Available online at www.iseec2012.com

I-SEEC 2012

Proceeding - Science and Engineering (2013) 465–470

Proceeding
Science and Engineering

www.iseec2012.com

Science and Engineering Symposium
4th International Science, Social Science, Engineering and Energy Conference 2012

Photonic Waveguide Bragg Grating Ring Resonator for Bio-sensor Applications

K. Srinuanjan[a,*], W. Tipaphong[a], P.P. Yupapin[a]

[a]Advance Research Center for Photonics, Faculty of Science,
King Mongkut's Institute of Technology Ladkrabang, Bangkok, 10520, Thailand

Abstract

This paper proposed the mathematical model of Bragg grating ring resonator. A quarter secession of ring resonator is alternated by the periodic slabs waveguide with varied refractive index called a planar Bragg grating. The model is analyzed by using the principle of multilayer transfer matrix for photonic crystal and then applied to the micro-ring resonator. The proposed model is simulated for all of the parameters, regarding the bio-sensor applications. The simulation results were shown and discussed. Furthermore, Bragg grating ring resonator can be a good condition to become a Nano bio-sensor in the near future.

Selection and/or peer-review under responsibility of Faculty of Science and Technology, Kasem Bundit University, Bangkok.

Keywords: Planar Bragg grating, Micro-ring resonator, Bio-sensor

1. Introduction

An application of planar Bragg grating has been used as an optical devices world wide. One of a planar Bragg grating consists of a periodic modulation of the refractive index such as an optical fiber grating. The dominate property of a planar Bragg grating is the localization some specific wavelength which we want to investigat. It functions like a spectral filter that reflected light over a limit range of wavelength and transmitted the others along its path. If the refractive index of the grating is varied, the transition wavelength ranges also changed; therefore, we can apply the phenomena to be the optical sensor [1, 2, 3] base on the varied in refractive index. In the past few years, The study of the grating inside micro ring resonator has been demonstrated by L. Goddard, et.,al. [4, 5], with the used of semi-analytical model base on an analysis of the distributed Bragg reflector in a micro ring resonator.

In this paper, we presented the mathematical model of Bragg grating in ring resonator by using a directional analysis base on multilayer transfer matrix modeling. The analytical model is shown and demonstrated. The refractive index of the planar brag grating is varied, then the relationship between the refractive index and the

* Corresponding author.*E-mail address:* kskeeray@kmitl.ac.th

wavelength spacing is presented and discussed. The simulation results show that the model could be applied to be the optical Bio-sensor base on refractive index change. [6, 7, 8]

2. Mathematical Model

The mathematical model of Bragg grating ring resonator consist of two parts one is a general ring resonator, and the second part is a periodic layers planar Bragg grating located at a quarter part of the ring resonator waveguide which functions as a sensing region. For the mathematical modeling, we analyze each structure separately and then recombined it together for the whole system, and the schematical diagram is show in figure 1

For the first part, the ring resonator, we apply the optical field (E_{in}) of Gaussian pulse into the model. The operating wavelength (λ) range is set between 0.500 – 3.000 µm, and the center wavelength (λ_0) is 1.550 µm, which is defined by

$$E_{in} = A_0 e^{-\frac{1}{2}(\lambda-\lambda_0)^2/T_0^2} \tag{1}$$

where A_0 is amplitude of the optical field that is applied into the ring, and T_0 is the full wide at half max of the optical field. The optical field changes with distance, which is defined by

