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Molecular transport network security using multi-wavelength optical spins

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Abstract

Multi-wavelength generation system using an optical spin within the modified add-drop optical filter known as a PANDA ring resonator for molecular transport network security is proposed. By using the dark-bright soliton pair control, the optical capsules can be constructed and applied to securely transport the trapped molecules within the network. The advantage is that the dark and bright soliton pair (components) can securely propagate for long distance without electromagnetic interference. In operation, the optical intensity from PANDA ring resonator is fed into gold nano-antenna, where the surface plasmon oscillation between soliton pair and metallic waveguide is established.

Keywords: molecular network, magnetic networks, spin networks, spin transport network

Introduction

Optical spin has been recognized as the promising key for future digital and computing technologies, which can be used for many applications such as semiconductors (Myers et al. 2008), magnetic tunnel junctions (Gordon et al. 2009), nano-antenna (Thammawongsa et al. 2012), thin-film nano-magnets (Ozatay et al. 2008), and cell communications (Meyl 2012). Till date, the optical excitation of nanoparticle with circularly light is an interesting idea, in which light pulse is used for spin generation and detection (Lampel 1986). By using the optical orientation (Galvez et al. 2007), the angular momentum of light is converted to be electronic spin and vice versa, which is very efficient in semiconductors. The consequence of this effect assists as an important aspect of spintronics, where it is used to spin-polarize electrons. These techniques were used to explain the behavior of paramagnetic ion resonance in quantum geometric confinement, where the optical spin resonance and transverse spin relaxation in magnetic semiconductor quantum wells are generated and achieved (Crooker et al. 1997). Moreover, the optical spin manipulation in electrically pumped vertical-cavity surface-emitting lasers is analyzed (Hövel et al. 2008), where the output polarization

for mixed electrical and optical excitations is demonstrated. After that, the spin magnetic state and the static magnetic field were used to build the AND, OR, XOR (CNOT), and NAND gates by optical spin manipulation (Hübner et al. 2009). Optical spin generation using dark-bright soliton pair by PANDA ring resonator was proposed by Yupapin and his colleagues (Muhammad et al. 2012, Glomglome et al. 2012) that generate soliton pair called “soliton spin” (photonic spin) for optical communication system.

Recently, molecular communication has become a new communication pattern based on biological mechanism, which is used to encode molecules as information carrier. The most promising technique is one that converts molecular signal into optical information and transports the molecular information into a nano networking channel (Parcerisa et al. 2009). The important aim to develop molecular communication is to design and control the nano network devices that can transport the biological information, for instance, a number of techniques were shown such as molecular array and network (Atakan et al. 2012, Nakano et al. 2012) and multi-wavelength transportation by dark-bright soliton (Sarapat et al. 2009) and other applications (Amiri and Ali 2013, Amiri et al. 2013a, 2013b, 2013c, 2013d, Amiri and Ali 2014).

In this paper, Multi-wavelength molecular capsules for molecular transport network security are generated, which can be formed by optical spins, in which a dark-bright soliton pair is used to generate the high magnetic field using the gold nano-antenna coating, which is applied on device surface. The obtained results have shown that the soliton spin rotation and the spin sets can be obtained. In application, the molecular transport network security with soliton spin may be useful for molecular communication network, where the use of such a system for molecular nanosensor, molecular transportation, and optical spin cryptography can be realized.

Background

In this study, a modified add-drop filter called “PANDA” ring resonator which consists of add-drop filter (Rad)

