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Molecular Filter On-Chip Design

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Abstract

This paper presents the use of a modified add-drop optical filter known as a PANDA microing resonator which can be designed on a chip. By using an optical tweezer, the required molecules can be trapped and moved to the required destinations, where finally, the required molecules can be retrieved (filtered) by using the tunable filter via the add-drop filter control. In application, storage molecules in the bottle in the designed chip can be trapped and moved to the required targets by optical tweezers, which can transport via the optical waveguide. Therefore, this technique can be used to form the molecular filter. This is a new technique and important for drug delivery, drug targeting and molecular electronics, which is described, the optical tweezer generation using a PANDA ring resonator is also reviewed. Results obtained have shown that the multivariable filter can be obtained by tunable trapping control.

Keywords: Molecular filter; Molecular electronics; Drug delivery; Drug targeting

Introduction

Molecular devices have been recognized as the promising devices for future technology, especially, for electronic device applications, which have been the interesting researches of investigations [1-4] due to the following advantages such as a small size and good environmental adapted devices. Moreover, the hybrid devices of between semiconductor and molecular electronics are also challenged and plausible. Till date, many research works have been investigated in the molecular electronic research areas in both theoretical [5-8] and experimental [9-12] works, however, many research aspects are required to investigate and remained. In this paper, we propose the use of optical tweezers for molecule/atom trapping in the modified add-drop filter for molecular filter applications. Regarding to the very promising works that have presented the use of trapped molecules (atoms) in optical waveguide for transportation [13,14], especially, the use of optical tweezers for molecule trapping is new and seems it may go a long way in the future. In principle, the trapped molecules can be transported along the waveguide surface by the gradient force. The theoretical background of optical tweezers by using an optical pulse in a modified add-drop filter (a PANDA ring) is reviewed in this work. A PANDA ring resonator is a modified optical add-drop filter, in which the required optical tweezers can be generated and obtained by using the two additional (modified) nonlinear side rings. By changing the structure of PANDA (i.e. parameters) ring and input light signals, the different output signals can be obtained. By providing and controlling the suitable input power signals in the system, the dynamic optical tweezers can be generated, tuned, and stored within the ring resonator system before reaching the desired destination via an optical waveguide. The use of a PANDA microring device is also founded in many applications such as drug delivery [15-19], hybrid transistor [20] and therapeutic applications [21]. In practice, the optical tweezers (light signals) can propagate within the optical waveguide, which means that the trapped molecules can transport to the required destinations via the surface based on the gradient potential (force) and surface plasmonic behaviors. Therefore, by using the proposed system, molecules can be trapped and transported via the suitable waveguide to the required targets with some specific molecule sizes, in which the molecular filter concept is established. In this proposed work, the device parameters were chosen closely to the fabricated device parameters, the simulation results are obtained by using the commercial MATLAB software, which is found that this device can be used to form the hybrid electronic device, in which the combination between the conventional electronics and molecular electronics can be established, moreover, the multivariable molecular filter can be formed, which can be available for high capacity molecular communication and networks.

Principles

A PANDA microring resonator structure was proposed by the authors in references [20-23]. By using a dark-bright soliton pulses propagating within a modified add/drop optical multiplexer (PANDA microring), the optical trapping tools can be generated and formed, which can be used to trap molecules/atoms and transported via the optical waveguide. In this work, the multiplexed signals with slightly different wavelengths of the dark solitons are controlled and amplified for multivariable applications. The dynamic behaviors of dark bright soliton interaction are also analyzed and described.

When a stationary dark soliton pulse is introduced into add/drop optical filter. The input optical field (E_{in}) and the add port optical field (E_{add}) of the dark, bright soliton or Gaussian pulses are given by

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

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

$$E_{add}(t) = E_0\exp\left[\left(\frac{z}{2L_D}\right) - i\omega_0 t\right], \tag{1c}$$

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Here A and x are the optical field amplitude and propagation distance, respectively.