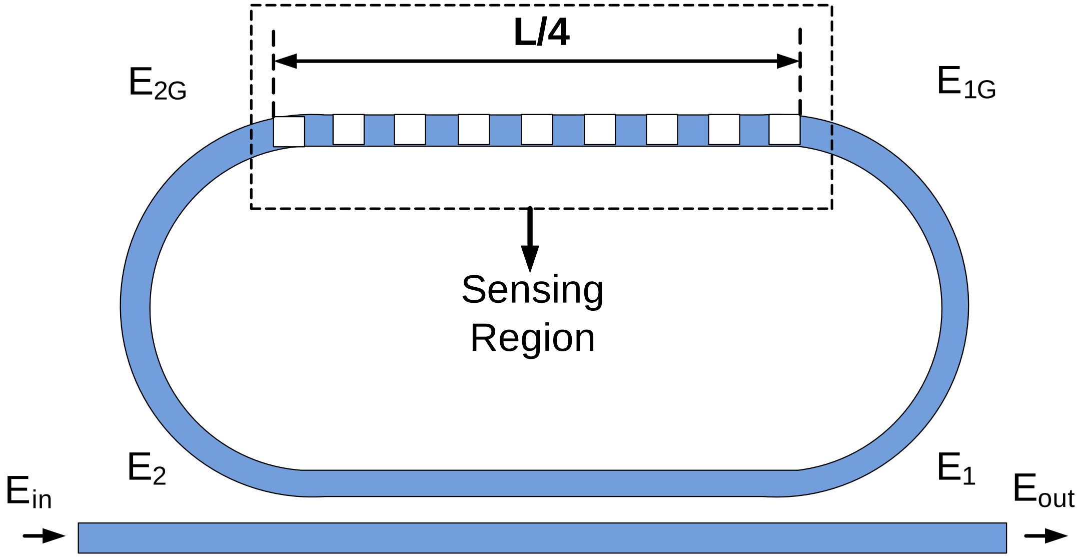


Fig. 1. The schematic diagram of Bragg grating ring resonator

$$\begin{bmatrix} E_{out} \\ E_1 \end{bmatrix} = \begin{bmatrix} \sqrt{1-\gamma}\sqrt{1-\kappa} & i\sqrt{1-\gamma}\sqrt{\kappa} \\ i\sqrt{1-\gamma}\sqrt{\kappa} & \sqrt{1-\gamma}\sqrt{1-\kappa} \end{bmatrix} \begin{bmatrix} E_{in} \\ E_2 \end{bmatrix} \tag{2}$$

$$E_{1G} = E_1 e^{-\alpha\frac{3L}{8} - jk_n\frac{3L}{8}} \tag{3}$$

$$E_{2G} = M_T E_{1G} \tag{4}$$

$$E_2 = E_{2G} e^{-\alpha\frac{3L}{8} - jk_n\frac{3L}{8}} \tag{5}$$

where E_1, the optical field, is coupler into the ring; γ is the fractional coupler intensity loss; κ is the coupling coefficient, and E_{1G} is the field before entering to Bragg grating; $L = 2\pi R$ is the waveguide length, α is an attenuation, and $k_n = 2\pi/\lambda$ is the wave propagation number in vacuum. After that, the optical field propagates into the Bragg grating; the optical field is calculated by the multilayer transfer matrix, where E_{2G} is the optical field leaves of the Bragg grating. Then the optical field is in the form of $M_T E_{1G}$,Where M_T which is the transfer matrix of multilayer, and E_{out} is the optical field leaves of the ring.

In the second part, the periodic high-low layers of refractive index functions as the planar Bragg grating, the multilayer transfer matrix is used for mathematical analysis. The relation of the optical field at boundary of layer in Bragg grating could be written in the form of matrix equation. The transfer function of the planar Bragg grating is the combination of high-low layer (n_L and n_H) refractive index matrix representation, which is defined by

$$M_T = M_H \cdot M_L \cdot M_H \cdot M_L \cdot \ldots \cdot M_H \tag{6}$$

where M_T is transfer function matrix; M_H and M_L are the transfer high(n_H) and low(n_L) refractive index matrix which is defined by

$$M_H = \begin{pmatrix} \cos\delta_H & \dfrac{i\sin\delta_H}{\gamma_H} \\ i\gamma_H \sin\delta_H & \cos\delta_H \end{pmatrix} \tag{7}$$

$$M_L = \begin{pmatrix} \cos\delta_L & \dfrac{i\sin\delta_L}{\gamma_L} \\ i\gamma_L \sin\delta_L & \cos\delta_L \end{pmatrix} \tag{8}$$

where $\delta_H = \frac{2\pi}{\lambda_0} n_H t$ and $\delta_L = \frac{2\pi}{\lambda_0} n_L t$, t is the thickness of periodic layer in Bragg grating. $\gamma_H = n_H \sqrt{\varepsilon_0 \mu_0}$ and $\gamma_L = n_L \sqrt{\varepsilon_0 \mu_0}$, ε_0 and μ_0 is permittivity and permeability in free space.

