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Generation of Nanometer Optical Tweezers Used for Optical Communication Networks

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Abstract*:* A system of Half-Panda microring resonator (MRR) is proposed to generate ultra-short nanometer (nm) optical tweezers. The dark soliton propagates inside nonlinear MRR. Molecules or photons transport within the system when the dark soliton is used as input pulse. Nano optical tweezers can be generated and used to many applications in optical communication networks. Here the smallest nano optical tweezers signals with full width at half maximum (FWHM) of 9 nm is obtained where the free spectrum range (FSR) of 50 nm is simulated.

Keywords: Half-Panda, Nano optical tweezers; Optical Communication

I. INTRODUCTION

Nano optical tweezers technique has become a powerful tool for manipulation of micrometer-sized particles/photons in three spatial dimensions [1-6]. Dark-Gaussian soliton controls within a semiconductor add/drop multiplexer has numerous applications in optical communication [7-10]. For communication's application purposes, the optical tweezers can be used to generate entangled photon within the proposed network system [11-14].

MRR's are type of Fabry-Perot resonators which can be readily integrated in array geometries to implement many useful functions [15-21]. Amiri *et al.* have proposed the new design of secured packet switching, where this method uses nonlinear behaviors of light in MRR which can be used for high-capacity and security switching [22-24]. Recently quantum network shows promising usage for the perfect network security [25-29]. Amiri *et al.* have shown that the continuous wavelength can be generated by using a soliton pulse in a MRR [30-38]. The secret key codes are generated via the entangled photon pair which is used to security purposes using the dark soliton pulse propagation [39-43]. In this study, a nano molecular cryptography system based on optical soliton is developed.

II. THEORETICAL MODELING

The multiplexer half-Panda system shown in figure (1) [44-48]. Dynamic behavior of the optical tweezers is appeared when the Gaussian soliton is input into the add port of the system [49-53]. The ring resonator is connected to the add-drop interferometer system with radius (R_{ring}) of 10 μm and coupling coefficient (κ) of 0.5. The effective area of the coupling section is A_{eff}=25 μm^2.

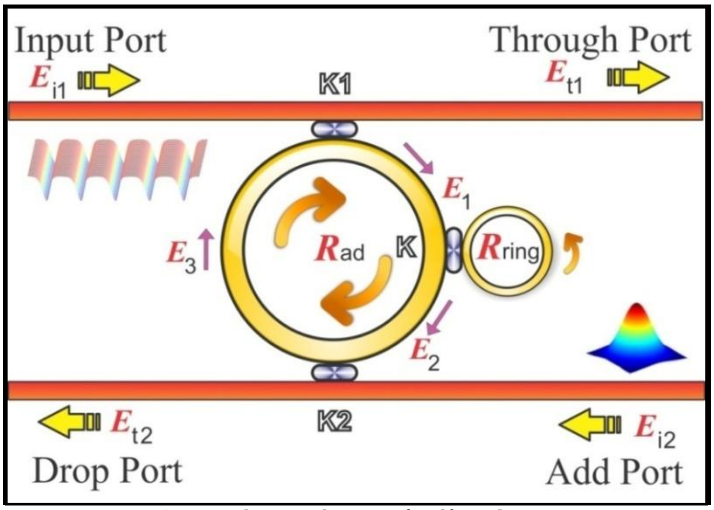

Fig.1. A schematic diagram of Half-Panda system

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The input optical field (E_{i1}) of the dark soliton and add optical field (E_{i2}) of the Gaussian pulses are given by [54-59]

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

$$E_{i2}(t) = A\exp\left[\left(\frac{z}{2L_D}\right) - i\omega_0 t\right] \tag{2}$$

