A Study of Dynamic Optical Tweezers Generation for Communication Networks

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ABSTRACT

We propose a novel system of the dynamic optical tweezers generated by a dark soliton in the fiber optic loop. A dark soliton known as an optical tweezer is amplified and tuned within the microring resonator (MRR) system. The required tunable tweezers with different widths and powers can be controlled. The analysis of dark-bright soliton conversion using a dark soliton pulse propagating within a MRR is analyzed. The control dark soliton is input into the system via the add port of the add/drop filter. The dynamic behavior of the dark-bright soliton conversion is observed. The required stable signal is obtained via a drop and throughput ports of the add/drop filter with some suitable parameters. In application, generation of optical tweezers and transportation can be realized by using the proposed system, where the communication network is performed.

KEYWORD: *Dynamic Optical tweezers, MRR, Add/drop filter, communication network*

I. INTRODUCTION

Over the last three decades, interferometric measurement methods have been applied in research and industry for investigation of deformation and vibration behaviour of mechanical components [1-3]. Optical tweezers are powerful tool for use in the three-dimensional rotation (location manipulation) of nano-structures such as micro and nano-particles as well as living microorganisms [4-7]. The benefit offered by optical tweezers is the ability to interact with nano-scaled objects in a non-invasive manner [8]. There is no physical contact with the sample, thus preserving many important characteristics of the sample, such as the manipulation of a cell with no harm to the cell [9-10]. Dark-bright soliton control within a semiconductor add/drop multiplexer has shown promising applications [11-12]. when the high optical field is configured as an optical tweezer or potential well [13-14]. In applications, the term dynamics can be realized and is suitable for dynamic wells/tweezers control [15-16]. This is available for atom/molecule trapping. An optical tweezer uses forces exerted by intensity gradients in a strongly focused beam of light to trap and move a microscopic volume of matter [17-18]. Optical tweezers are now widely used and are particularly powerful in the field of microbiology to study cell–cell interactions [19-20], manipulate organelles without breaking the cell membrane [21-22], physical sciences [23-24].

Ring resonators are waveguide realizations of Fabry-Perot resonators which can be readily integrated in array geometries to implement many useful functions [25-26]. Its nonlinear phase response can be readily incorporated into an interferometer to produce specific intensity output function [27-29]. Schematic of a single MRR is illustrated in figure 1, which depicts a ring resonator coupled with a waveguide by a coupler, even though single MRR is normally coupled with a straight waveguide of the same width [30].

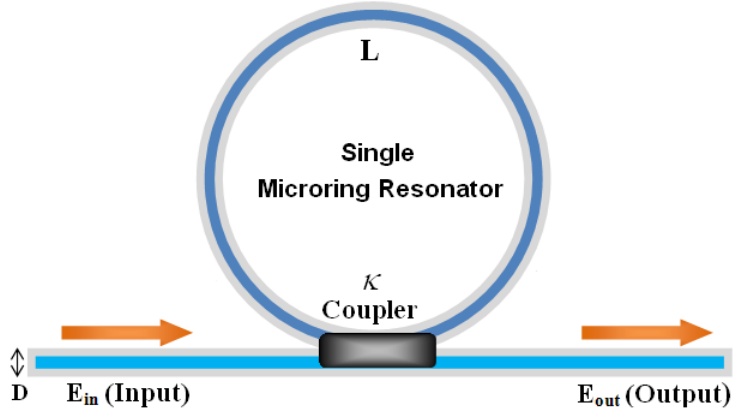

Fig.1: Schematic of nonlinear silicon MRR

The geometric parameters of a ring resonator are the radius of curvature (R), the gap distance between waveguide and ring (*g*), and the waveguide diameter (*D*). The coupling coefficient (κ) represents the fraction of the optical field that is coupled with the waveguide and ring resonator [31-33]. Even though the coupling strength needed is relatively low, it still requires a narrow gap between the ring and the waveguide due to the short interaction length and the high confinement nature of the waveguides [34-35]. The small gap not only is difficult to fabricate, but also dramatically increases the optical loss [36]. We propose a system consisting of series of microring resonators to multiplex the input powers controlled by specific parameters.

In this study, microring resonators are used as a single integrated interferometer system to generate optical soliton pulses in the form of optical tweezers. The used methodology is based on solving the nonlinear Schrödinger equation for soliton pulses propagating inside nonlinear Kerr effect type of the fibe optics where the communication networks can be performed by propagating of optical tweezers in a communication link. Simulation results of the optical tweezers are acheived by generation of computing MATLAB codes reserved in solutions of the nonlinear equations in the case of soliton pulse propagating within fiber optics ring resonators.

