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Characteristics of Whispering Gallery Mode of Light within Microring Resonator System

Nithiroth Pornsuwancharoen[1, a] and Phichai Youplao[1, b]

[1]Electrical Engineering Department, Faculty of Industry and Technology, Rajamangala University of Technology Isan Sakon Nakhon Campus, 199 Village No. 3, Phungkon, Sakon Nakhon, Thailand

[a]<jeewuttinun@gmail.com> [b]<phichai3112@yahoo.com>

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Abstract. A whispering gallery mode (WGM) of light generated by the light within a nonlinear microring resonator system is studied. Such a system is a microring structure and made of an InGaAsP/InP material. The simulation result shows that the proposed ring resonator system can be potentially fabricated within the micro-scale range and used for a micro light source, which can be employed as the passive laser source. The tunability of the source and beam size can be managed by the two side rings, which is the nonlinear microring resonator. Moreover, the output free spectral range are also increaded and suitable for the high capacity information requirement.

1. Introduction

Microring resonator has shown the very useful device that has been investigated and used in many areas of researchers and applications [1]. The resonator structure can be used for various applications, such as optical filters, lasers, modulators, spectrum analyzers, have lockers, interleave filters, and optical add-drop multiplexers and applied to the whispering-gallery mode microdisk lasers [more refeerences]. The application in microscale and a nonlinear whispering gallery modes are also found [2, 3], which is the integrating whispering gallery mode refractive index sensing with the capillary electrophoresis separations using the phase sensitive detection [4]. The WGM can be applied for the work such as ultrasensitive chemical sensors based on whispering gallery modes in a microsphere coated with zeolite [5], the ultra-low dissipation optomechanical resonators on a chip [6], the optomechanical transduction of an integrated silicon cantilever probe using a microdisk resonator[7], the optical liquid ring resonator sensor [8], the heterogeneous integration of InGaAsP microdisk laser on a silicon platform using optofluidic assembly [9]. This paper is composed of four main Sections. Section II describes the basic concepts of proposed WGM of microring resonator. Section III presents simulation result and Section IV gives conclusions.

2. Theory and Background

Whispering-gallery waves were first explained for the case of St Paul's Cathedral circa 1878 by Lord Rayleigh, who revised a previous misconception [9] that whispers could be heard across the dome but not at any intermediate position. He explained the phenomenon of travelling whispers with a series of secularly reflected sound rays making up chords of the circular gallery.

The ring resonator can be creating the whispering gallery mode (WGM) by light scattering of cavity micro resonator light coupling. The WGM micro cavities are intrinsically high quality resonators and the key point for applications is the efficiency of light coupling from the outside. Fig. 1 shows a schematic view of a spherical WGM resonator and its associated access line which represents any coupling system as will be discussed later.

$$S_{out}(t) = -S_{in}(t) + \sqrt{\frac{2}{\tau_e}}u(t) \tag{1}$$

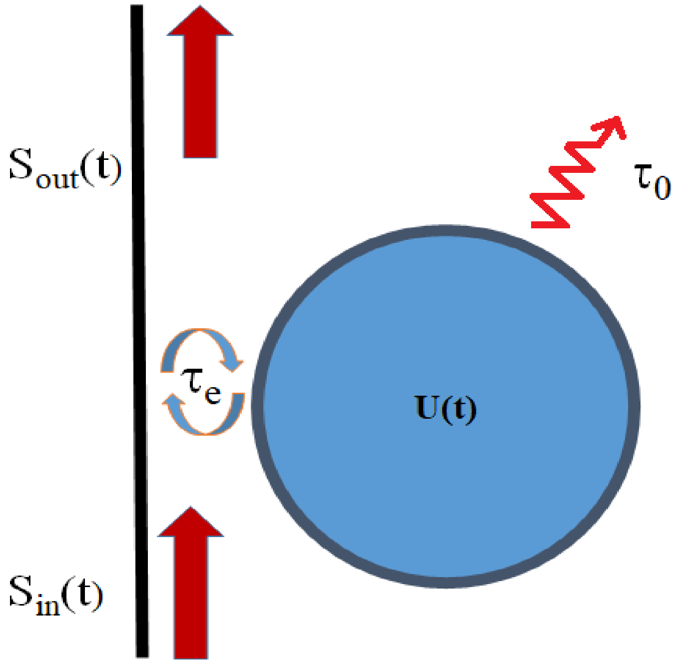


Fig. 1. Sketch of a WGM resonator coupled to it access line.

