Force of optical tweezers by micro ring resonator system

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Keywords: lasers, optical tweezers, optical design, optical trapping

Abstract. This research aimed to design optical tweezers for nanometer scale and find the force of optical tweezers. The principle of absorption and reflection of light passing through the optical theory of four-wave mixing (FWM) caused a phenomenal optical nonlinearity. The parameter can be variable the coupling coefficient (k) of the cavity resonance light from 0.2 - 0.8 and the size of the radius (r) are between 10 - 150 microns. The wavelength is 1,550 micrometers and the resulting consist of two forces are the gradient force equal to 2.00 x 10^{-18} Newton and scattering force equal to 5.44 x 10^{-30} Newton, in this case with particles are between 10 - 20 microns into the pure water. This system, the optical devices microring resonator can be the application to optical, medical and the quantum computer device in the near future.

1. Introduction

In this technology about the detection of optical scattering and gradient forces on micron sized particles was first reported in 1970 by Ashkin, a scientist working at Bell Labs.[1] Years later, Ashkin and colleagues reported the first observation of what is now commonly referred to as optical tweezers: a tightly focused beam of light capable of holding microscopic particles stable in three dimensions [2].Optical tweezers have proven useful in other areas of biology as well. For instance, in 2011, the review summarizes the recent advances in the emerging field of plasma-based optical trapping and discusses the details of Plasmon tweezers along with their potential applications to bioscience and quantum optic [3]. Optical tweezers have also been used to probe the cytoskeleton, measure the viscoelastic properties of bio-polymers [4] and study cell sperm competition and motility [5]. A dynamic multiple-beam optical tweezers [6], laser tweezers for atomic solutions [7], holographic optical tweezers [8-9] and experimentally demonstrated optical tweezers [10-12] were reported.

In this paper, we combine laser trapping for optical tweezers with computer software Optiwave and Matlab to study the microring resonator for nanoscale optical tweezers, where the force of optical trapping and confirm the result by experiment the polymer in water for finding the gradient force and scattering force [13].

2. Theory and background

The purpose of this research is to simulate the effect of the length of the ring resonance phenomenon that affects non-linear cavity resonance of the ring. Considering that the radius of the ring is a 5 -12 microns and diameters of core equipment ring resonance is 250 nm by changing the phase linear static ($\phi_L = 0$) , the coupling coefficient ratio of light (κ) are 0.2 -0.9 and a refractive index of a nonlinear $n_2 = 2.69 \times 10^{-17}$ m^2/W [14].

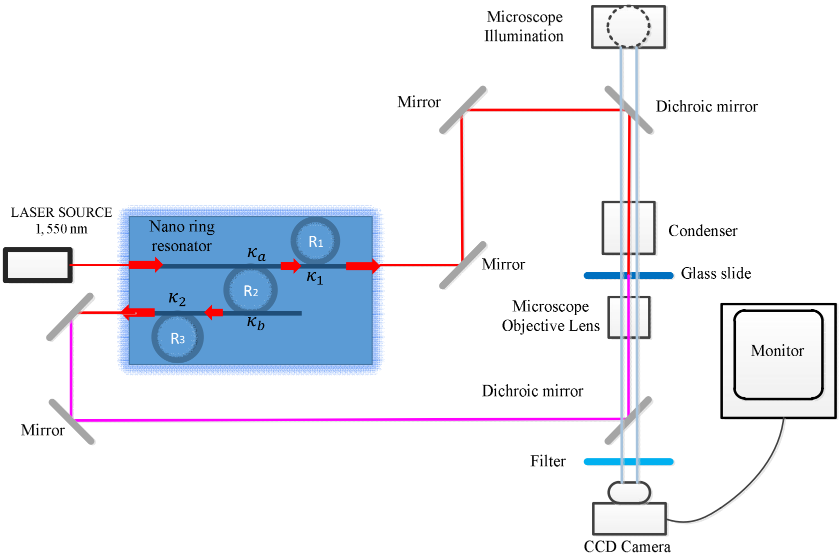

Fig. 1. System design optical tweezers for passing light through small molecules. The device is a small cavity resonance wavelength 1.550 micrometers. The systems that have been designed by the computer program such results.