II. THEORETICAL MODELING AND RESEARCH METHODOLOGY

In this proposal, we are looking for a stationary dark soliton pulse, which is introduced into the multistage MRRs as shown in figure 1. The input optical fields E_{in} and E_{add} of the dark and bright soliton pulses input is given by [37-38]

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

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

where *A* and *z* are the optical field amplitude and propagation distance, respectively. *T* is a soliton pulse propagation time in a frame moving at the group velocity, $T = t-\beta_1 z$, 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 is a soliton pulse propagation time at initial input (or soliton pulse width), where *t* is the soliton phase shift time, and the carrier frequency of the soliton is ω_0. When a soliton of peak intensity ($|\beta_2/\Gamma T_0^2|$) is given, then T_0 is known [39]. When light propagates within a nonlinear medium, the refractive index (*n*) of light within the medium is given by [40-41]

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

where n_0 and n_2 are the linear and nonlinear refractive indices, respectively. Thus, the normalized output is given by Equation (4) as [42-44]

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

Here κ is the coupling coefficient, and $x=\exp(-\alpha L/2)$ represents a roundtrip loss coefficient, $\Phi= \Phi_0+ \Phi_{NL}$ where $\Phi_0=kLn_0$ and $\Phi_{NL}=kLn_2|E_{in}|^2$ are the linear and nonlinear phase shifts, $k=2\pi/\lambda$ is the wave propagation number in a vacuum and the fractional coupler intensity loss is introduced by γ, where L and α are a waveguide length and linear absorption coefficient, respectively. The methodology of this study can be performed by configuration and using of an interferometer add/drop filter system connecting to series of microring resonators [45]. Variation of the system's parameters affect the output results in which tuned and amplified optical tweezers can be generated.

In application, the dynamic optical tweezers, occurs when the bright soliton is added via an add port as shown in figure 2 [46-47]. Here, series of microring resonators are connected to an add/drop multiplexer system where the input pulses of dark and bright solitons are inserted into the input and add ports of the system.

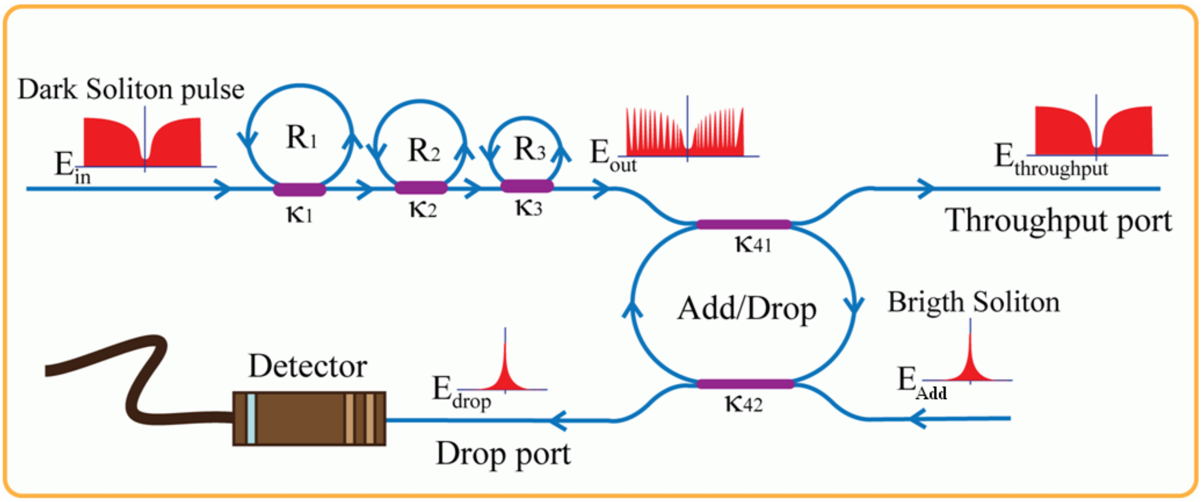

Fig. 2: Schematic diagram of a dark-bright soliton conversion system.

The dark soliton pulse propagates within microring resonators R_1, R_2 and R_3 where the filtering of the chaotic signals occurs within the rings system during the propagation. Clear signals can be obtained when the cancelling of the chaotic signals is performed using the add/drop interferometer system, thus clear optical soliton pulses can be generated and seen at the through and drop ports of the system.

III. RESULT AND DISCUSSION

Result obtained when a dark soliton pulse is input into a MRR system as shown in figure 3. The add/drop filter is formed by using two couplers and a ring with radius (R_d) of $10\mu m$, the coupling constants (κ_{41} and κ_{42}) are the same values (0.50).