The normalized output of the light field is the ratio between the output and input field which is defined by

$$\frac{E_{out}}{E_{in}} = \frac{\sqrt{(1-\gamma)(1-\kappa)} - (1-\gamma) M_T Z_1^2}{1 - \sqrt{(1-\gamma)(1-\kappa)} M_T Z_1^2} \tag{9}$$

$$\left|\frac{E_{out}}{E_{in}}\right|^2 = \left|\frac{\sqrt{(1-\gamma)(1-\kappa)} - (1-\gamma) M_T Z_1^2}{1 - \sqrt{(1-\gamma)(1-\kappa)} M_T Z_1^2}\right|^2 \tag{10}$$

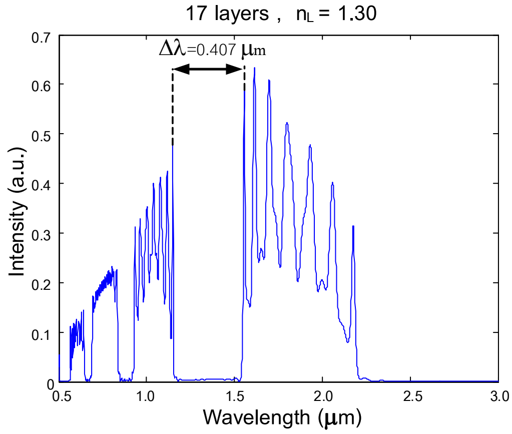
where E_{out} and E_{in} is the optical field leave and enter to the ring and $Z_1 = e^{-\alpha\frac{3L}{8} - jk_n\frac{3L}{8}}$.

For the mathematical model simulation, The value of each parameters simulation is used as follows: the refractive index of ring resonator $n_0 = 3.34$. (The material is InGaAsP/InP) which the length of the ring L= 3.10

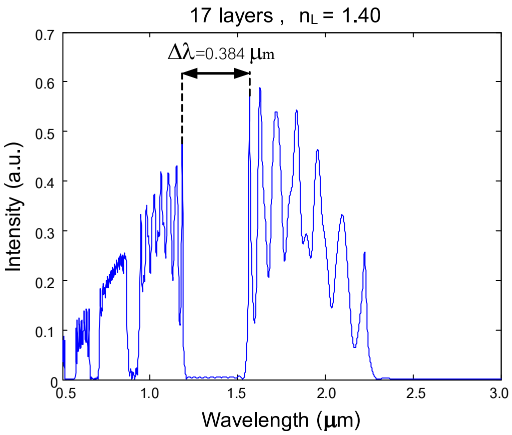
μm. L_B is the length of Bragg grating which is located at a quarter part of ring resonator, $L_B = L/4$. The Bragg grating consists of the periodic high-low refractive index, 17 multilayers. High refractive index (n_H) is 3.34, and the low refractive index (n_L) is varied, from 1.20 – 1.80; i.e., optical Bio-sensor region. The wavelength of Bragg grating reflection is defined by the relationship, $\lambda_B = 2\Lambda n_{eff}$ where n_{eff} provides the effective index, and Λ is the period of the grating. The simulation result is plotted and shown in Figure 2.

3. Simulation and discussion

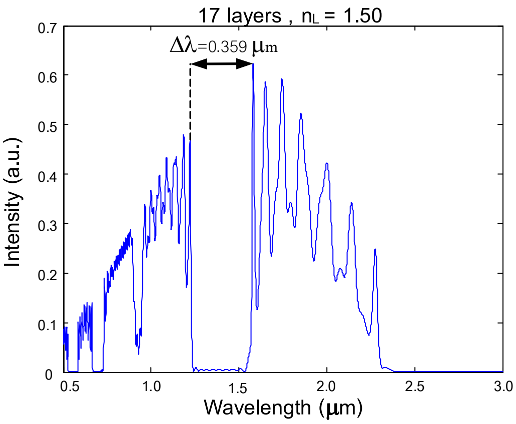
The simulation results of the mathematical model with periodic refractive index for 17 layers of Bragg grating is shown in Figure 2. The high refractive index of n_H is set as 3.34. The relationship between Intensity and Wavelength is shown and indicates that (a) when the refractive index of n_L is 1.30, the wavelength spacing is 0.407 μm. (b) when the refractive index of n_L is 1.40, the wavelength spacing is 0.384 μm. (c) when the refractive index of n_L is 1.50, the wavelength spacing is 0.359 μm. (d) when the refractive index of n_L is 1.60, the wavelength spacing is 0.335 μm. (e) when the refractive index of n_L is 1.70, the wavelength spacing is 0.312 μm., and (f) when the refractive index of n_L is 1.80, the wavelength spacing is 0.292 μm.