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 [10, 11]. The input and output is ($E_{out}(t)$ and $E_{in}(t)$) as shown in equation (2).

$$E_{in}(t) = E_{out}\, e^{j\emptyset(t)} \tag{2}$$

where E_{in} is the input electric field, E_{out} is the output electric field and $\emptyset$ is the linear phase shift and non-linear phase shift of optical waveguide loop in the ring is:

$$\emptyset = \emptyset_L + \emptyset_{NL} \tag{3}$$

$$\emptyset_{NL} = \frac{2\pi n_2 L}{\lambda_0 A_{eff}} |E_1(t)|^2 \tag{4}$$

λ_0 is the wavelength of the light traveling in a vacuum and A_{eff} is cross section area of core in the waveguide by equation (3) and equation (4) and a written form of the equation iteration is time-dependent.

The device structure is formed by the multiple vertical Panda ring structure, from which the WGM of light is generated and form the light beam using the commercial laser as an input light source. The WGM theory concern is given, the simulation results using the suitable ring device parameters related to the fabrication technology are also given. The mathematical model is used to explain the pattern formation of WGM for a single micro ring resonator in the propagation direction (Z), which is shown in Fig. 2, where the electric field output (E_{WGM}) is given by [12].

$$E_{WGM}(\rho,\varphi) = \frac{4\pi coscch\left(k_{0n}\frac{\pi a}{2}\right)}{a^2 J_1^2(k_{0n}a)}\left[\frac{x_1\sqrt{\kappa_1}}{1-2x_1y_1e^{-\frac{\alpha}{2}L}cos(k_nL)+e^{-\alpha L}x_1^2y_1^2}\right]\times\frac{wA_0\sqrt{k_0n_0}}{B^{\frac{1}{4}}}J_0(k_{0n}\rho)\int_0^a J_0(k_{0n}\rho)\left[\rho-\left(\frac{A}{2(B+C\rho^2)}+\frac{C}{4B}\right)\rho^3\right]d\rho \quad (5)$$

Where $A = k_{mn}^2 k_0^2 w^2 n_0^2 \rho^2$, $B = w^4 k_0^2 n_0^2$, $C = \varphi^2$, wA_0 is constant of input signal, a= radius of center ring, $x_1 = \sqrt{1-\gamma_1}$, $y_1 = \sqrt{1-\kappa_1}$, n_0= linear refractive index, $k_0 = \frac{2\pi}{\lambda_0} n_{eff}$, n_{eff} is effective index, λ_0 is input wavelength, ρ and φ are the cylindrical coordinate radius and phase respectively, κ_1, γ_1 is the coupling constant and attenuation coefficient between linear waveguide and center of Panda ring resonator, k_{0n} is the wave number in the Bessel's function (J) by n is mode of electromagnetic field, L is the center ring circumference. Each layer dramatically increased the propellant velocities along the length of the Panda ring resonator devices, which required less power of source in system than the conventional system.

