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Numerical Examination on Transmission Properties of FBG by FDTD Method

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Abstract. *Fiber Bragg grating (FBG) is one of important component in optical system as band reject filter. It could act as a sensor also in engineering area. It is important to examine the design of FBG both in optical systems and in sensor regions. Finite difference time domain (FDTD) method is used to simulate FBG and evaluate the transmission properties. FBG here is simulated as two-dimensional periodic waveguide structures for single mode only. Higher grating refractive index value affect in smaller value of transmission in specific wavelength, and the center wavelength drop is shifted to higher value. Increasing grating period will affect to the output shifting to higher wavelength value with a linear correlation. Longer grating length will reduce the transmission value with linear correlation between them. Chirped FBG (CFBG) show a weaker reflectance, but with wider broadband wavelength reflected. Higher temperature will result in wavelength shift to the higher wavelength value, with a linear correlation between them.*
Keywords: FBG, CFBG, FDTD. frequency filter

1. **Introduction.** Optical fibers are changing the telecommunication systems to the higher speed level. Fiber Bragg grating (FBG) is one of the important part in it. Without FBG, optical amplifier can't work as intended [1]. It could reflect and reject certain wavelength or frequency depends on the parameter design of the FBG [2]. It could be act as wavelength filter and can be used as a dispersion compensator [3, 4]. In other area, FBG could act as a sensor, such as temperature and strain sensor [5], gas sensor [6] or refractive index measurement device [7].
In this paper, to minimize the computer resource required, FBG is simulated as two-dimensional periodic structures for a single mode propagation only. Finite difference time domain (FDTD) method is used to simulate and analyze output characteristic FBG structure [8, 9, 10].

2. **Basic Properties of FBG.** FBG is an optical fiber that the grating was printed on the core region. With those gratings, FBG will reflect some area of wavelength. λ_B is the wavelength reflected by FBG which satisfies Bragg condition shown in Eq. (1) [1].

$$\lambda_B = 2\, n_{eff}\, \Lambda \tag{1}$$

Where n_{eff} is an effective refractive index in the fiber core region, and Λ is a grating period of the FBG.

3. **Numerical Simulation and Result.** With FDTD method, the transmission properties from the FBG are simulated. For simulation parameter, the analytical region is $z = 430\mu m$ times $x = 7\mu m$, the length of grating structure is up to $200\mu m$, the core width is $3\mu m$. The refractive index of the cladding is $n_3 = 1.44$, while core refractive index is $n_2 = 1.46$. The cell sizes are set to be $\Delta x = \Delta z = 100nm$, and the time step size $\Delta t = 2.06475 \times 10^{-16}$s is used.

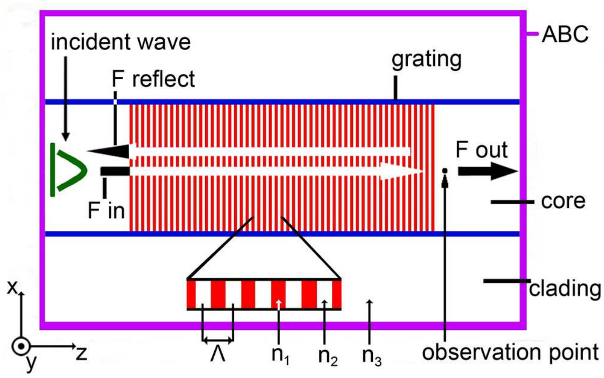

Figure 1. Illustration of FBG simulation area

The Gaussian pulse is applied as the incident wave in the simulations. The value of grating period is set as $\Lambda_0 = 529nm$. Fast Fourier transform (FFT) technique is applied to the data that collected in time domain to get output characteristic in the frequency domain.