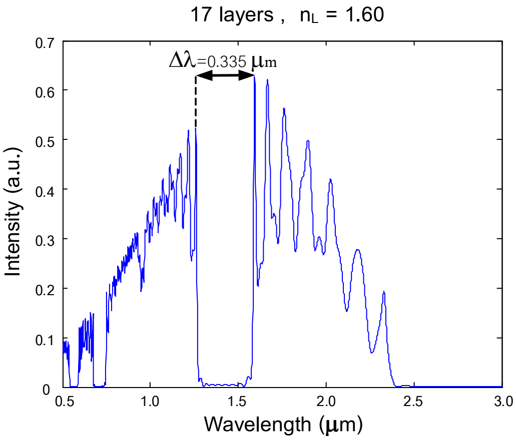
(a)



(b)



(c)



(d)

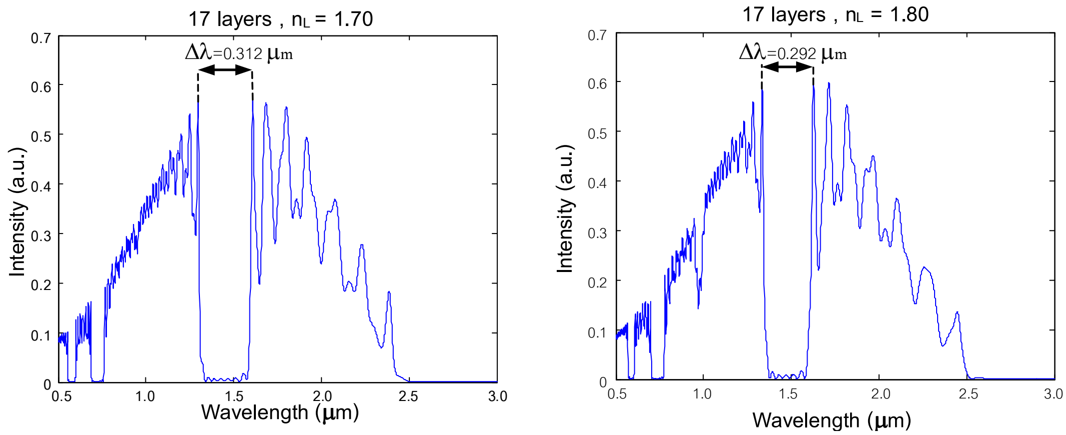


Fig. 2. For the relationship between Intensity and wavelength, the refractive index is varied as followes: (a) the refractive index n_L is 1.30, the wavelength spacing is 0.407 μm. (b) the refractive index n_L is 1.40, the wavelength spacing is 0.384 μm. (c) the refractive index n_L is 1.50, the wavelength spacing is 0.359 μm. (d) the refractive index n_L is 1.60, the wavelength spacing is 0.335 μm. (e) the refractive index n_L is 1.70, the wavelength spacing is 0.312 μm. ,and (f) the refractive index n_L is 1.80, the wavelength spacing is 0.292 μm

Figure3. Shows the relationship between the refractive index and the wavelength spacing. The simulation results from Figure 2 presented the linear relationship between Intensity and Wavelength. When the low refractive index of n_L is increased, the wavelength spacing is then decreased.