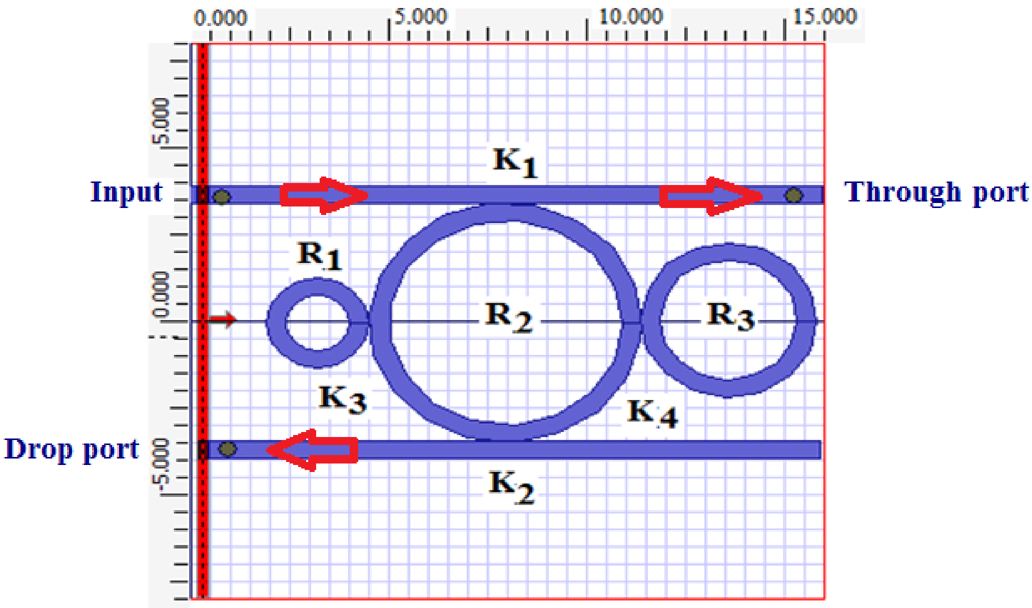
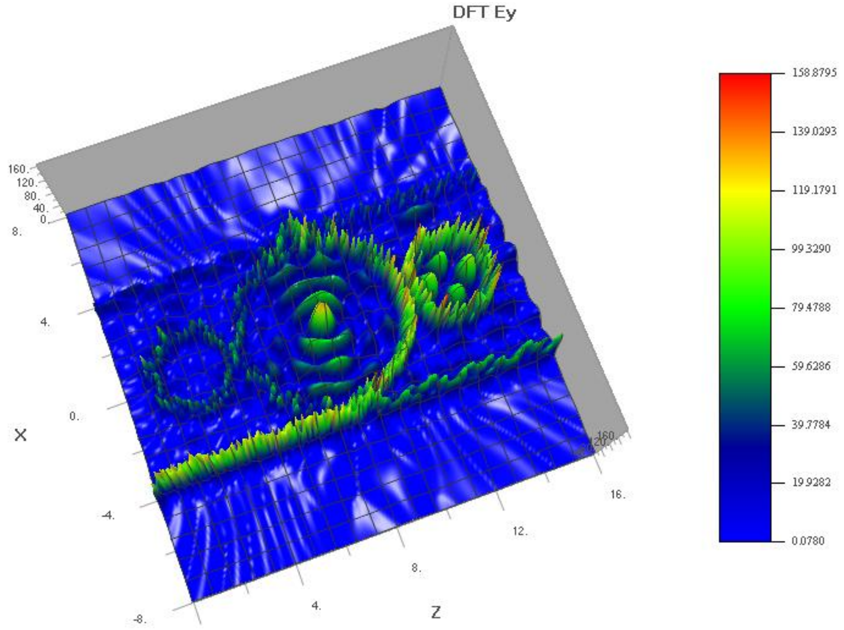


Fig. 2. The layout of the ring resonator system design by Optiwave program.

3. Results

Figure 2 is the design of micro-optical whispering gallery mode in the waveguide system, which consist of 3 rings R_1-R_3 have various ring parameters as the ring radius between 1.0 µm-4.0 µm. The coupling coefficients ($\kappa_1 - \kappa_4$) are 0.2-0.5. The material of the ring is InGaAsP/InP. Figure 3 shows the simulation result of the ring system with R_1-R_3 are 1.0 µm, 4.0 µm, and 1.5 µm, respectively, and the couple coefficients are 0.5. The obtained output power of the WGM is 158 mW, which appears at the second ring (R_2) and each the WGM output power of 99.00 mW in the third ring (R_3). This system can be tuned to control the output WGM by varying the radius of ring R_1-R_3 as shown in Fig 3.