3.1. **Grating refractive index value.** The transmission property of FBG for several different values of grating refractive index n_1 is examined. Fig. 2 shows the transmittance characteristic results for various grating refractive indexes $n_1 = 1.46$, $n_1 = 1.462$, $n_1 = 1.464$, $n_1 = 1.466$, $n_1 = 1.468$ and $n_1 = 1.470$. When $n_1 = n_2 = 1.46$, this condition corresponds to no grating structure. Sinusoidal grating refractive index is applied, with the grating period $\Lambda = 529nm$.

By observing Fig. 2, it is shown that if there is no grating ($n_1 = 1.46$), FBG transmit all range of wavelength in this area. For $n_1 = 1.462$, the transmission for some wavelength is dropped. While for $n_1 = 1.464$ and larger value, we can see different transmission amplitude occur and center of transmission wavelength drop also shifted. Comparison between five difference grating refractive indexes shown that higher grating refractive index value affect to smaller value for transmission amplitude, and the center of transmission wavelength drops slightly shifted to higher value.

3.2. **Grating period.** Several FBG structures with different grating period are simulated to see the effect in their transmission characteristic properties. For this simulation, refractive index of the cladding is $n_3 = 1.44$, core refractive index $n_2 = 1.46$, grating refractive index $n_1 = 1.47$, and the sinusoidal type grating refractive index shape applied. Grating period structure ranged from $\Lambda = 525nm$ to $\Lambda = 533nm$ with gap $1nm$ for each simulation.

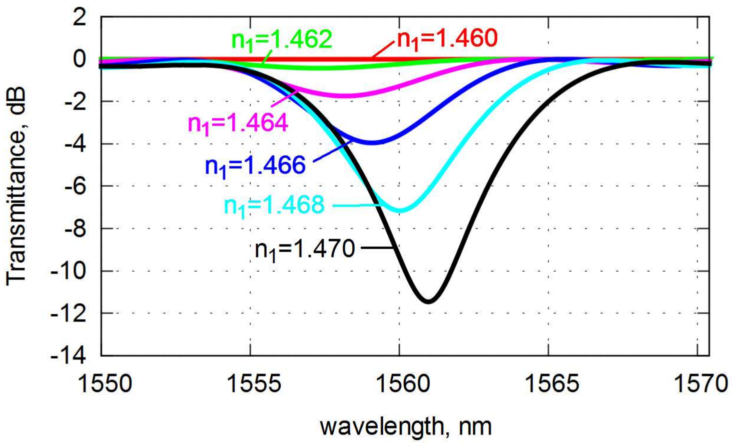

Figure 2. Transmittance for FBG with grating refractive index n_1 changes

Fig. 3 show 5 different grating period results from $527nm$ to $531nm$, while Fig. 4 shows the relation between the center of transmission wavelength drop and all grating period results from $525nm$ to $533nm$. The mark indicates numerical results for every center of transmission wavelength drop and the solid line means the linear polynomial regression. Data list for Fig. 4 are shown in Table 1.

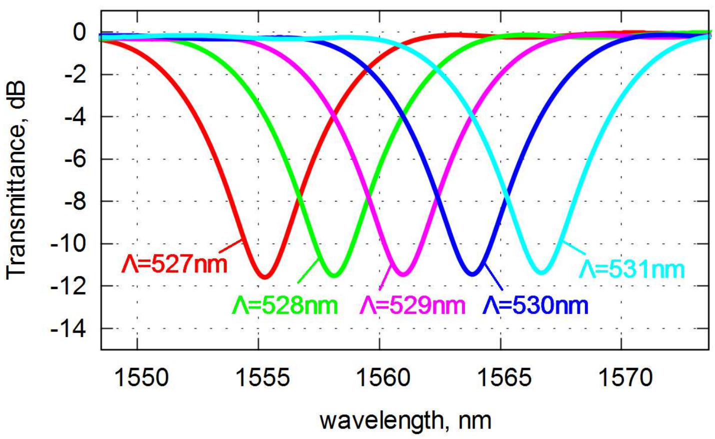

Figure 3. Transmission wavelength drop of FBG with several grating periods Λ

Results show that the grating period and the reflected wavelength have a positive correlation. Higher grating period will correspond to the higher wavelength. From this picture and the table, we can observe that correlation between them is in a linear correlation. This is suits to the Bragg condition.

