Molecular network using molecular circuit for drug delivery use

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ABSTRACT

A novel design of molecular networks for drug delivery application using a PANDA ring resonator is proposed. By using the intense optical vortices generated within the PANDA ring resonator, the required molecules can be trapped and moved (transported) dynamically within the wavelength router and bus networks, in which the required drug delivery can perform within the wavelength router before reaching the required destination. PANDA ring is a modified optical add/drop filter. It is a name of Chinese bear, which is used to name the device by the authors. The advantage of the proposed system is that the drug delivery networks can perform within the tiny system (thin film device), where the large molecular drug networks such as ring, star and bus networks are also proposed, in which the applications such as Alzheimers’ and Parkinson diagnosis, blood circulation networks and in situ surgery operation are discussed.

Keywords: Molecular Networks; Blood Circulation Network; Drug Networks; Neural System and Network

1. INTRODUCTION

Since over 20 years ago, optical traps have emerged as a powerful tool with broad-reaching applications in biology and physics. Optical tweezers have been applied widely in many research areas such as biology, medicine, engineering and physics [1]. Optical trapping techniques provide unique means to manipulate biological particles, biological cells such as virus, living cells and subcellular organelles, without nondestructive manipulating molecules, since this technique was the first invented by Ashkin et al. [2] and his colleagues used it to trap viruses and bacteria, although the bacteria were killed by the high energy of the laser. With the application of a less damaging infrared (IR) laser, it is now possible to trap and manipulate a single yeast, bacterium and organelle without damage [3]. In specific to medicine and the application of nanotechnology, which is the field of interest, obviously experiment of a single red blood cell (RBC) deformability test is performed by using optical trapping plastic in microfluidic chip was clearly demonstrated experiment by Lee et al. [4,5] and lab-on-a-chip for RBCs transportation in the capillary network to circulate oxygen and carbon dioxide throughout the human body [6]. For the optical trapping manipulation molecules in liquid core wave guide and application to drug delivery has reported by Suwanpayak et al. [7] in a PANDA ring resonator is used to form, transmit and receive the microscopic volume (drug) by controlling the ring parameters. The microscopic volume can be trapped and moved (transported) dynamically within the wavelength router or network.

Optical buffer is recognized as an essential component in a wavelength router, in which the packets of data can be stored for resolving packet contention problem and also delay the outgoing packets [8,9]. In practice, the optical router patents have been proposed and recorded [10-12], which can be useful for various applications. Recently, the promising techniques of microscopic volume trapping and transportation within the add/drop multiplexer have been reported in both theory [13] and experiment [14], respectively, in which the transporter is known as an optical tweezer. Here, the optical tweezer generation technique has become a powerful tool for manipulation of micrometer-sized particles. To date, the useful static tweezers are well recognized and realized. Moreover, the use of dynamic tweezers is now also realized in practical works [15-17]. Schulz et al. [18] have shown that the transfer of trapped atoms between two optical potentials could be performed. In principle, an
optical tweezers use forces exerted by intensity gradients in the strongly focused beams of light to trap and move the microscopic volumes of matters, in which the other combination of force is induced by the interaction between photons, which is caused by the photon scattering effects. In application, the field intensity can be adjusted and tuned, in which the desired gradient field and scattering force can form the suitable trapping force. Hence, the appropriated force can be configured for the transmitter/receiver part, which can perform the long distance microscopic transportation.

In this paper, the dynamic optical tweezers/vortices are generated using a dark soliton, bright soliton and Gaussian pulse propagating within an add/drop optical multiplexer incorporating two nanoring resonators (PANDA ring resonator). The dynamic behaviors of solitons and Gaussian pulses are well described in reference [19]. By using the proposed system, the transceiver can be integrated and performed by using a single device. Here, the use of the molecular buffers and bus networks to form the drug volume transportation, especially, for large drug volumes delivery and transportation, which can be available for molecular diagnosis and networks, blood circulation networks, Alzheimer’s and Parkinson’s diagnosis.

2. PRINCIPLES AND METHODS

In operation, the trapping forces are exerted by the intensity gradients in the strongly focused beams of light to trap and move the microscopic volumes of matters, in which the optical forces are customarily defined by the relationship [18]

$$F = \frac{Qn_m P}{c}$$  \hspace{1cm} (1)

where $Q$ is a dimensionless efficiency, $n_m$ is the index of refraction of the suspending medium, $c$ is the speed of light, and $P$ is the incident laser power, measured at the specimen. $Q$ represents the fraction of power utilized to exert force. For plane waves incident on a perfectly absorbing particle, $Q$ is equal to 1. To achieve stable trapping, the radiation pressure must create a stable, three-dimensional equilibrium. Because biological specimens are usually contained in aqueous medium, the dependence of $F$ on $n_m$ can rarely be exploited to achieve higher trapping forces. Increasing the laser power is possible, but only over a limited range due to the possibility of optical damage. $Q$ itself is therefore the main determinant of trapping force. It depends upon the NA (numerical aperture), laser wavelength, light polarization state, laser mode structure, relative index of refraction, and geometry of the particle.