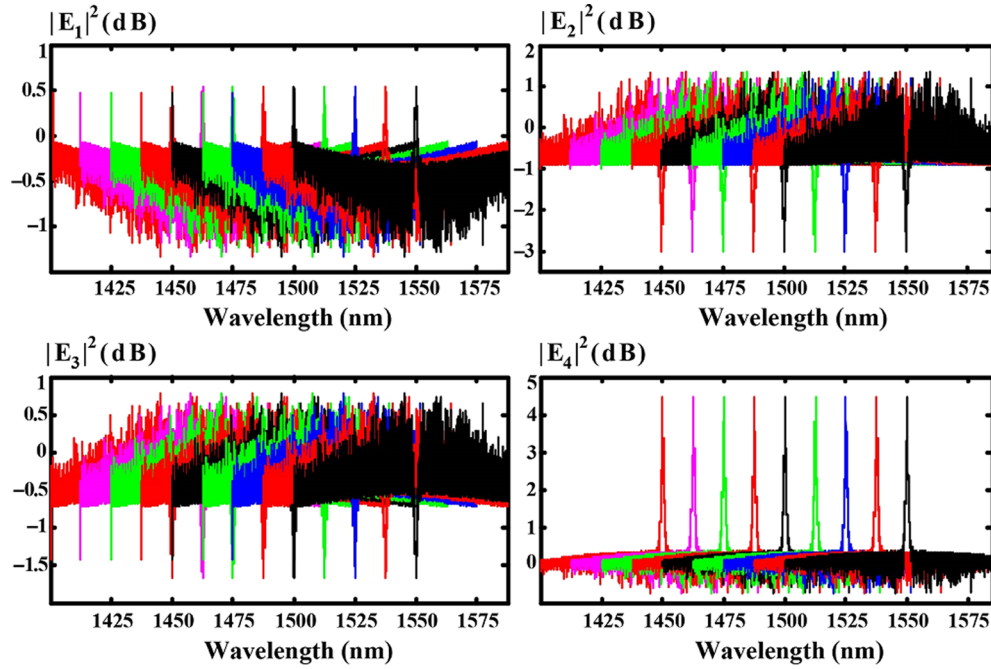


Figure 2. Many soliton spins within a PANDA ring are generated using a dark-soliton pump input at center wavelength 1400, 1425, 1450, 1475, 1500, 1525, 1550, 1575, and 1600 nm.

Figure 4 shows the 3D drawing of ring laterally gold coupled to the straight waveguides in Figure 4a and the cross section of add-drop in Figure 4b. The ring was coated by gold on the top as a nano-antenna, where the surface plasmonic resonance is produced, in which the output spin states can be confirmed by using the output polarizing beamsplitter arrangement. The dark-bright soliton conversion pulses within a PANDA ring resonator is generated and transmitted to gold coupled add-drop multiplexer, in which the multiplexed optical spins can be obtained and propagated into the provided network. Figure 5 shows the results of many spins by the proposed add-drop optical filter device which is coated by gold nano-antenna. A nano-antenna's current density is established by using the Pocklington's integral equation (Pocklington 1897). The complex one dimensional

current density is calculated using MATLAB program (Biagioni et al. 2012), where the antenna input impedance is expressed by the simplify impedance, which is transmitted at different lengths (Balanis 1992). Generally, the gold (Au) material is the most popular material used for nano-antenna, which can provide a good effective resonance and dielectric constant values. The surface plasmon resonance of the interface between add-drop optical device and nano-antenna in terms of dispersion relation is described by using the Drude model (Rakic et al. 1998) as in following details.

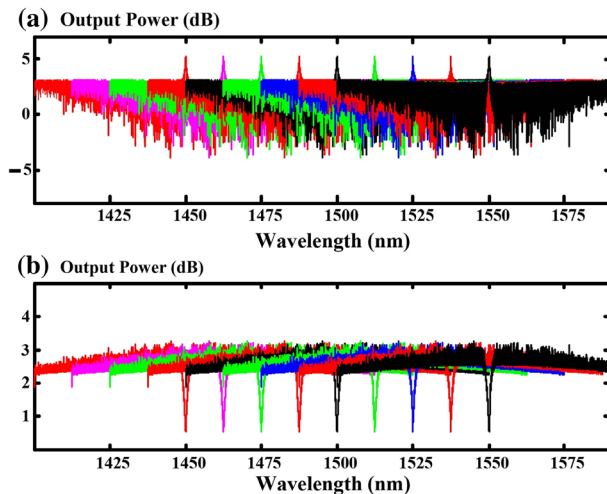


Figure 3. A set of spins obtained at (a) Through port (spin up) and (b) Drop ports (spin down).