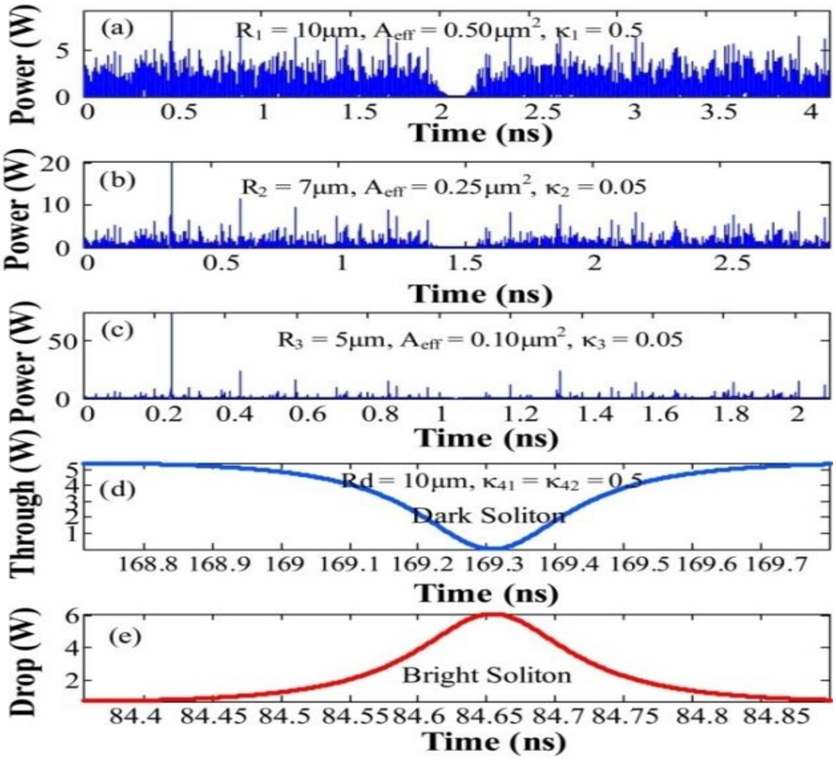

Fig. 3: Results of the soliton signal within the ring resonator system, where (a) R_1, (b) R_2, (c) R_3, and (d) – (e) dark – bright soliton conversion at the add/drop filter.

The input dark soliton power is 2W. The bright soliton is generated at the central wavelength $\lambda_0 = 1.5\mu m$. When the bright soliton propagates into an add/drop system, the occurrence of dark-bright soliton collision in add/drop system is shown in figure 4(a)-(d) and figure 5(a) – (d). The dark soliton valley (dept), i.e. potential well, was changed when it was modulated by the trapping energy (dark-bright soliton interaction) as shown in figure 5(a) - (d). The bright soliton input with the central wavelength λ_0 = 1.5μm, where (a) the add/drop signal, (b) dark – bright soliton collision, (c) tweezers at throughput port, and (d) tweezers at drop port.

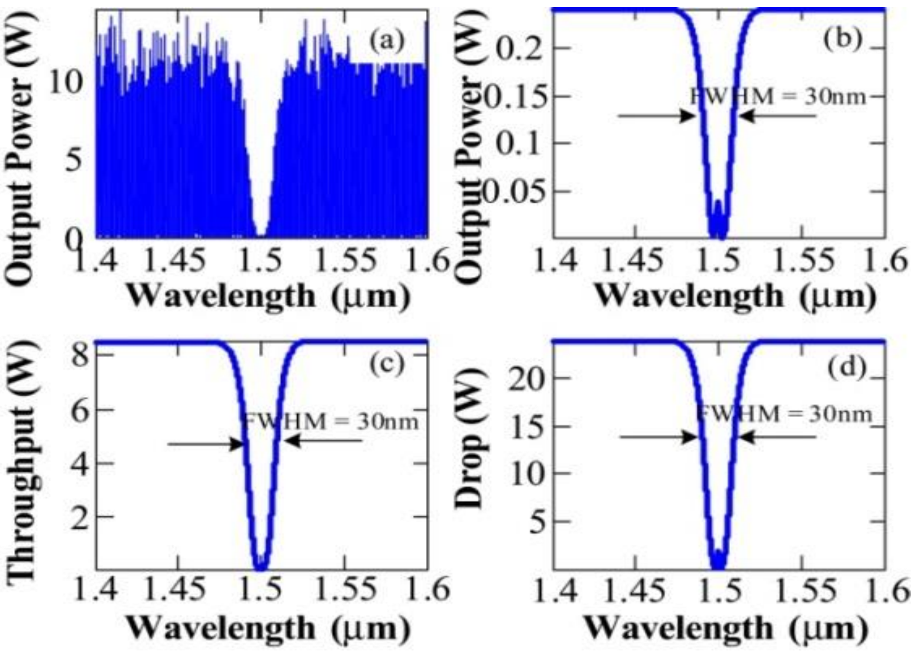

Fig. 4: The dynamic optical tweezers output within an add/drop filter, when the bright soliton input with the central wavelength λ_0 = 1.5μm.