Figure 4 shows the output signals, the double peak of intensity along the X-axis with 8 µm of free spectrum range (FSR). The peak powers are 125 mW and 225 mW, which can be used to the optical motor with optical force [13]. Figure 4(b) shows the multi-peaks signals along the Z-axis with 160 mW to 320 mW, and the results show that it can be used as multi-channel for optical communication.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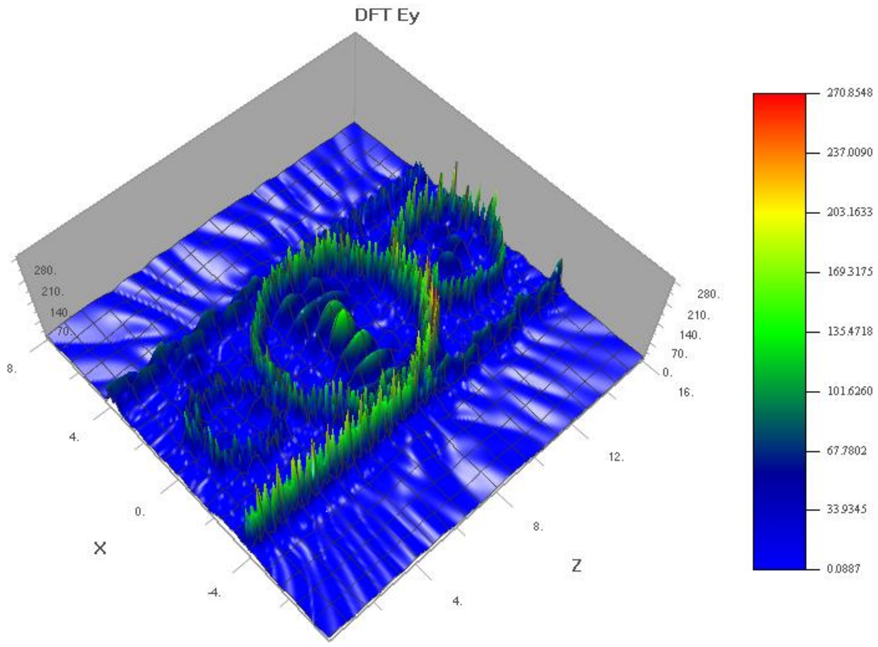
(a)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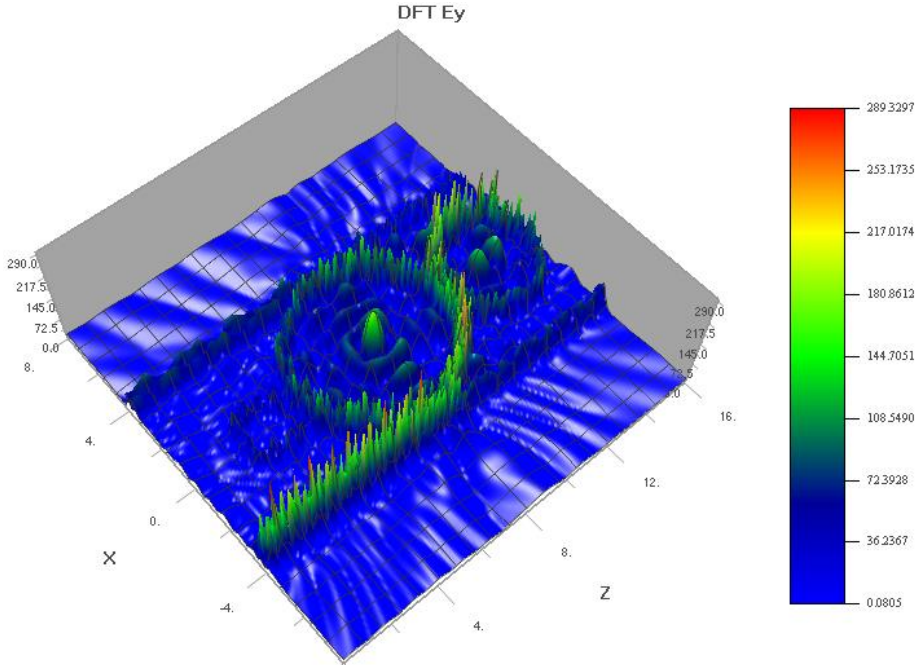
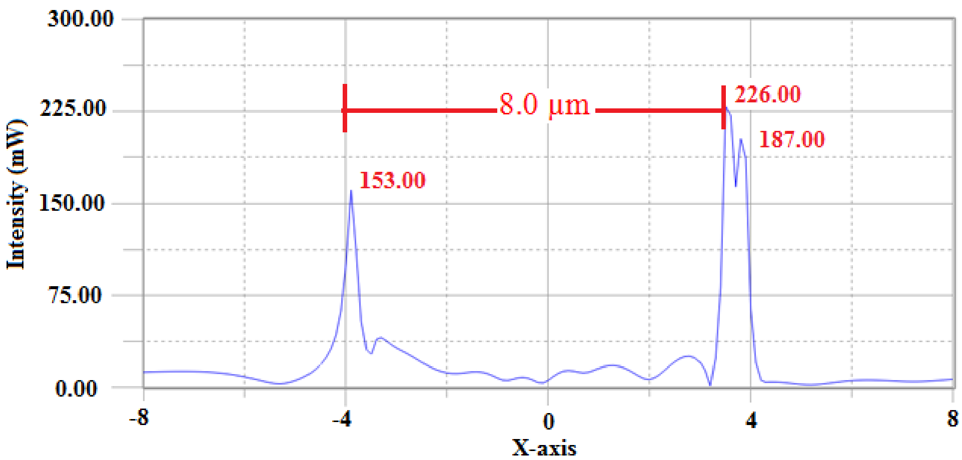
(b)