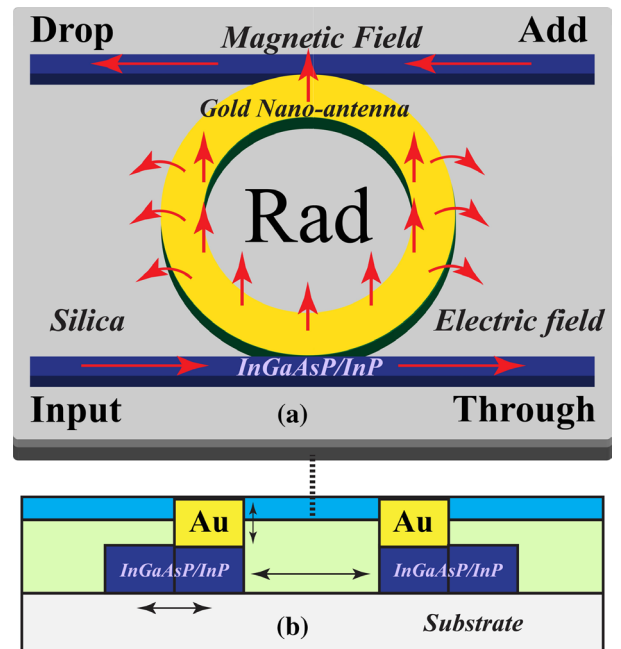


Figure 4. (a) 3D drawing of ring laterally gold coupled to the straight waveguides (b) and cross section of add-drop.

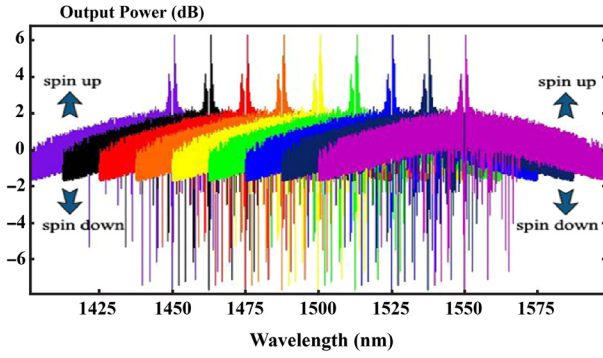


Figure 5. A set of spins obtained at Through and Drop ports of the Rth Add-Drop (Yupapin et al. 2013).

$$\varepsilon_m(\omega) = \varepsilon_1 + i\varepsilon_2, \quad (21)$$

$$\varepsilon_1(\omega) = 1 - \frac{\omega_p^2}{\omega^2 + \Gamma^2}, \quad (22)$$

$$\varepsilon_2(\omega) = \frac{\Gamma\omega_p^2}{\omega(\omega^2 + \Gamma^2)}, \quad (23)$$

Where $\omega_p = 2\pi f = 1.36 \times 10^{16} \text{ rad s}^{-1}$ and $\Gamma = 1.05 \times 10^{14} \text{ rad s}^{-1}$ are the size and temperature dependent plasma and collision frequency (f) of the nanoparticles, respectively. The intensity of surface plasmon resonance is improved when there is increase in the photothermal conversion process efficiency. Therefore, the extinction metal nanoparticle cross section given in Mie theory is derived by

$$E(\omega) = \frac{24\pi R \varepsilon_m^{3/2}}{\lambda} \frac{\varepsilon_2(\omega)}{(\varepsilon_1(\omega) + 2\varepsilon_m)^2 + \varepsilon_2^2(\omega)} \quad (24)$$

Where R is the radius of the ring and λ is the wavelength of the light in media, ω is the angular frequency of the exciting light, c is the velocity of light in vacuum, $\varepsilon_m(\omega)$ is the dispersive relative permittivity of the metal and math type is the dielectric functions of material. The surface plasmons oscillation is obtained by using a longitudinal electric field w , where TM-polarization and exponential decay of electric field are calculated by the Maxwell equations. The surface plasmon propagation constant (K_p) of the wave propagating along the metal-dielectric interface is given by

$$k_p = k_0 \sqrt{\left(\frac{\varepsilon_d \varepsilon_m(\omega)}{\varepsilon_d + \varepsilon_m} \right)}. \quad (25)$$

Where k_0 is the wave vector in air, ε_d is the relative permittivity of the dielectric constant. This wave can be optically excited using a coupling coated by a thin gold film (Kretschmann configuration), whereas a TM-polarized light beam is imposed on the gold face under total internal reflection conditions. The user add-drop filters are employed to retrieve the required signals, where the different wavelength signals (spins) can be obtained using the wavelength selectors (add-drop filters) at the end of the drop port. On the