T is a soliton pulse propagation time in a frame moving at the group velocity, $T=t-\beta_1 x$, where β_1 and β_2 are the coefficients of the linear and second-order terms of Taylor expansion of the propagation constraint. $L_D=(R_0)_2/|\beta_2|$ is the dispersion length of the silicon 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. This solution describes a pulse that keeps its temporal width invariance as it propagated, and thus is called a temporal soliton. When a soliton of peak intensity $|\beta_2/\Gamma\ (T_0)^2|$ is given, then T_0 is known. For the soliton pulse in the microring device, a balance should be achieved between the dispersion length (L_D) and the nonlinear length ($L_{NL}=1/\Gamma\phi_{NL}$). Here $\Gamma=n_2k_2$ is the length scale over which dispersive or nonlinear effects make the beam become wider or narrower. For a soliton pulse, there is a balance between dispersion and a nonlinear length. Hence $L_D=L_{NL}$. For Gaussian pulse in Equation (1c), E_0 is the amplitude of optical field.

When light propagates within the nonlinear medium, the refractive index (n) of light within the medium is given by

$$n = n_0 + n_2 I = n_0 = \left(\frac{n_2}{A_{eff}}\right)P, \tag{2}$$

Here n_0 and n_2 as the linear and nonlinear refractive indexes respectively. I and P are the optical intensity and the power, respectively. The effective mode core area of the device is given by A_{eff}. For add/drop optical filter design, the effective mode core areas range from 0.50 to 0.10 μm^2, in which the parameters were obtained by using the related practical material parameters (*InGaAsP/InP*). When a dark soliton pulse is input and propagated within add/drop optical filter as shown in Figure 1, the resonant output is formed.

The resonator output field, E_{t1} and E_1 consists of the transmitted and circulated components within add/drop optical filter system, which can perform the driven force to molecule/atom. For the first coupler of the add/drop optical filter system, the transmitted and circulated components can be written as

$$E_{t1} = \sqrt{1-\gamma_1}\left[\sqrt{1-\kappa_1}E_{i1} + j\sqrt{\kappa_1}E_4\right] \tag{3}$$

$$E_1 = \sqrt{1-\gamma_1}\left[\sqrt{1-\kappa_1}E_4 + j\sqrt{\kappa_1}E_{i1}\right] \tag{4}$$

$$E_2 = E_0 E_1 e^{-\frac{\alpha}{2}\frac{L}{2} - jk_n\frac{L}{2}} \tag{5}$$

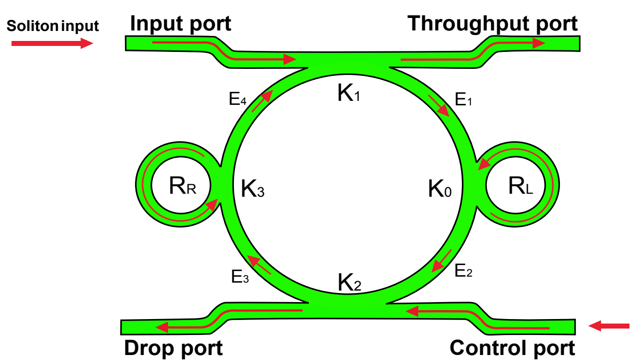

Figure 1: A PANDA microring resonator.

Here κ_1 is the intensity coupling coefficient, γ_1 is the fractional coupler intensity loss, α is the attenuation coefficient, $k_n=2\pi/\lambda$ is the wave propagation number, λ is the input wavelength light field and $L=2\pi R_{ad}$, R_{ad} is the radius of add/drop device.