Furthermore, in the Rayleigh regime, trapping forces decompose naturally into two components. Since, in this limit, the electromagnetic field is uniform across the dielectric, particles can be treated as induced point dipoles. The scattering force is given by

$$F_{\text{scatt}} = n_m \frac{\langle S \rangle \sigma}{c},$$  \hspace{1cm} (2)

where

$$\sigma = \frac{8}{3} \pi (k \alpha)^4 r^2 \left( \frac{m^2 - 1}{m^2 + 2} \right)^2$$  \hspace{1cm} (3)

is the scattering cross section of a Rayleigh sphere with radius $r$. $\langle S \rangle$ is the time averaged Poynting vector, $n$ is the index of refraction of the particle, $m = n / n_m$ is the relative index, and $k = 2n \alpha^2 / \lambda$ is the wave number of the light. Scattering force is proportional to the energy flux and points along the direction of propagation of the incident light. The gradient field ($F_{\text{grad}}$) is the Lorentz force acting on the dipole induced by the light field. It is given by

$$F_{\text{grad}} = \frac{\alpha}{2} \nabla \left( E^2 \right),$$  \hspace{1cm} (4)

where

$$\alpha = n_m^2 r^3 \left( \frac{m^2 - 1}{m^2 + 2} \right)$$  \hspace{1cm} (5)

is the polarizability of the particle. The gradient force is proportional and parallel to the gradient in energy density (for $m > 1$). The large gradient force is formed by the large depth of the laser beam, in which the stable trapping requires that the gradient force in the $-\hat{z}$ direction, which is against the direction of incident light (dark soliton valley), and it is greater than the scattering force. By increasing the NA, when the focal spot size is decreased, the gradient strength is increased [19,20], which can be formed within the tiny system, for instance, nanoscale device (nanoring resonator).

In our proposal, the trapping force is formed by using a dark soliton, in which the valley of the dark soliton is generated and controlled within the PANDA ring resonator by the control port signals. From Figure 1, the output field ($E_{\text{o}}$) at the through port is given by [19]

$$E_{\text{o}} = AE_{\text{i}} - BE_{\text{e}}e^{\frac{\alpha t}{2} \beta e^L}$$

$$- C E_{\text{i}} \left( e^{\frac{-\alpha t}{2} - \beta e^L} \right)^2 + D E_{\text{e}} \left( e^{\frac{-\alpha t}{2} - \beta e^L} \right)^2$$

$$1 - E \left( e^{\frac{-\alpha t}{2} - \beta e^L} \right)^2$$  \hspace{1cm} (6)

where
The power output \( P_1 \) at through port is written as
\[
P_1 = |E_{t1}|^2.
\]

The output field \( E_{t2} \) at drop port is expressed as [19] (see Eq. 8)
\[
X = \sqrt{(1 - \gamma_2)(1 - \gamma_1)(1 - \kappa_1)\kappa_2(1 - \kappa_2)}, \quad
Y = \sqrt{(1 - \gamma_1)(1 - \gamma_2)(1 - \kappa_1)(1 - \kappa_2)}.
\]

The power output \( P_{t2} \) at drop port is
\[
P_{t2} = |E_{t2}|^2.
\]

In operation, the optical tweezers can be trapped, transported and stored within the PANDA ring resonator and wavelength router, which can be used to form the microscopic volume (molecule) transportation, drug delivery via the waveguide [14], in which the manipulation of trapped microscopic volumes within the optical tweezers has been reported.

3. DRUG DELIVERY NETWORKS

Molecular buffer is a device that can be used to store or delay atoms/molecules for a period of time (see Figure 2), where light intensity and velocity can also be controlled, which was described by the authors in references [21,22], which is available for medical application. Molecular buffer is the new device, which is operated in the same way as gases buffer [23]. The polarizibility of the particle is calculated by using an Eq. 5, in this case, we assume that the sphere particle is polystyrene \((n = 1.5894)\) and the liquid medium is water \((n = 1.33)\), and the optical power which is required to trap particles of a certain size/polarizibility is 9.1 W, which is the slope as shown in Figure 3(a). In simulation, the bright soliton with center wavelength at 1.50 µm, peak power 2 W, pulse 35 fs is input into the system via the input port, the coupling coefficients are given as \(\kappa_0 = 0.5, \kappa_1 = 0.35, \kappa_2 = 0.1\) and \(\kappa_3 = 0.35\), respectively. The ring radii are \(R_{add} = 100 \mu m\), \(R_R = R_L = 40 \mu m\), respectively. To date, the evidence of the practical device with the radius of 2 - 3 µm has been reported by the authors in reference [24]. \(A_{eff}\) are 0.50, 0.25 and 0.25 \(\mu m^2\): In this case, the dynamic tweezers (gradient fields) can be in the forms of bright solitons, Gaussian pulses and dark solitons, which can be used to...
Figure 2. Schematic of molecular buffer work in core waveguide.