When the input light Gaussian pulse into the cavity resonance devices smaller and the third ring, which is a phenomenal rise is not linear. (Kerr-effect) is called Chaos and optical isolation add / drop Filter serves to separate the optical signal into multiple wavelengths, as shown in Figure 4.15 of such relationships. The input and output are ($E_{out}(t)$ and $E_{in}(t)$) as shown in equation (1) [15].

$$E_{in}(t) = E_0\, e^{j\phi_0(t)} \tag{1}$$

where E_{in} is input electric field , E_0 is output electric field and ϕ_L is linear phase shift and non-linear phase shift optical waveguide loop in the ring is

$$\phi = \phi_L + \phi_{NL} \tag{2}$$

$$\phi_{NL} = \frac{2\pi n_2 L}{\lambda_0 A_{eff}} \left|E_1(t)\right|^2 \tag{3}$$

λ_0 is the wavelength of the light traveling in a vacuum and A_{eff} is the cross section area of core in the waveguide by equation (2) and equation (3) and a written form of the equation iteration is time dependent.

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

(4)

From Equation (4) is based on the principle of Fabry-Perot cavity which input to use mirrors to reflect back and forth in a systematic manner(1- κ), κ is Coupling coefficient and

$x = \exp(-\alpha L/2)$ is the roundtrip loss coefficient, $\phi_0 = kLn_0$ and $\phi_{NL} = kL(\frac{n_2}{A_{eff}})P$ are linear phase shift and non-linear phase shift optical waveguide and $k = 2\pi / \lambda$ is the wave propagation number in a vacuum and L is waveguide length and α is linear absorption coefficient.

In this paper used the equation (4) in the experiment for signal integrity and the suitable in design and multi-channel optical isolation to Add/drop filter device. Similarly, we can connect to the micro ring resonator system to an input signal. Input field of the optical signal is shown in Equation (1) Gaussian beam, which the optical signal is linear. From equations with variable causes, the signal is nonlinear. When the signal chaos from the equation (2), which can create chaos and filtering by wavelengths, with many using the supplied splitter, multi-wavelength by Add/drop filter device which can be calculated from equation (5) and (6)

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

and

$$\left|\frac{E_d}{E_{in}}\right|^2 = \frac{\kappa_1\kappa_2 e^{-\frac{\alpha}{2}L}}{1 + (1-\kappa_1)(1-\kappa_2)e^{-\alpha L} - 2\sqrt{1-\kappa_1}\cdot\sqrt{1-\kappa_2}\,e^{-\frac{\alpha}{2}L}\cos(k_n L)} \tag{6}$$

When E_t and E_d are the light field outputs of the transmission of the Throughput port and output of Drop port from the transmission output can be controlled. And select the best value of the variable coupling ratio of the cavity resonance device [16]. Where $\beta = kn_{eff}$ and β is the propagation constant, n_{eff} is the coefficient of reflection index and the length of the waveguide is $L = 2\pi R$ and $\boldsymbol{R}$ is the radius of the micro ring resonator, $\phi = \beta L$ is the phase constant. We can control the chaos signal using the splitter optical Add / drop device, which can be split into multiple wavelengths of the Kerr effect and Four-wave mixing (FWM) phenomena, in which the used parameters are the reflection coefficient of separate wavelength, the κ_1 and κ_2 are the coupling coefficient of add / drop filters, $k_n = 2\pi / \lambda$ is the wave propagation number of a vacuum and the loss in waveguides (is a = 0.5 dBmm^{-1} and the coupler intensity loss is $\gamma = 0.1$.

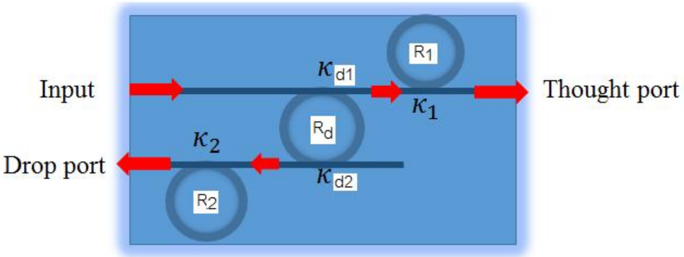

Fig. 2 shows the structure of the ring resonator of optical tweezers.