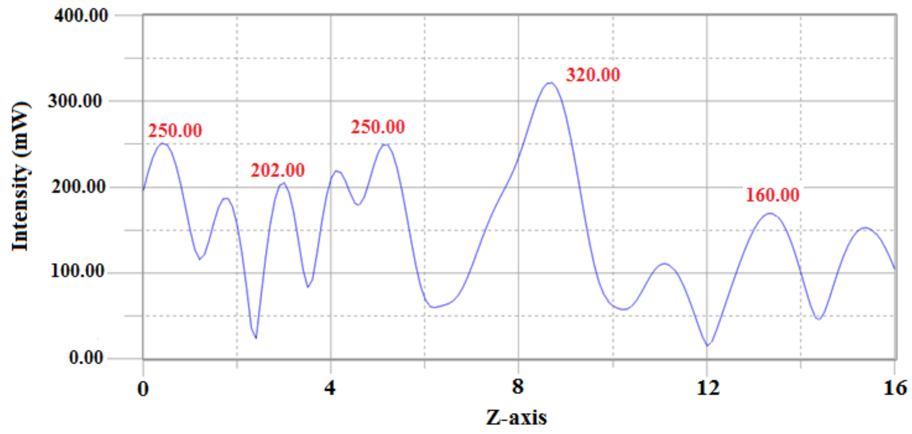


(c)

Fig. 3. The results for varying the radius of the micro ring system, (a) R_1=1.0 µm, R_2=4.0 µm, R_3 =1.2 µm, κ_1 and κ_2 = 0.2, κ_3 and κ_4 4 = 0.5 (b) R1=1.0 µm, R2=4.0 µm, R_3 =1.3 µm, κ_1 and κ_2 = 0.2, κ_3 and κ_4 = 0.5, (b) R_1=1.0 µm, R_2=4.0 µm, R_3 =1.4 µm, κ_1 and κ_2 = 0.2, κ_3 and κ_4 = 0.5.



(a)



(b)

Fig. 4. The results in X-axis and Z-axis, where (a) double peaks for optic communication, (b) multi-peaks for multi-channels.

4. Conclusion

Based on this research, we have investigated of nonlinear microring resonator system and the appearance of WGMs occurring in the middle of different rings. Depending on the parameters in the system. From mathematical equations to simulation results appear in the computer program Optiwave and processed by the Matlab program. The results obtained have shown that the state of the field of light and the field of energy that occurs. We may be able to apply the simulation results to a wide range of applications involving high-speed optical communication. A small capacitor design application with optical tweezers and nano-scale optical sensor and in the future may be linked to artificial neural networks for communication between cells.

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