For the second coupler of the add/drop system,

$$E_{t2} = \sqrt{1-\gamma_2}\left[\sqrt{1-\kappa_2}E_{i2} + j\sqrt{\kappa_2}E_2\right] \tag{6}$$

$$E_3 = \sqrt{1-\gamma_2}\left[\sqrt{1-\kappa_2}E_2 + j\sqrt{\kappa_2}E_{i2}\right] \tag{7}$$

$$E_4 = E_{0L} E_3 e^{-\frac{\alpha}{2}\frac{L}{2} - jk_n\frac{L}{2}} \tag{8}$$

Here κ_2 is the intensity coupling coefficient; γ_2 is the fractional coupler intensity loss. The circulated light fields, E_0 and E_{0L} are the light field circulated components of the nanoring radii, R_r and R_L which coupled into the right and left sides of the add/drop optical filter system, respectively. The light field transmitted and circulated components in the right nanoring, R_r, are given by

$$E_2 = \sqrt{1-\gamma}\left[\sqrt{1-\kappa_0}E_1 + j\sqrt{\kappa_0}E_{r2}\right] \tag{9}$$

$$E_{r1} = \sqrt{1-\gamma}\left[\sqrt{1-\kappa_0}E_{r2} + j\sqrt{\kappa_0}E_1\right] \tag{10}$$

$$E_{r2} = E_{r1} e^{-\frac{\alpha}{2}\frac{L}{2} - jk_n\frac{L}{2}} \tag{11}$$

$$E_{t1} = AE_{il} - BE_{i2} e^{-\frac{\alpha}{2}\frac{L}{2} - jk_n\frac{L}{2}}\left[\frac{CE_{il} e^{-\frac{\alpha}{2}L - jk_n L} + DE_{i2} e^{-\frac{3\alpha}{2}\frac{L}{2} - jk_n\frac{3L}{2}}}{}\right] \tag{12}$$

Where $A=x_1x_2$, $B = x_1x_2y_2\sqrt{\kappa_1}E_{0L}$, $C = x_1^2 x_1 \kappa_1\sqrt{\kappa_2}E_0E_{0L}$, $D = (x_1x_2)^2 y_1y_2\sqrt{\kappa_1\kappa_2}E_0E_{0L}^2$ and $F = x_1x_2y_1y_2E_0E_{0L}$.

The power output of the though port (P_{tl}) is written by

$$P_{t1} = (E_{t1})\cdot(E_{t1})^* = |E_{t1}|^2 \tag{13}$$

Similarly, the output optical field of the drop port (E_{t2}) is given by

$$E_{t2} = x_2y_2E_{i2} - \left[\frac{x_1x_2\sqrt{\kappa_1\kappa_2}E_0E_{t1} e^{-\frac{\alpha}{2}\frac{L}{2} - jk_n\frac{L}{2}} + x_1x_1^2y_1y_2\sqrt{\kappa_2}E_0E_{0L}E_{i2} e^{-\frac{\alpha}{2}l - jk_nL}}{1 - x_1x_2y_1y_2E_0E_{0L} e^{-\frac{\alpha}{2}l - jk_nL}}\right] \tag{14}$$

The power output of the drop port (P_{t2}) is expressed by

$$P_{t2} = (E_{t2})\cdot(E_{t2})^* = |E_{t2}|^2 \tag{15}$$

Results

In this work, the optical tweezers can be designed and generated for molecule trapping in the device base on silicon which can be used to form the molecule trapping and transportation by using the gradient potential and surface plasmonic behaviors. The required molecules in the bottle can be trapped and transported to required destinations or targets, and the transport time and molecule sizes can also be controlled, in which the optical tweezers sizes can be varied and selected for suitable molecules trapping by controlling the PANDA ring input signals. Figure 2 shows the optical tweezers model for particle trapping, in which the trap size(d) can be adjusted and tuned between these two conditions (i) d >molecule size, this case molecule can escape from the

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trap in the transport process, (ii) d <molecule size, molecule cannot be trapped when the size of the trap too small. Therefore, in order to fit the molecule size [24], therefore, the trap sizes must be the multiple of the single molecule, which is required to generate and control. By using the proposed design, the optical waveguide can be used to trap molecules (atoms) [22,23,25], where the molecular filter can be constructed incorporating with the optical tweezer assembly, in which the trapped molecules can transfer to the device via the optical waveguide as shown in Figure 3a, where in Figure 3b, the trapped molecules can