2.1 The force of optical tweezers to Ray Leigh particle

In principle, there are two forces that force is the force gradient and a scattering force.

2.1.1 The gradient force

The force caused by electromagnetic induction cause separation between the positive and negative charge inside. The particles become dipole, which drawn to the point where the intensity of light, which is the focus point has the strong gradient values.

$$F_{grad} = \frac{\alpha}{2}\nabla\langle E^2\rangle \tag{7}$$

and

$$\alpha = n_m^2 r^3\left[\frac{m^2-1}{m^2+1}\right] \tag{8}$$

Where $\nabla\left\langle E^2\right\rangle$ is the average result of electric field squared n and n_m are the refractive indexes of the particles and the refractive indexes of medium and m = n/n_m is the refractive index ratio of particles and medium, r is the radius of polymer particles.

2.1.2 Scattering force

Caused by the particles absorb light (absorption) and scattering of light from the particles in all directions (scattering) causes transfer momentum to the particle momentum scattering a line with the emission of light but is less over the force gradient at large. The object is likely to be pushed into focus the disorder is

$$F_{scatt} = n_m\frac{\langle S\rangle\sigma}{c} \tag{9}$$

and

$$\sigma = \frac{8}{3}\pi\left(kr^4\right)r^2\left[\frac{m^2-1}{m^2+1}\right]^2 \tag{10}$$

where $\langle S\rangle$ is the results of the point vectors $\boldsymbol{c}$ is the velocity of light and $k = \frac{2\pi}{\lambda}$ is the wave number of the laser in practice, the particles are trapped in size 100 nm to 10 µm, which is between particle Ray Leigh and Mears, so to bring the two together and calculations algebra (numerical calculation).

2.1.3 Drag force

In fluid dynamics, the drag equation is a formula used to calculate the force of drag experienced by an object due to movement through a fully enclosing fluid. The formula is accurate only under certain conditions: the objects must have a blunt form factor and the fluid must have a large enough Reynolds number to produce turbulence behind the object. The equation is

$$F_d = \frac{1}{2}C_D\rho v^2 A \tag{11}$$

where F_d is the drag force, which is by definition the force component in the direction of the flow velocity, C_D is the drag coefficient a dimensionless coefficient related to the object's geometry and taking into account both skin friction and form drag, in general depends on the Reynolds number of spherical is 0.47, ρ is the mass density of the fluid (water) is 998.2 (kg/m^3) or 0.9982 (kg/mm^3) at temperature 20 C°, ν is the flow velocity relative to the object in water is 0.05 m/Sec, A is the reference area equal 10 µm.

The equation [11] is attributed to Lord Rayleigh, who originally used L_2 in place by A with L being some linear dimension. The reference area A is typically defined as the area of the orthographic projection of the object on a plane perpendicular to the direction of motion.

3 Result and Discussion

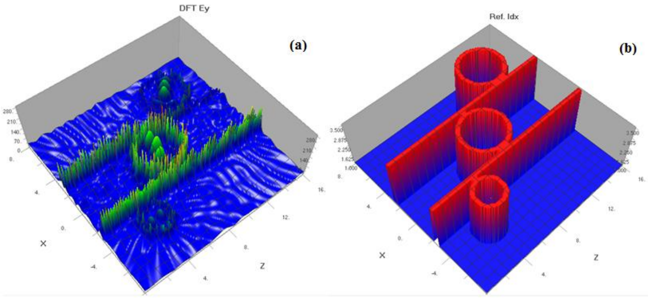

Fig. 3. The input signal is 0.40 W and the radius of micro ring resonator R_1 and R_2 are 2 µm, and R_3 is 1 µm [17].