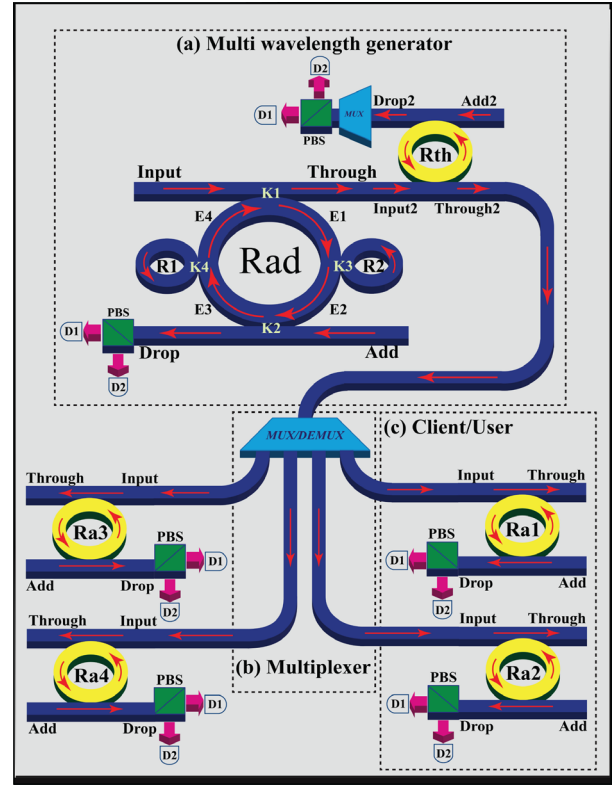


Figure 6. A schematic diagram of spin distributed networks using the multi-wavelength optical spins, where D1: detectors, PBS: polarizing beamsplitter, Rgs: output ring radii (users).

other hand, the modified data can be input into the network via the add port of each user in the transmission networks, which is shown in Figure 6. The received signals of each user (1–4) from add-drop filters at the through and drop ports are shown Figures 7 and 8, in which the spin wavelength selectors are employed as the key instrumental components. The certain or a narrow band wavelength can be obtained before the required spin signals are being detected via the end users. In terms of signal quality, the simulated free spectral range (FSR) transmission = 25 nm and full width half maximum (FWHM) = 4 nm are achieved as shown in Figure 9, where the output optical spins with different wavelengths can be obtained.

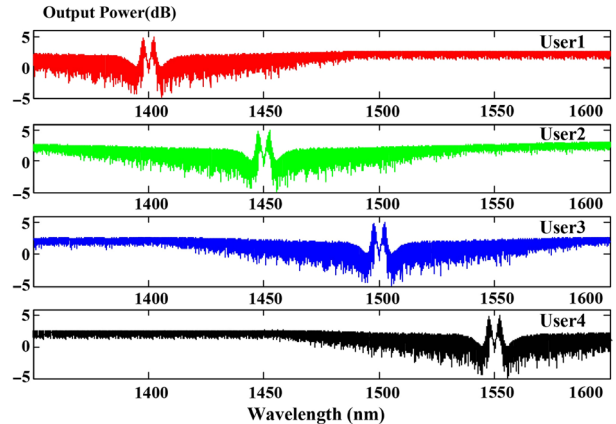


Figure 7. Results received by each user (1–4) from add-drop filter at Through port.

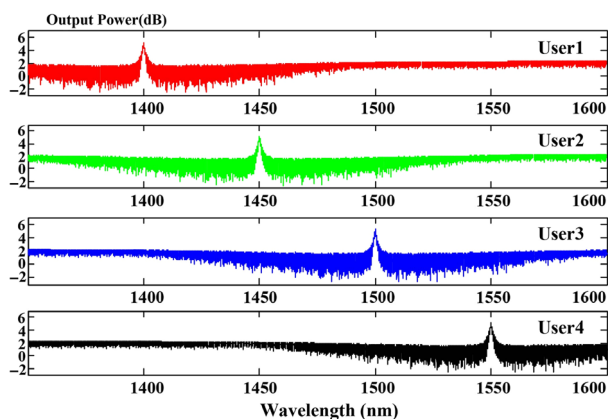


Figure 8. Results received by each user (1–4) from add-drop filter at Drop port.

In simulation, the optical spins and the magnetic fields can be generated by applying gold film coating, in which the magnetic induction on the device surface can be induced, as shown in Figure 4. Hence, the proposed system in Figure 8, a polarizing beam splitter (PBS) is used to distinguish the data and reference signals at the required destination in part (a). After that, data from the device enters into the multiplexing device (multiplexer, MUX) to encrypt data and transmit into the optical network. The generated multi-spins (many optical spins) can be used to form the wavelength division multiplexing data transmission, which offers the advantage of a long journey without interference and safely arrives at the destinations. Finally, the required signals can be retrieved (decoded by the demultiplexing, DEMUX) in part (b). After travelling through the DEMUX, the information will also be sent to the end users using the add-drop filters, in which the magnetic field is generated to identify the required data in part (c).