3.3. **Grating length.** Several FBG with different grating length are simulated. Grating length that applied to the FBG is ranged from $0mm$ (correspond to no grating structure) to $200\mu m$, with the differences of $50\,um$ for each FBG structures simulated. Grating period $\Lambda = 529nm$ and grating refractive index value $n_1 = 1.470$ are used. Fig. 5 show comparison from some results from the simulation in wavelength domain, while Fig. 6 show comparison between the transmittance value and total grating lenght from $50\mu m$ to $200\mu m$ with different of $25\mu m$ between the data. Table 2 show all data that presented in Fig. 6.

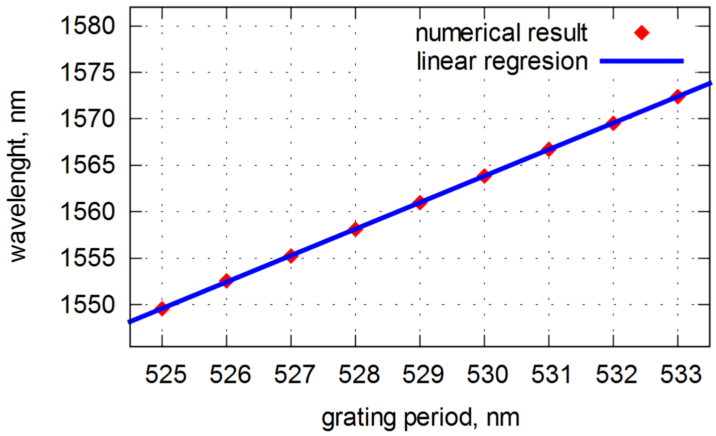

FIGURE 4. Center transmission wavelength drop of FBG with several grating periods Λ

TABLE 1. Center wavelength drop for several grating periods

Grating period (in nm)	Wavelength (in nm)
525	1549.55
526	1552.56
527	1555.27
528	1558.12
529	1560.97
530	1563.83
531	1566.69
532	1569.54
533	1572.40

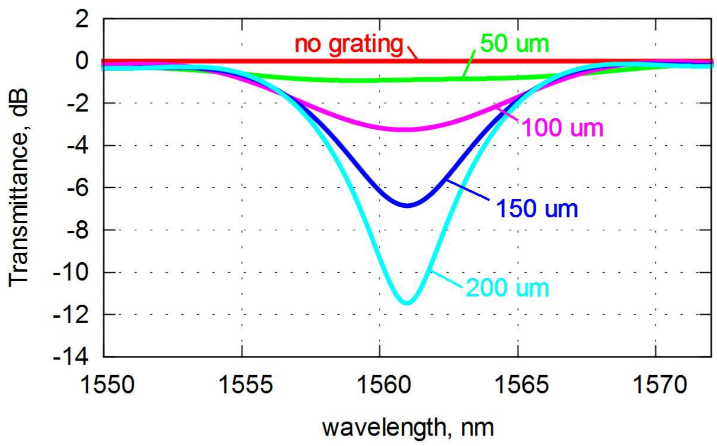

FIGURE 5. Transmittance for FBG with different total grating length

Results show that all FBG with gratings structure give similarity in the center of wavelength that dropped. We can see clearly also that increasing grating total length will affect to the lower transmission value.