In equations (1) and (2), A and z are the optical field amplitude and propagation distance, respectively [60-62]. T is defined as soliton pulse propagation time in a frame moving at the group velocity [63, 64], $T = t\text{-}\beta_1 \times z$, where β_1 and β_2 are the coefficients of the linear and second order terms of Taylor expansion of the propagation constant [65-67]. $L_D = T_0^2/|\beta_2|$ represents the dispersion length of the soliton pulse [68, 69]. The carrier frequency of the soliton is ω_0. When a soliton pulse keeps its temporal width invariance as it propagates, it is called a temporal soliton [70-72]. T_o is known for the intensity of soliton peak as $\left(\left|\beta_2/\Gamma T_0^2\right|\right)$ [73, 74]. A balance should be achieved between the dispersion length *(L_D)* and the nonlinear length *(L_{NL}= (1/$\gamma\varphi_{NL}$)* [75-77], where γ and φ_{NL} are the coupling loss of the field amplitude and nonlinear phase shift [78, 79]. They are the length scale over which dispersive or nonlinear effects makes the beam becomes wider or narrower [80, 81]. It means that the L_D=L_{NL} should be satisfied [82, 83]. Within the nonlinear medium, the refractive index (n) changes according to given following equation (3) [84-86],

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

n_0 and n_2 are the linear and nonlinear refractive indexes, respectively [87, 88]. I and P represent the optical intensity and optical power, respectively [89]. The effective mode core area of the device is given by A_{eff} [90]. In this work, the iterative method is inserted to obtain the needed results. Two complementary optical circuits of a ring-resonator add-drop filter can be expressed by the equations (4) and (5) [91, 92].

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

and

$$\left|\frac{E_d}{E_{in}}\right|^2 = \frac{\kappa_1\kappa_2 e^{-\frac{\alpha}{2}L_{ad}}}{1 + (1-\kappa_1)(1-\kappa_2)e^{-\alpha L_{ad}} - 2\sqrt{1-\kappa_1}\cdot\sqrt{1-\kappa_2}\,e^{-\frac{\alpha}{2}L_{ad}}\cos(k_n L_{ad})}, \tag{5}$$

where E_t and E_d represent the optical fields of the throughput and drop ports respectively [93-95]. β=kn_{eff} is the propagation constant [96, 97], n_{eff} is the effective refractive index of the waveguide and the circumference of the ring is L_{ad}=2πR_{ad} [98]. R_{ad} is the radius of the ring. The phase constant can be simplified as $\Phi=\beta L$ [99, 100]. The chaotic noise cancellation can be managed by using the specific parameters of the add-drop device in which required signals can be retrieved by the specific users [101, 102]. The waveguide (ring resonator) loss is α=*0.5 dBmm*$^{-1}$. The fractional coupler intensity loss is γ= 0.1 [103, 104]. In the case of add-drop device, the nonlinear refractive index is neglected . The output fields, E_{t1} and E_{t2} at the throughput and drop parts of the Half-Panda are expressed by [105-107]

$$E_{t1} = -x_1x_2y_2\sqrt{\kappa_1}E_{i2}e^{-\frac{\alpha L_{ad}}{2}} - jk_n\frac{L_{ad}}{2} + \left[\frac{x_2x_3\kappa_1\sqrt{\kappa_2}E_0E_{i1}\left(e^{-\frac{\alpha L_{ad}}{2}} - jk_n\frac{L_{ad}}{2}\right)^2 + x_3x_4y_1y_2\sqrt{\kappa_1}\sqrt{\kappa_2}E_0E_{i2}\left(e^{-\frac{\alpha L_{ad}}{2}} - jk_n\frac{L_{ad}}{2}\right)^3}{1 - x_1x_2y_1y_2E_0\left(e^{-\frac{\alpha L_{ad}}{2}} - jk_n\frac{L_{ad}}{2}\right)^2}\right], \tag{6}$$

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$$E_{t2} = x_2 y_2 E_{i2} + \left[\frac{x_1 x_2 \kappa_1 \sqrt{\kappa_1}\sqrt{\kappa_2} E_0 E_{i1} e^{-\frac{\alpha L_{ad}}{2} - jkn\frac{L_{ad}}{2}} + x_1 x_3 y_1 y_2 \sqrt{\kappa_2} E_0 E_{i2} (e^{-\alpha\frac{L_{ad}}{2} - jk_n\frac{L_{ad}}{2}})^2}{1 - x_1 x_2 y_1 y_2 E_0 (e^{-\frac{\alpha L_{ad}}{2} - jk_n\frac{L_{ad}}{2}})^2} \right]. \quad (7)$$