Generally, the long distance link means the soliton output power that can be useful for $> 1,000$ km via an optical fiber link (Grigoryan et al. 2000), where the proposed system power of 10 dBm is obtained, which can be transmitted over 4,000 km for nine-channel transmission (Essiambre et al. 1997), while the time jitter in a soliton communication can be reduced by using the periodic optical phase conjugation (OPC) device (Parcerisa et al. 2009). By using the small waveguide effective area, the polarization-dependent loss of < 0.1 dB at 1550 nm can be achieved (Van Laere et al. 2009,

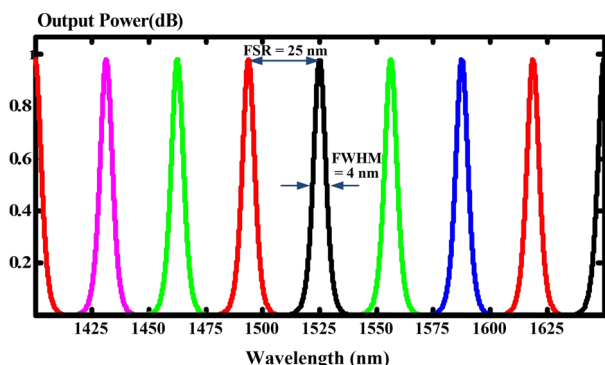


Figure 9. Simulated transmission FSR = 25 nm and FWHM = 4 nm.

Yang et al. 2009), where the spin detection can be realized in the form of polarization mode by using the polarizing beamsplitter and detected by the end users. The minimum detuning of the two signals (solitons) can be obtained, where in this case the detuning of 6.8 THz can be obtained between two signals (bands), where more detail can be found in reference (Yang et al. 2009). However, this is a simulation work in practice, if the propagation loss varies with wavelength, then the solitons away from the center (peak) wavelength (1500 nm) will not be valid for long distance propagation.

Molecular network security

Molecular encapsulation network is the confinement of a molecule inside the cavity such as molecular capsule, molecular container or cage to transport along network. The essential suggestions are security and separation molecular capsules for specific destination.

In this model, we propose a network by using dark-bright soliton conversion control (Yupapin et al. 2013, Thammawongsa et al. 2013a) as shown in Figure 6, in which molecules (drug) can be trapped and moved securely along the network. The end users can perform the recovered molecules by using the molecular filter via the through port (Aziz et al. 2012), the transmission security can also be realized by using the soliton spin up-down coded and decoded (codec) technique via the drop port (Yupapin et al. 2014). Moreover, the optical spin states can be formed by polarization states via the polarizing beam splitter, while the state confirmation can be initialized by the transmitter (Alice) related to the receiver (Bob), where finally the security is confirmed by both parties. The optical capsules by soliton pair within the optical network for molecular delivery can securely trap the required molecules as shown in Figure 10, which is transmitted by the gradient force and scattering force as shown in Figure 10a. Finally, the specific codes between Alice and Bob can be recognized. The detached signals are shown in Figure 10b. In applications, the multi-wavelength optical spins network may be useful for network controls of molecular communication, switching, routing, and addressing at nano scale, coding in molecular networks, molecular networks security, nano computer networks, monitoring, and nano networks with larger-scale network integration.

Conclusion

In this work, multi-wavelength optical spin network system is proposed using the orthogonal dark-bright soliton conversion pulses within a PANDA ring resonator. The surface plasmonic resonance is induced by applying gold nano-antenna coating on the surface of the device. The coupling between the optical fields and the gold coating waveguide generates the transverse electric (TE) and magnetic field (TM) that can be separated using the add-drop filter and PBS for reference source and required signals at the destinations (end users). The results obtained have shown that multi-optical spins in the optical networks, i.e., spin networks (SpinNet) can be formed in which optical capsules by soliton pair within the optical network for molecular