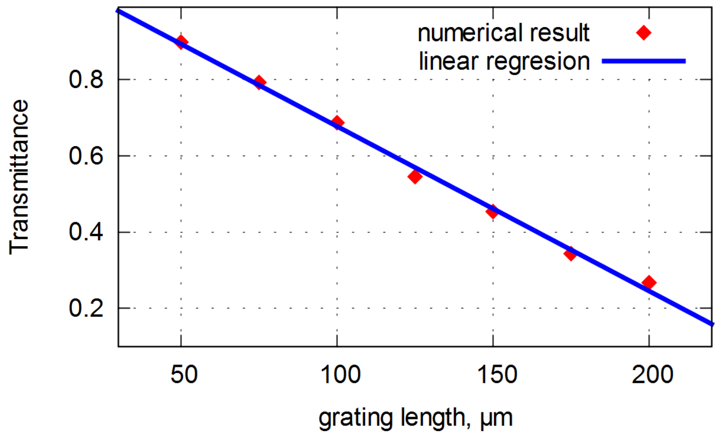

FIGURE 6. Transmission drop of FBG with different total grating length

TABLE 2. Transmittance for different total grating length

Grating length (in μm)	Transmittance
50	0.8989
75	0.7922
100	0.6871
125	0.5451
150	0.4544
175	0.3428
200	0.2670

3.4. **Chirped Fiber Bragg Grating (CFBG).** CFBG is a FBG with different grating period in the core. Grating period is gradually changing from the first grating toward the end of the FBG. Illustration of CFBG is shown in Fig. 7.

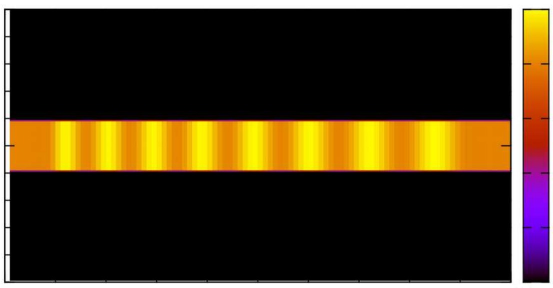

FIGURE 7. Illustration of simulation model area for Chirped FBG structure

CFBG will be simulated with same first grating periods while having different end grating period between each structures. First grating period is fixed at $529nm$, while end grating period simulated here is $529nm$ (uniform FBG), $531nm$, $533nm$, and $535nm$. Result from the simulation is shown in Fig 8.

The result show that CFBG with different end grating period will generate different output characteristic. If we increase end grating, wider wavelength broadband will be reflected by CFBG, but the reflection power is decreased. This is result is reasonable,

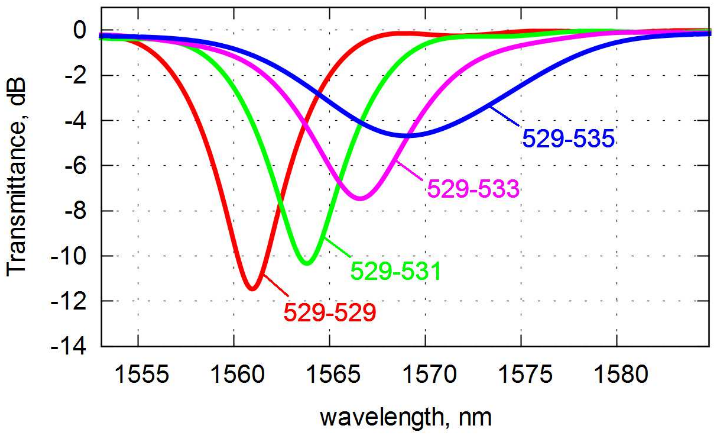

FIGURE 8. Transmittance of FBG with different end grating period

since increasing end grating period while maintaining first grating period will create more variation of grating period in the structure. Thus, will reflect wider number of wavelengths. With same total grating structures length, increasing end grating period will reduce the number of grating that reflect a certain wavelength, which affect to lower reflectance power.

Another simulation for CFBG is simulating structure that have its first and end grating period swapped. Results from CFBG that have first grating period 529nm and last grating period 533nm is compared to the similar structure with 533nm grating period as the first and 529nm grating period as the last structure. The result is shown in Fig. 9.