Figure 3. Graph of optical power which is required to trap the particle of a certain size/polarizability.

trap the required microscopic volume. There are four different center wavelengths of tweezers generated, where the dynamical movements are seen in Figure 4, where (a) different sizes and wavelengths tweezers, (b) tunable tweezers by coupling constant variation, where the required drug volumes can be obtained by the drop port outputs.

In practice, the fabrication parameters which can be easily controlled are the ring resonator radii instead of coupling constants. The important aspect of the result is that the tunable tweezers can be obtained by tuning (controlling) the add (control) port input signal, in which the required number of microscopic volume (atom/photon/molecule) can be obtained and seen at the drop/through ports, otherwise, they propagate within a PANDA ring before collapsing/decaying into the waveguide. In application, the trapped drug molecules can transport into the wavelength router via the through port, while the retrieved drug volumes are received via the drop port (connecting target). The advantage of the proposed system is that the transmitter and receiver can be fabricated on-chip and alternatively operated by a single device. The magnitude of optical trapping force is the pico Newton (pN), which depends upon the relative refractive index of particle, which was given by the authors in reference [25]. The particle radius was given by the authors in references [26-28], which is located in the cavity. It decreases with the decreasing in refractive indices compared to the host medium.

The waveguide of the drug delivery system can be an optical waveguide with liquid core which is allowed to trap drug molecules smoothly within the network. By using the drug bus network, the trapped drug molecules can be transported to the required drug targets and delivery, in which the specific drug molecules can be obtained by using the molecular transceiver. To form the trapping tools, the PANDA ring resonator has 4 ports as shown in Figure 1. Firstly, the dark-soliton is fed into the system via the input port. Secondly, output trapping tools transmit into the through port and bus networks. Thirdly, the required drug molecules are filtered and obtained via the drop ports. Finally, there are some molecules transport within the bus networks and drug routers, in which the control port is available for additional applications. In Figure 5, the molecular trapping probe can be adjusted to fit the drug molecule size from 10 nm to 15 nm, which can be used for drug molecule transportation at the through port and networks. The number of molecules can be increased within the PANDA ring resonator as shown in Figure 5(a). In addition, the trapping tool (probe) or dynamic well size can be adjusted by varying the coupling coefficient of PANDA microring as shown in Figure 5(b), where the other parameters are given in the figure captions.

4. DISCUSSION

Several works have shown that the use of fluidics particles (drug volumes) can perform the realistic applications [29-31]. In this paper, the proposed system has shown that a tiny device in the form of thin film can be fabricated and used [32], in which the integrated system of drug network can be inserted into the application area, where the feasibility applications such as drug delivery
network for large area diagnosis can be available as shown in Figure 6. Moreover, the use of such a system for artificial bone and blood circulation network is also available, in which the use for in situ surgery or operation, neural and brain diagnosis is plausible.

By using the design networks, the required trapped volumes can be transported within the network via the molecular buffer (storage) into the required destinations, for instance, the trapped tangle protein can be filtered via the add/drop filter before reaching the desired destinations. The throughput port (Et1) output of add/drop filter is connected to the axon (axon terminal), then to neural cell and dendrite.

The effective area of the waveguide is 2.01 $\mu m^2$ ($r =$...
Figure 5. Result of the dynamic tweezers with different (a) wavelengths and (b) coupling constants, where $R_{add} = 15 \mu m$, $R_g = R_L = 3 \mu m$.

800 nm) and the outside diameter of the microtubule is 25 nm [33]. The size of axons diameter at birth is 1 µm, it increases through childhood (7 years) to 12 µm and later to 24 µm at adulthood [34]. In case of Alzheimer’s diagnosis as shown in Figure 6(b), the optical tool is connected the axon and between the nerve cells, which can be used to trap the tangle protein into the removal storage by add/drop filter (control port), otherwise, the
bus network as design can be used to trap the molecular motor to activate the information of neuronal cell at the same time. For better access, the coupling material is required to use as waveguide-axon coupling.

5. CONCLUSIONS

We have proposed the interesting system that can be used form the molecular networks to trap (delay) and transport molecules into the liquid core waveguide and networks by using the optical tweezers, which can be used to form the drug storage and delivery system. Such a system can be available for molecular drug targeting and diagnosis. By utilizing the reasonable dark soliton input power, the dynamic tweezers can be controlled and stored (delayed) within the system before reaching the final destination.

In conclusion, we have shown that the use of a molecular networks to form the long distance drug molecule transportation being realized by using the proposed system, in which the drug delivery or molecular communication can be performed via the wavelength router to the required (connecting) targets, which can be available for large network system (neural system) in the near future.

REFERENCES