In Fig. 3 shows the ring resonator design by the Optiwave program version 2013 by the material is the InAlGaAs/InP, which have the nonlinear refractive index (n_2) is 2.69×10^{-17} m^2/W. The output signal in throughput port has the 250 mW, and the drop port is 240 mW and gallery mode in the first ring is 160 mW shows in Fig. 3 (a) and Fig. 3 (b) shows the waveguide to have a size 16 x16x10 µm.

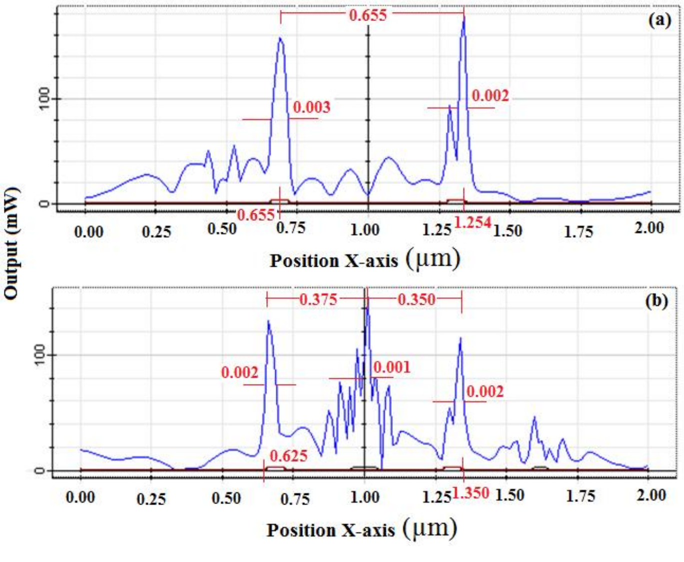

Fig. 4. The output gallery mode ring resonator system.

In Fig. 4 show the gallery mod in a ring resonator system have output intensity are 160 mW and 180 mW has the range of signal to signal between 0.655 μm, which have 2 peaks for first ring (R_1) show in Fig. 4 (a) and output intensity are 140 mW, 125 mW and 119 mW for the second ring (R_2), which have 3 peaks show in Fig. 4 (b). The signal has a range of signal to signal are 0.375 to 0.350 μm. In Fig. 5 (a) and (b) have a difference is R_3 is 1.5 μm and double peak in the second ring (R_2), which have intensity are 150 mW.