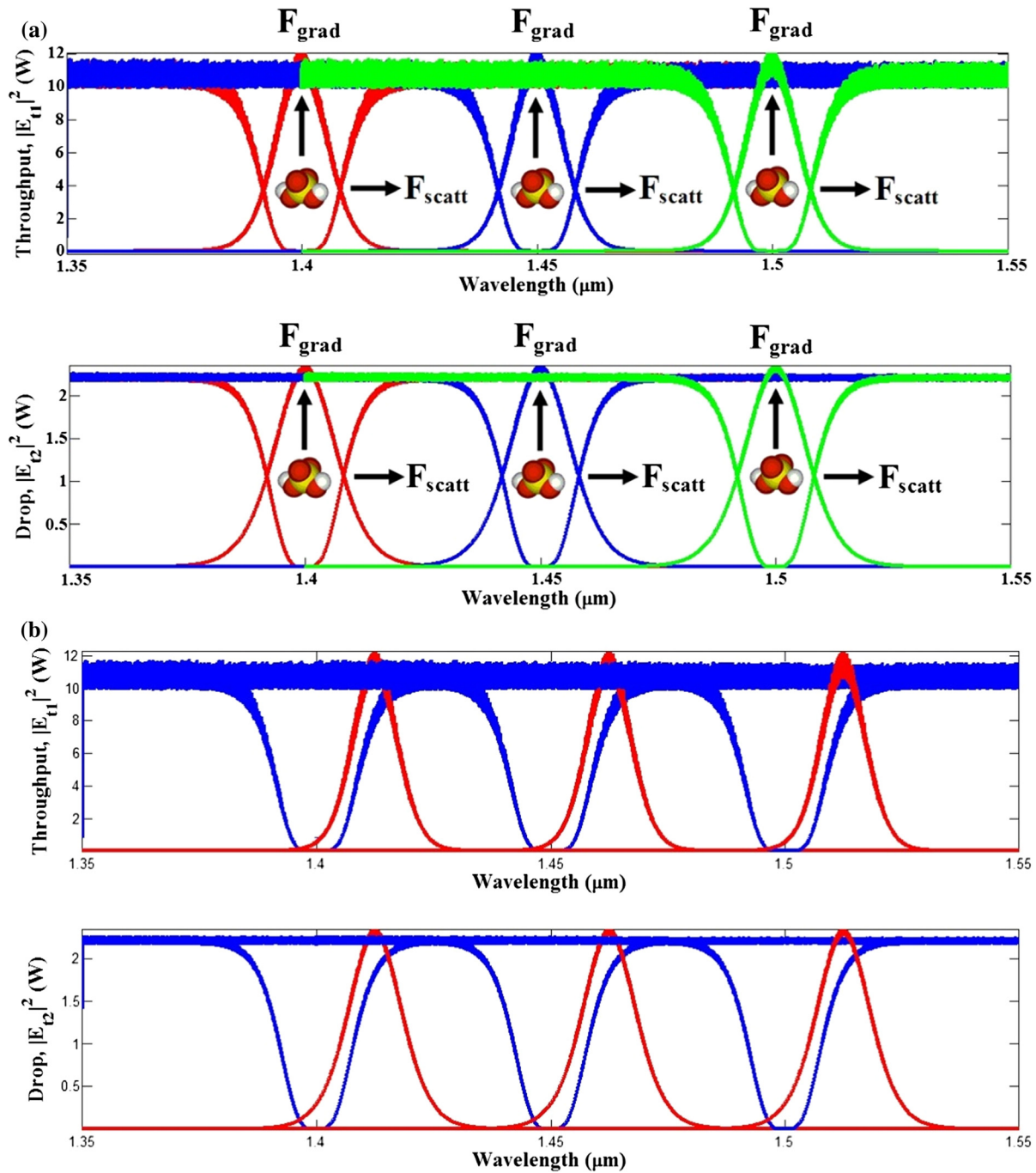


Figure 10. Schematic of trapped molecules within the optical capsules, (a) optical capsules, (b) open optical capsules; F_{grad} : gradient force, F_{scatt} : scattering force.

delivery can securely trap the required molecules. The maximum force is given by Stokes' drag calibration that could be exerted on the particles, where the particle diameters ranging from 101 to 254 nm, the maximum force was found to be within the range of 0.56–2.2 pN, with a laser power of 135 mW. Therefore, the maximum force can be exerted into the proposed system by using the full laser power of 7 W, which will be around 20 pN, which can be found in ref (Thammawongsa et al. 2013b).

The advantage of the optical spin in network is absence of electromagnetic interference during propagation within the network. However, this is a small scale device and system, which gives the advantage for short range communication,

where the multi-wavelength soliton spin may be of benefit for optical network communication and cryptography based spins, where the link loss can be assumed small. Moreover, the use of secure trapped molecules (drug) for long distance link can also be available by using the optical capsules, which can be useful for multi-access drug delivery with long distance link.

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Declaration of interest

The authors report no declarations of interest. The authors alone are responsible for the content and writing of the paper.

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