The electric field of the small ring on the right side of the Half-Panda system is given as:

$$E_0 = E_1 \frac{\sqrt{(1-\gamma)(1-\kappa)} - (1-\gamma) e^{-\frac{\alpha}{2}L_{ring} - jk_n L_{ring}}}{1 - \sqrt{1-\gamma}\sqrt{1-\kappa} e^{-\frac{\alpha}{2}L_{ring} - jk_n L_{ring}}}, \quad (8)$$

where $L_{ring} = 2\pi R_{ring}$ and R_{ring} is the radius of the ring and the $x_1 = \sqrt{1-\gamma_1}$, $x_2 = \sqrt{1-\gamma_2}$, $x_3 = 1-\gamma_1$, $x_4 = 1-\gamma_2$, $y_1 = \sqrt{1-\kappa_1}$ dna $y_2 = \sqrt{1-\kappa_2}$ [108-110].

III. RESULT AND DISCUSSION

The add-drop optical filter has radius of R_{ad} = 15 μm where the coupling coefficients are κ_1 = 0.35 and κ_2 = 0.25. The dark solitons are propagating inside the Half-Panda system with central wavelengths of λ_0 = 1.4 μm, 1.45 μm, 1.5 μm, 1.55 μm, 1.6 μm. In order to make the system associate with the practical device (InGaAsP/InP), the selected parameters of the system are fixed to $n_0 = 3.34$ and $n_2 = 2.5\times10^{-17}$.

The signals can be controlled and tuned by power's variation of the input Gaussian laser pulse. Figure (2) shows the generation of nanometer optical tweezers. Here the input powers of the optical dark soliton pulses and Gaussian laser beam are 2W and 2.5W respectively.

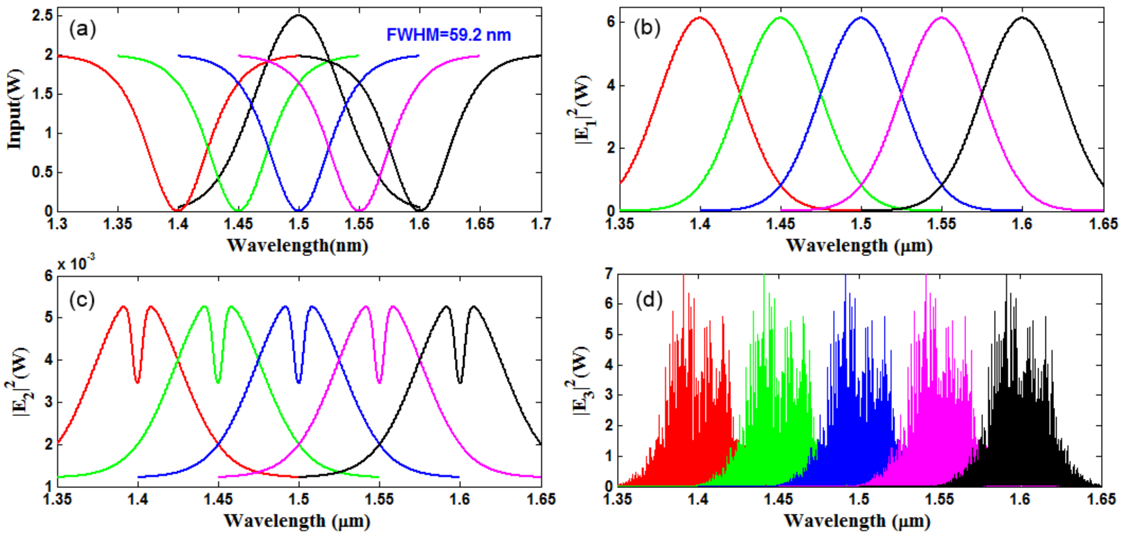

Fig.2: Optical tweezers generation within a Half-Panda system where (a): input of dark solitons and Gaussian laser beam, (b-d): tuned and controlled optical tweezers

Filtered and clear optical tweezers are seen in figure (3) where the peaks have FWHM and FSR of 9 nm and 50 nm respectively. In the case of communication networks, generation of narrower signals is recommended. Therefore soliton signals can be used in optical communication where the capacity of the output signals can be improved by generation of peaks with smaller FWHM [111-113]. The sensitivity of the sensing systems such as optical sensors and ring resonators can be improved significantly by generation of peaks with wider space or bigger FSR [114-120].