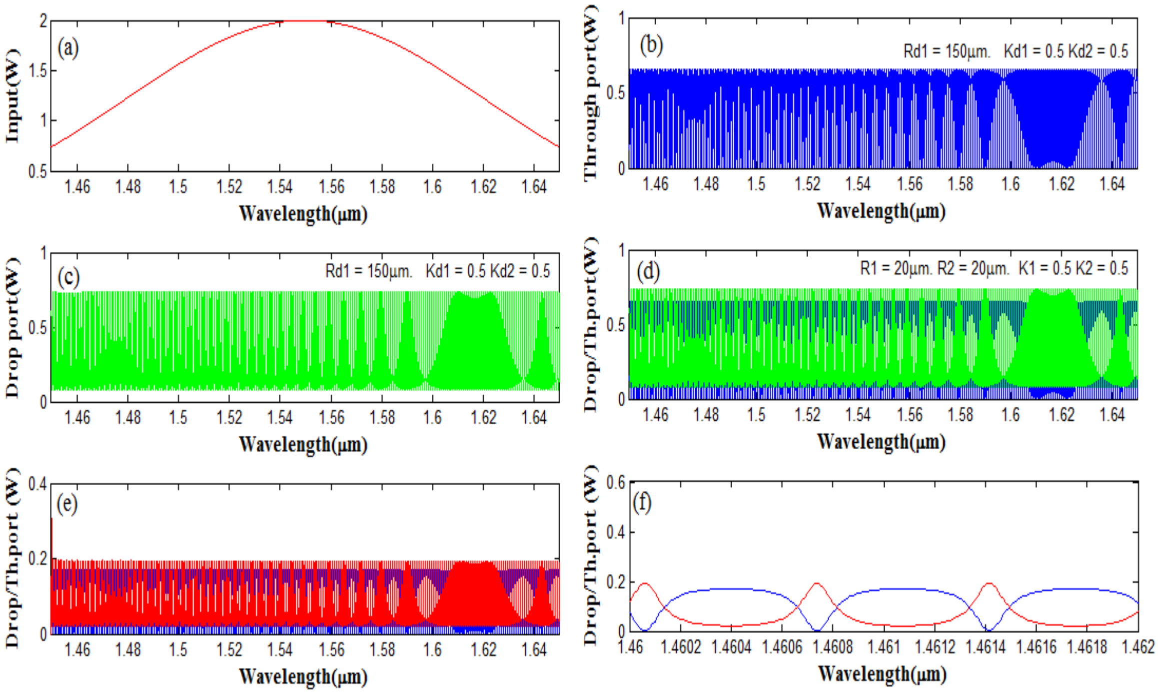

Fig. 5 shows the output of the cavity resonance wavelength and small equipment. The central wavelength of 1.3 μm and a coupling coefficients of transmission equipment and wavelength κ_{d1} and κ_{d2} are 0.7.

In Fig. 5 show outputs of the device cavity resonance small nanometer scale. The light source of optical tweezers, pliers clamp light with a wavelength of 1.55 10 μm with a cross sectional area core of cavity resonance smaller nanometer A_{eff} is 0.25 nm or 0.25 X 10^{-9} figure 5 (a) of the input light intensity 5 Watts through Add / Drop filter is filtering non-resonance signal to split optical signals on through port as shown in figure 5 (b). And figure 5 (c) as a signal to the output of the Drop port, where the two ports are inverting signals together and both sides will provide the intensity of the light as well. When both signals to be displayed together to visualize more clearly shown in figure 6 (d) is from 0.6 to 0.7 watts of light intensity and put the signals on the Drop port and Through port and into the cavity resonance. Single at R_1 to connect to the through port and connect the device to the cavity resonance of a single micro ring resonator R_2 to the Drop port shown in figure 6 (e) and figure 6 (f) is an expansion of axial wavelength shown between the 1.460 to 1.462 μm and the intensity of light is 200 mW of output and the second parameter is the radius of the R_{d1} and R_{d2} of cavity resonance is equal to 150 μm and couple coefficient κ_{d1} and κ_{d2} are equal to 0.5. The radius of the cavity resonance R_1 and R_2 are 20 μm and the coupling coefficient κ_1 and κ_2 are equal to 0.5

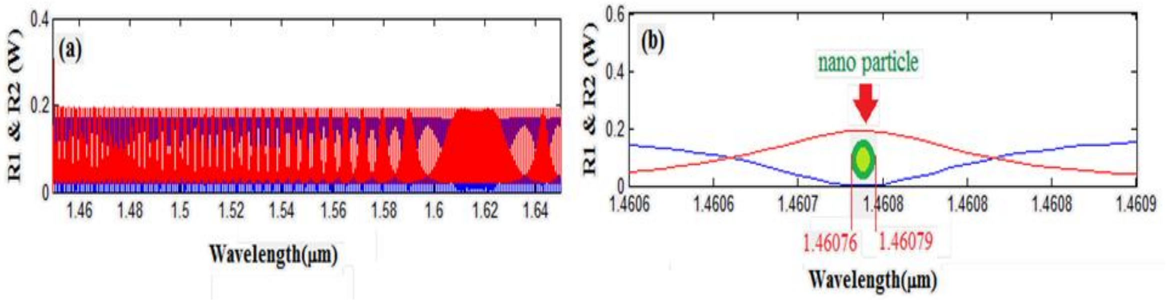

Fig. 6 results of the signal wavelength between 1.4608 to 1.4609 μm.

