequency carrier
λ = Wavelength
k = Wave propagation number
Variable parameters:
T = Propagation time
z = Propagation distance
L = Waveguide length
L_D = Dispersion length
L_{NL} = Nonlinear length
n = Total nonlinear refractive index
ϕ_{NL} = Nonlinear phase shift
ϕ_0 = Linear phase shift
A = Optical amplitude
E_0 = Electric field of the ring
I = Optical intensity
P = Optical power
x = Round trip loss coefficient
E_1 = Input electric field into the ring resonator
E_2 = Output electric field of the ring resonator
E_3 = Left side's electric field of the of add-drop
$\lvert E_{t1}\rvert^2$ = Throughput output power
$\lvert E_{t2}\rvert^2$ = Drop port output power

Smallest tweezers width of 8.85 nm is generated at the drop port shown in figure (3), where the through port shows the output intensity signals with FWHM and FSR of 33 nm and 50 nm respectively. The cancelling of the chaotic signals can be obtained within the add-drop ring resonator using suitable parameters of the system. The signals can be controlled and tuned by power's variation of the input bright soliton pulse.

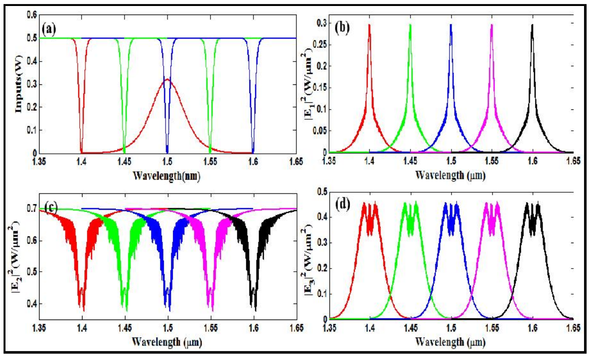

Fig.2: Optical tweezers generation within a Half-Panda system where (a): input optical dark and bright solitons, (b-d): tuned optical tweezers

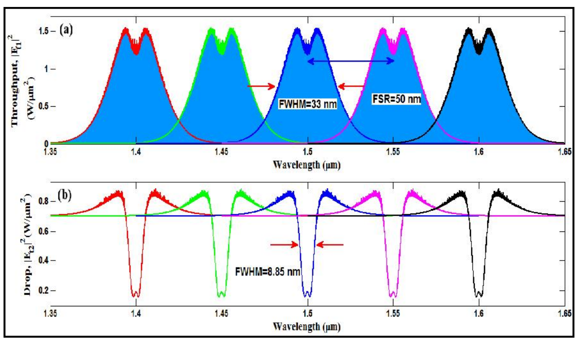

Fig.3: Through and drop port output signals of the Half-Panda system where (a): Through port output with FWHM=33 nm, (b): drop port output with FWHM=8.85 nm

Transportation of the optical tweezers can be obtained via a network system using a transmission link (Sadegh Amiri *et al.* 2013). Detection of the transmitted tweezers signals can be assembled using the single photon detection method (Amiri *et al.* 2013b; Ali *et al.* 2010a). Thus, the tweezers transportation for long distance communication via fiber optics is realistic.

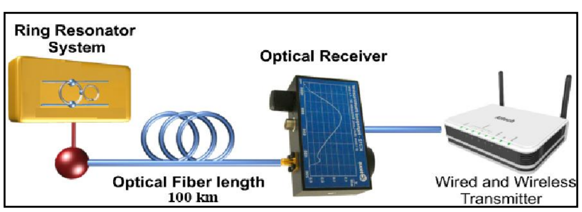

Fig.4: System of optical tweezers transmission link

The fiber optic has a length of 100 *km*, attenuation of 0.2 dB/km, dispersion of 5 ps/nm/km, the differential group delay of 0.2 ps/km, the nonlinear refractive index of 2.6×10^{-20} m^2/W, effective area of 25 μm^2 and the nonlinear phase shift of 3 mrad (I. S. Amiri *et al.* ; Ali Shahidinejad *et al.* 2014; Amiri *et al.* 2013d). In operation, the signals can be modulated via an optical receiver unit which is encoded in the quantum signal transmission link. The receiver unit can be used to detect the transmitted optical tweezers. Transmitted optical tweezers can be sent to the users via a wired/wireless transmitter shown in figure 4. The advanced transmitter topologies are desirable for application in both wired and wireless communication inasmuch as they are able to provide power-efficient amplification of signals with large peak-to average power ratios (PAPRs) without compromising system linearity. Figure 5 shows the detected and filtered optical tweezers using an optical receiver.

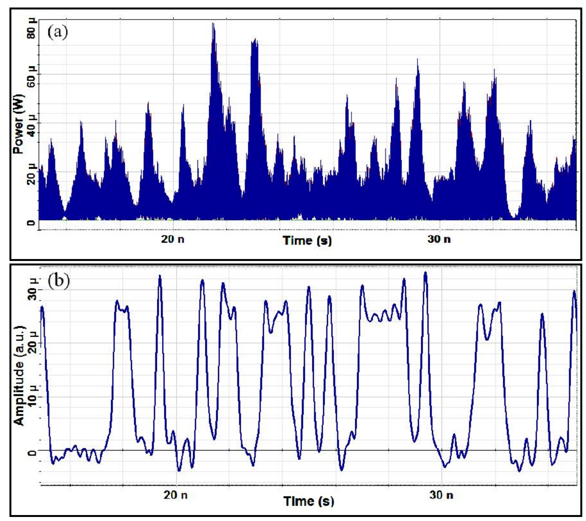

Fig.5: Detected and filtered optical tweezers via a 100 km optical fiber optic using an optical receiver, where (a): detected signals, (b): filtered signals

By using suitable dark-bright soliton input powers, tunable optical tweezers can be controlled (I. S. Amiri and Ali 2013; Amiri and Ali 2013c; Suwanpayak *et al.* 2010). High capacity data transmission can be applied by using more wavelengths (Tanaram *et al.* 2011; Amiri *et al.* 2011c). The advantage of this study is that optical tweezers can be generated and transmitted via a network system thus improving the transmission capacity (Ali *et al.* 2010o).

4. CONCLUSION

A system of nano optical tweezers generation is presented for optical communication. Nano optical tweezers can be generated by the dark soliton propagation in a Half-Panda system. The control process of the dark-bright collision can be performed by using suitable parameters of the ring system such as the input power, coupling coefficient, ring radius, coupler loss and effective core area. The generated tweezers with FWHM and FSR of 33 nm and 50 nm respectively can be transmitted experimentally via a fiber optic with a length of 100 km. The results show the detected tweezers, where the clear signals can be obtained by cancelling the chaotic signals.

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