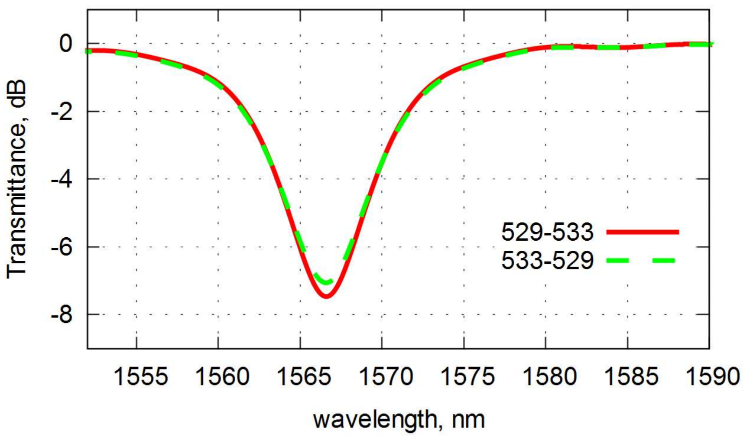

FIGURE 9. Transmittance for FBG with swapped first and end grating period

Fig. 9 show that both structure have a similar output characteristic. There are small differences occurred between two results, but center of the wavelength drop and overall characteristic is identical.

3.5. **Temperature sensing.** Other than act as wavelength or frequency filter, FBG could be used as a sensor also. One of the application is as a temperature sensor. With the increasing of the temperature, the FBG will be expanded which will expand the grating period also. Even this expansion is very small, we still need to calculate it. Other parameter that will be changed with the increasing of the temperature is the refractive index of the fiber core, cladding, and the grating. Total wavelength shift that caused by temperature changes is shown in Eq. 2 [5]

$$\Delta\lambda_B/\lambda_B = (\alpha + \eta)\Delta T \tag{2}$$

Where α is thermal expansion of silica and η is thermo-optic coefficient representing the temperature dependence of the refractive index (dn/dT). These parameters for silica with a germanium doped core are having values $\alpha = 0.55 \times 10^{-6}/°C$ and $\eta = 8.6 \times 10^{-6}/°C$ [5]. With this parameter included in the programming code, we can simulate the effect of temperature changes to the FBG output characteristic. For the simulation, several different delta T is given to the FBG. This delta T value are ranged from $0°C$ to $80°C$ with $10°C$ difference in every simulation. Fig. 10 show output characteristic for 6 different temperatures, while Table 3 and Fig. 11 show comparison between delta T and center of wavelength drop from all data.