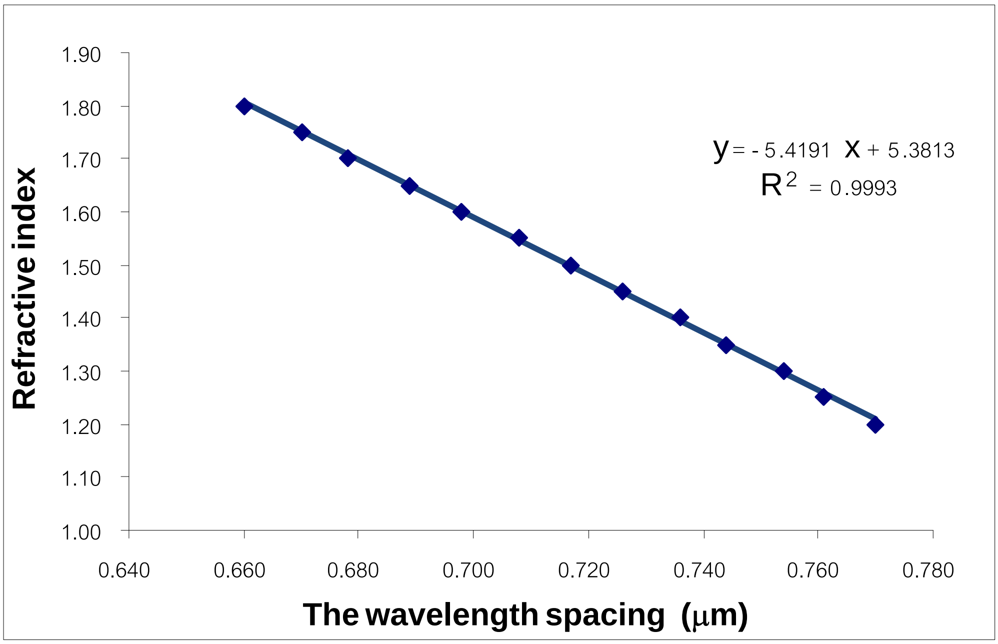


Fig. 3. The relationship between the refractive index and the wavelength spacing

4. Conclusion

In this paper, we proposed the model of Bragg grating in ring resonator and its application. The mathematical model is then analyzed. The simulation results show that the relationship between the refractive index and the wavelength spacing for each parameter varies in low refractive index of periodic layers , has the linearity relationship, the least square $R^2 = 0.9993$ approaching unit. That means it is a good sensing performance. This model can be an application of the optical Bio-sensor device in the near future.

References

[1] Sunita Ugale, Dr. V. Mishra. Fiber Bragg Grating Modeling, Characterization and Optimization with different index profiles. International Journal of Engineering Science and Technology; Vol 2(9), 2010: 4463-4468.
[2] Stephen J. Mihailov. Fiber Bragg Grating Sensors for Harsh Enviroments. Sensors 2012; 12: 1898-1918
[3] Ho Sze Phing, Jalil Ali, Rosly Abdul Rahman, Bashir Ahmed Thir. Fiber Bragg grating modeling, simulation and characterstics with different grating lenths. Journal of Fundamental Sciences 3; 2007: 167-175.
[4] Young MoKang, AmirArbabi, Lynford L. Goddard. Engineering the spectral reflectance of Microring resonators with integrated reflective elements. Optics Express; Vol. 18, No 16, 2 August 2010: 16813-16825.
[5] Young MoKang, AmirArbabi, Lynford L. Goddard. A microring resonator with an integrated Bragg grating: a compact replacement for a sampled grating distributed Bragg reflector. Opt Quant Electron; 2009: 689-697.
[6] Agostino Iadicicco, Stefania Campopiano, Antonello Cutolo, Michele Giordano, Andrea Cusano. Refractive Index Sensor Based on Microstructured Fiber Bragg Grating. IEEE Photonics Technology Letters; Vol 17, No. 6, June 2005: 1250-1252.
[7] Maiko Girschikofsky, Manuel Rosenberger, Stefan Belle, Malte Brutschy, Siegfried R. Waldvogel, Ralf Hellmann. Highly Sensitive Detection of Naphthalene in Solvent Vapor Using a Functionalized PBG Refractive Index Sensor. Sensors 2012; 12: 2018-2025.
[8] Y L Jin, J Y Chen, L Xu, P N Wang. Refractive index measurement for biomaterial samples by total internal reflection. Phys. Med. Biol; 51, 2006: 371-379.