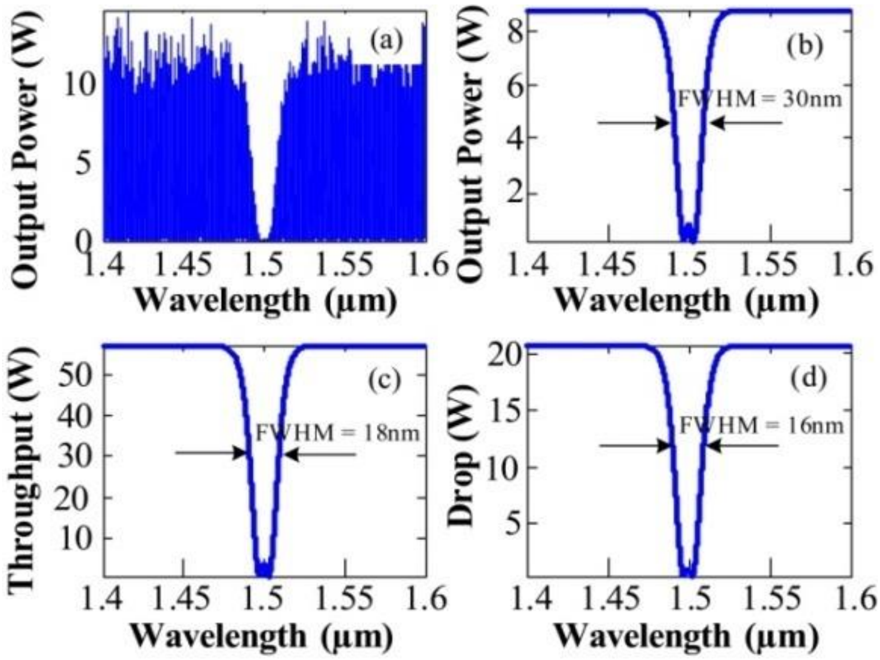

Fig. 5: Tuned dynamic optical tweezers output within an add/drop filter.

In application these types of signals generated by MRR system can be connected into a network communication system shown in figure 6. Therefore, narrow signals of optical tweezers can be transmitted to the different users via a networks transmitter system. New interesting applications of ring resonator interferometers can be carried out by introducing new configuration of numbers parallel add/drop systems in which ultra-short of femtosecond optical tweezers can be generated and applied for high bit rate transmission link and ultra-fast communication systems.

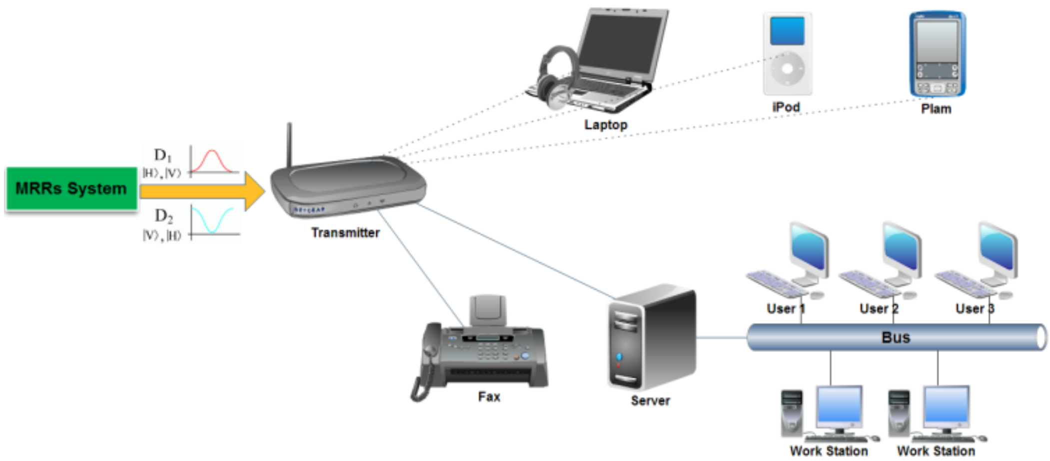

Fig.6: Networks communication system, where the transmission of signals can be implemented using optical tweezers

IV. CONCLUSION

We have shown that the propagating dark soliton within the MRR and NRR system can be converted. By using a reasonable dark-bright soliton input power, the tunable optical tweezers can be controlled, which can be then used as the dynamic optical tweezers probe. Hence, the tuned and amplified dark soliton in which the suitable sides (FWHM, Full Width at half Maximum) and amplitudes of tweezers can be generated. Thus, localized optical tweezers pulses are generated, whereas the required signals can be used to perform the optical communication network. Furthermore, the applications such as quantum repeater, quantum entangled photon source are available, which can complete the concept of optical tweezers communication networks.

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