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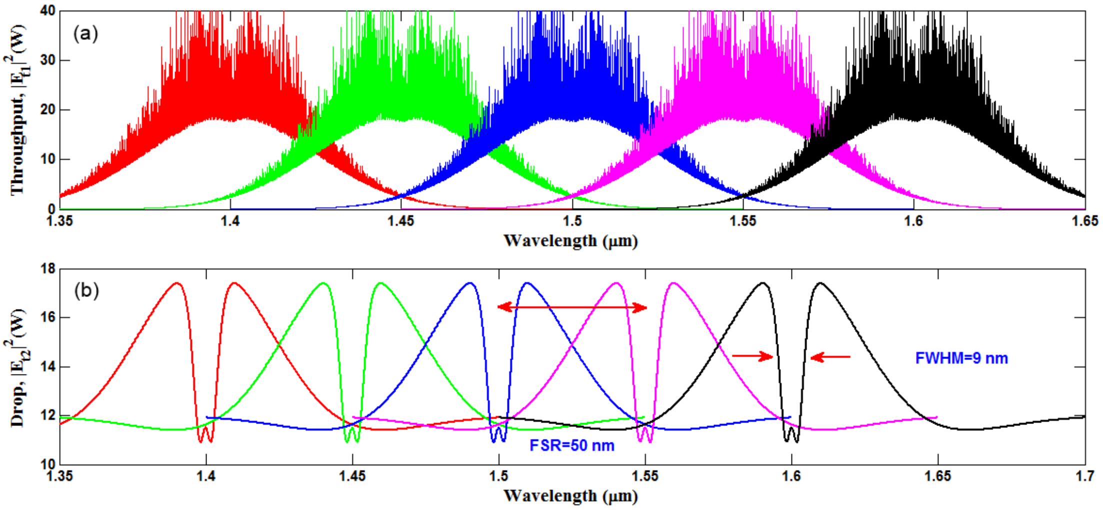

Fig.3: Through and drop port output signals of the Half-Panda system where (a): Through port chaotic output signals (b): drop port output with FWHM=9 nm anf FSR=50 nm

In operation, the computing data can be modulated and input into the system via a wavelength router. Schematic of the wavelength router is shown in figure (4), in which quantum cryptography for internet security can be obtained.

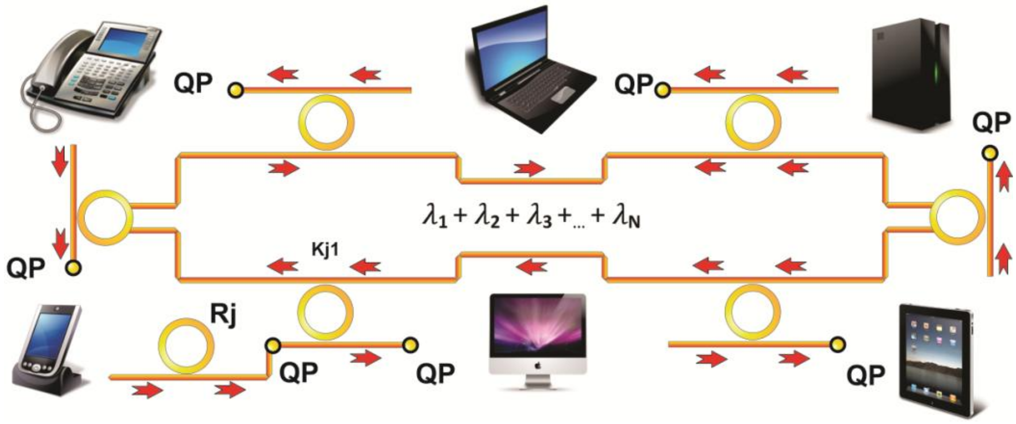

Fig.4: Quantum cryptography system for internet security via a wavelength router, where QP: Quantum Processor, R_j : ring radii, λ_i : output wavelength, κ_j , κ_{ji} are coupling coefficients.

IV. CONCLUSION

Nanometer optical tweezers generation is presented for cryptography and secured optical communication. Nano optical tweezers can be generated by the dark soliton propagation in a Half-Panda system. Suitable parameters of the ring system such as the input power, coupling coefficient, ring radius, coupler loss and effective core area are used. The generated optical tweezers can be easily transmitted via a communication network system.

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