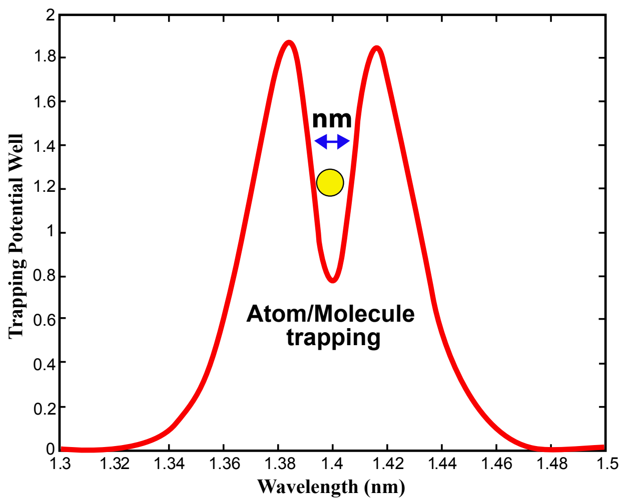

Figure 2: An optical tweezer and trapped molecule generated by a PANDA microring resonator.

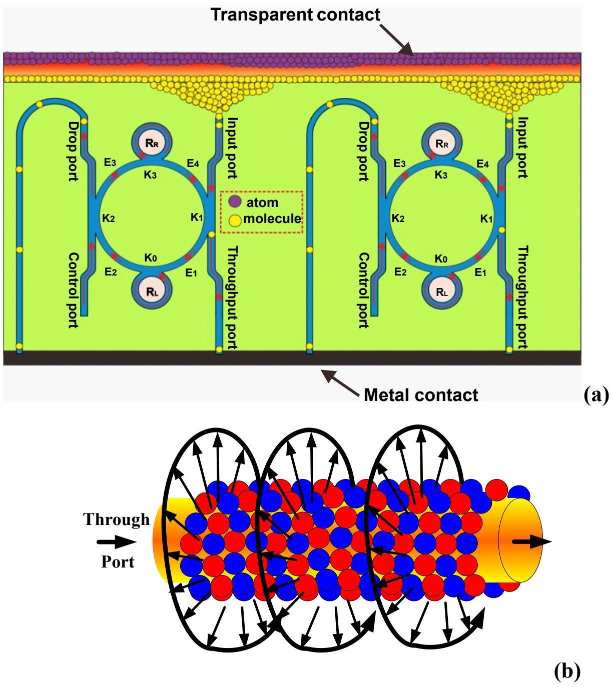

Figure 3: Schematic diagram of molecular filter, where (a) an embedded PANDA microring resonator, (b) molecule movement along the waveguide via a through port.

move along the waveguide due to the gradient force introduced by the surface plasmon. In simulation, the input signal is a bright soliton and Gaussian pulses at the peak power of 100 mW. The ring parameters are the ring radii $R_R = R_L$ = 5 μm and the add/drop R_{ad} = 20 μm. The coupling coefficients of the PANDA ring resonator are set to be $\kappa = \kappa_1 = \kappa_2 = \kappa_3 = 0.5$. The effective core areas (A_{eff}) are 300 μm². The waveguide loss coefficient (α) is 0.1 and coupling loss (γ) is 0.01 and the refractive index (n_0) is 1.37. The dimensions of optical tweezers are controlled by using the various tweezer size and kappa (κ) for fit of particle size. Figure 4 shows the optical tweezers with different positions (E_1, E_2, E_3 and E_4) generated by the PANDA ring, where E_{t1} and E_{t2} are the throughput and drop ports, respectively. In this figure, the results of different center wavelength tweezers are red=1.4 μm, green=1.45 μm, blue=1.5 μm and black=1.6 μm, where the shape and peak power of the fields are different for each of center wavelengths. The highest peak signal of optical tweezers is at wavelength of 1.4 μm. In this work, the optical tweezers are generated for molecule trapping and transportation via the optical waveguide. In which the trapping tool size (d) is required to tune between these two conditions, where (i) d > particle size, this case an electron can escape from the trap in the transport process to the contact, (ii) d < particle size, this case an electron cannot be trapped when the size of the trap too small. Therefore, the trap size is required to fit the molecule size (0.22 nm) [24]. We can filter many molecule sizes by controlling kappa parameters as shown in Figure 5, where the optical tweezers can be tuned and chosen to fit the molecule size for trapping via the optical waveguide.