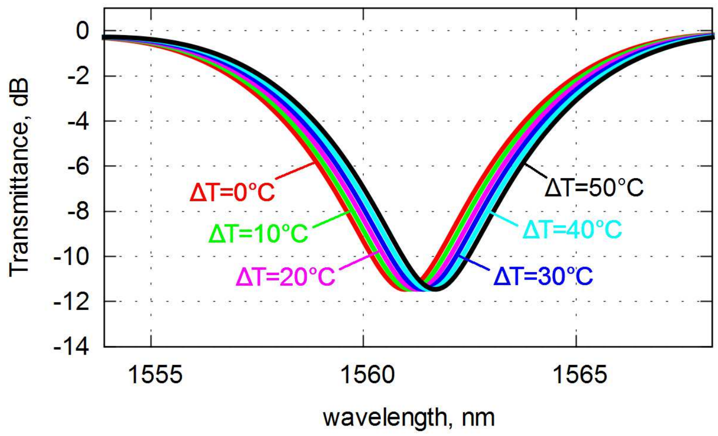

Figure 10. Transmission of FBG with different ΔT

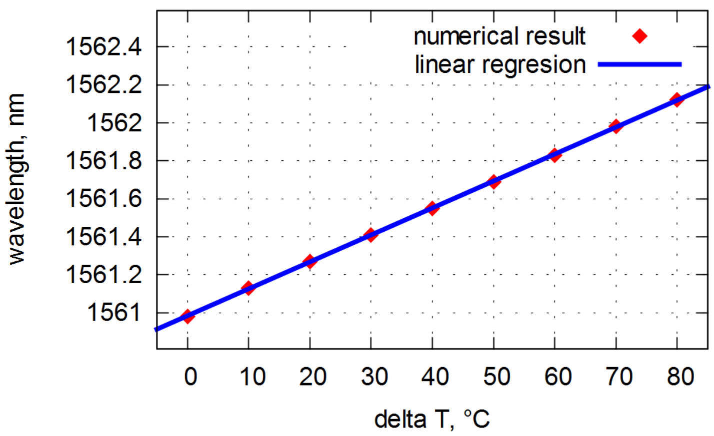

Figure 11. Center transmission wavelength drop of FBG with different ΔT

Results show that changing in temperature of the FBG could be simulated well. When the temperature of the FBG increases, it will reflect higher wavelength value with similar power of transmittance. Correlation between temperature increase and wavelength shift is in a linear condition.

Table 3. Center transmission wavelength drop of FBG with different ΔT

Delta T (in $^{\circ}C$)	Wavelength (in nm)
0	1560.98
10	1561.13
20	1561.27
30	1561.41
40	1561.55
50	1561.69
60	1561.83
70	1561.98
80	1562.12

4. **Conclusions.** FBG structures with different parameters have been simulated by using FDTD Methods. Higher grating refractive index value affect in smaller value of transmission in specific wavelength, and the center wavelength drop is shifted to higher value. Increasing grating period will affect to the output shifting to higher wavelength value with a linear correlation. Longer grating length will reduce the transmission value with linear correlation between them. Chirped FBG (CFBG) show a weaker reflectance, but with wider broadband wavelength reflected. Higher temperature will result in wavelength shift to the higher wavelength value, with a linear correlation between them.

REFERENCES

[1] R. Kashyap, *Fiber Bragg Grating 2nd Ed.*, Elsevier, Burlington-Massachusetts, USA, 2010.

[2] A. Orthonos, K. Kalli, *Fiber Bragg grating fundamental and application in telecommunication and sensing*, Artech House, Norwood-Massachusetts, USA, 2010.

[3] I. Riant, et al, Chirped fiber Bragg gratings for WDM chromatic dispersion compensation in multispan 10-Gb/s transmission, *IEEE Journal of Selected Topics In Quantum Electronics*, vol.5, no.5, pp.1312-1324, 1999.

[4] P. Singh, Dispersion compensation in an optical fiber by using chirp grating, *International Journal of Research in Engineering and Technology*, vol.3, issue.7, pp.506-508, 2014.

[5] M. M. Werneck, R. C. S. B. Allil, B. A. Riberio, F. V. B. Nazare, and C. Cuadrado-Laborde (eds.), *A Guide to Fiber Bragg Grating Sensors, Current Trends in Short and Long period Fiber Gratings*, InTech, DOI: 10.5772/54682, 2013.

[6] A. Khare, J. Singh, Design and study of chirped fiber Bragg grating for sensing of hazardous gases, *International Journal of Computer Application*, vol.23, no.9, pp.40-43, 2011.

[7] A. Sun, Z. Wu, A hybrid LPG/CFBG for highly sensitive refractive index measurement, *Sensor Open Access Journal*, pp.7318-7325, 2012.

[8] T. Kudou, K. Shimizu, Y. Takimoto, and T. Ozeki, Bragg grating filter synthesis using Fourier transform with iteration, *IEEE Trans. Electron*, E83-C, no.6, pp.898-902, 2000.

[9] T. Miyamoto, M. Momoda, and K. Yasumoto, Numerical analysis for 3-dimentional optical waveguide with periodic structure using Fourier series expansion method, *IEICE Trans. Japan (section J)*, J86-C, no.6, pp.591-600, 2003.

[10] A. Tavlove, *Computational electrodynamics*, Artech House, Norwood-Massachusetts, USA, 1995.