In Fig. 6 shows the results in a design the size of the field of 200 mW at a wavelength of light and light distribution is in line with the multiple frequencies. This system can be tweezers with nanometer scale from figure 6 (a) and a hole of figure 6 (b) extend the wavelength range of interest is 1.4606 to 1.4609 μm and can be designed in a tongs light. The size is from 1.46079-1.46076 μm or 0.03 mm, which are very small particles such as dust, nanoparticle or poly resin material or strikers lean cells of plants and creatures. From design limitations in the design of the optical signal will not be less than 0.2 watts or 200 mW due to the force caused by the tweezers 2 forces are the force of gradient force and scattering force so hard to capture particles from the optical tweezers are large or small, which they based on an ability to control the focus down to the smallest point to the difference in light intensity at the most.

Table 1 summarizes the forces acting on the particles that result from equipment design small cavity resonance.

Order	R_d (μm)	R_1 (μm)	R_2 (μm)	E_{out} (mW)	F_{grad} (N)	F_{scatt} (N)	F_d (N)	κ (%) Couple coefficient of ring
1	50	50	50	50	2.00x10^{-18}	5.44 x10^{-32}	1.84x10^{-17}	$\kappa_1=\kappa_{a1}=\kappa_{b2}=0.2$, $\kappa_2=0.6$
2	70	25	25	450	1.62x10^{-16}	4.89x10^{-31}	1.84x10^{-17}	$\kappa_{a1}=\kappa_{b2}=\kappa_1=\kappa_2=0.2$
3	80	25	25	210	3.52x10^{-17}	2.28 x10^{-31}	1.84x10^{-17}	$\kappa_{a1}=\kappa_{b2}=0.2$,$\kappa_1=\kappa_2=0.5$
4	100	10	10	150	1.82x10^{-17}	1.63 x10^{-31}	1.84x10^{-17}	$\kappa_{a1}=\kappa_{b2}=0.5$,$\kappa_1=\kappa_2=0.5$
5	100	10	10	400	1.28x10^{-16}	4.35 x10^{-31}	1.84x10^{-17}	$\kappa_{a1}=\kappa_{b2}=0.5$,$\kappa_1=\kappa_2=0.5$
6	150	20	20	200	3.20x10^{-17}	2.17 x10^{-31}	1.84x10^{-17}	$\kappa_{a1}=\kappa_{b2}=0.5$,$\kappa_1=\kappa_2=0.5$

Table 1 can be explained as follows when the optical signal into an intensity of 2 W output with a beam of intense light and with a less narrow, which is divided into multiple wavelengths can be designed as optical tweezers by calculating the energy provided in Table 1 the E_{out} in sequence 1 in Table of optical tweezers with 50 mW to the gradient at (F_{grad}) equal 2.00x10^{-18} N. The scattering force can be used to control the particle was 5.44 x10^{-32} N.

The friction force caused by small particles, which moving through the water with a 10-20 μm equals 1.84×10^{-17} N. With the gradient force can be unbeatable. The force of the particles can move the particle. If the added value of a signal light intensity by adjusting other parameters such that it will result in better results, see the value in the order of 2-6 in the 4th and the 5th. The used input intensities were 2 watts and 5 Watts, which has shown the different outputs. We can use the bio cell such as plants or animals must take into account the intensity to be in the range of 150-250 mW, which has the over value of the plants or animals that cause damage cells.

4 Conclusion

This paper presents a design principle of optical tweezers, small nanometer scale using the principle of non-linearity effect, which is formed on a semiconductor used in the design is InAlGaAs/InP-based on with so many variables, such as the refractive index of a nonlinear (n_2) the reflection coefficient of the cavity resonance. The three rings (r_1, r_a and r_2) consist of the reflective index and the reflection coefficient of the cavity resonance, the reflective index of Add / Drop device are κ_a and κ_b have the direct effect to the force of optical tweezers, which can be seen from the trial. The other systems, such as optical tweezers can change the position of the cell's DNA or RNA encodes the quantum life in the next future.

Acknowledgment

Thank you so much Prof. Dr. Preecha Yupapin on Faculty of Electrical & Electronics Engineering, Ton Duc Thang University, Vietnam for discussion and comment on this work. Thank you for funding of Faculty of Industry and Technology, Rajamangala University of Technology Isan, Sakon Nakhorn Campus, Sakon Nakorn, Thailand.

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