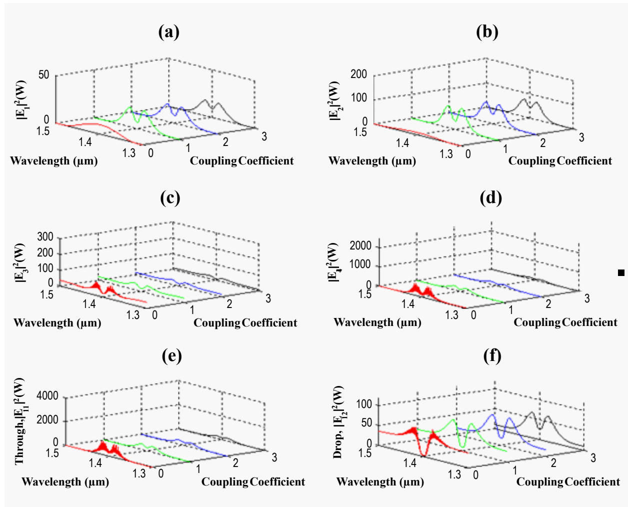

Figure 4: Results of dynamic optical tweezers generated at four different center wavelengths, where (a) $|E_1|^2$, (b) $|E_2|^2$, (c) $|E_3|^2$, (d) $|E_4|^2$, (e) through and (f) drop port signals.

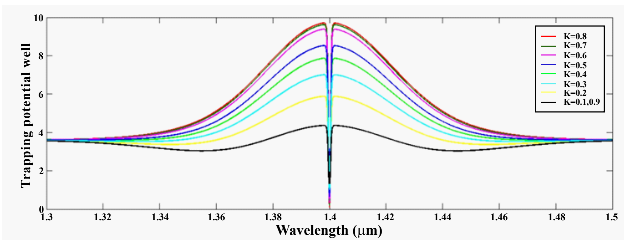

Figure 5: Results of the trapping potential well with various coupling coefficients (kappa, κ).

Discussion and Conclusion

The dynamic optical tweezers can be generated and obtained by using a soliton pulse input into a PANDA ring, where molecules in the bottle can be trapped and moved within a PANDA ring as shown in Figure 3a. The trapped molecules from the bottle can be transported to the through port by the gradient force induced by the surface plasmonic behaviors around the wave guide as shown in Figure 3b, where in this case light pulse is propagated within the waveguide, while molecules are trapped and dragged on the waveguide surface. To obtain the specific molecule sizes, the specific tweezer sizes can be tuned and generated as shown in Figure 4, where finally, the required molecules with different sizes can be retrieved (filtered) by using the control port signal. In which the required tweezers with different powers and sizes can be generated and controlled to obtain (filter) the specific molecule sizes as shown in Figure 5, in which the trapping sizes can be tuned by varying the coupling coefficients, where finally the required molecule sizes can be filtered and obtained.

In conclusion, we have proposed an interesting technique of molecular filter, which can be a good candidate for drug delivery or molecular electronics use. By using optical tweezers generated by an embedded modified optical filter, molecules can be trapped and transported via the optical waveguide to the required destination or device. The dynamic behaviors of optical tweezers are generated and controlled by using PANDA microring resonators. This technique can be used to form the multivariable molecular filter. From the obtained simulation results, it is shown that this technique can be a significant way for molecular filter and electronics, which will be drawn the attention to new era of electronic device known as a hybrid electronics. Furthermore, this technique can also be used to improve the device performances in the same way such as molecular capacitor, transistor and other molecular devices, which will be our continuing works.

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