Numerical Examination of Fiber Bragg Grating by FDTD

Angger Abdul RAZAK[a], Reya NAGATA[b], Mitsuhiro YOKOTA[c]

Abstract

Optical fiber has made a big revolution in telecommunication systems. This optical technology involving lots of components has to be working together. Fiber Bragg Grating (FBG) is one of components involved in optical telecommunication technology. The existence of FBG is needed when an optical fiber amplifier and filter are used. FBG can be used as band reject filter or band pass filter for optical devices. It is important to examine the characteristics of FBG for the design of the practical use.

This paper aims to simulate and analyze the design of FBG to determine its output characteristic. Simulation and analyzing process of FBG structure are using Finite Difference Time Domain (FDTD) methods. It is assumed that FBG is 2 dimensional periodic structures in this research, where a single mode can propagate.

Analysis of FBG structure shows that FBG output characteristic affected by design parameter. Grating refractive index and grating periods are the parameters that affect the output characteristics, while the grating refractive index shape does not. It is found that the larger refractive index will occur in wider reflected frequency and larger reflectance result. The longer grating periods affect in lower reflected frequency. The analysis also shows that the correlation between grating periods and reflected frequency is not in linear correlation.

Keywords: FDTD, Fiber Bragg Grating, Band reject filter.

1. INTRODUCTION

It is well known that optical fibers have made a big revolution in telecommunication system. With the existence of optical fiber, it is possible to communicate with wide bandwidth and very high speed data rate. This optical technology involving lots of components has to be working together. One of the components is Fiber Bragg Grating (FBG). FBG has an important role when the optical amplifier and filter are used. An optical amplifier would not work well without the existence of FBG[1)-3)]. FBG can reflect, transmit or filter certain wavelength based on the design[4)]. FBG also can be used as band reject filter or band pass filter for optical devices.

Output characteristic of FBG is determined by its design parameter. There are several parameters involved in design parameter such as grating refractive index and grating periods. The changes in design parameter will affect the output characteristic of FBG. It is important to examine the characteristics of FBG for the design of the practical use.

This paper aims to simulate and analyze the design of FBG to determine its output characteristic. Simulation and analyzing process of FBG structure are using Finite Difference Time Domain (FDTD) methods[5)]. It is assumed that FBG is 2 dimensional periodic structures, where a single mode can propagate.

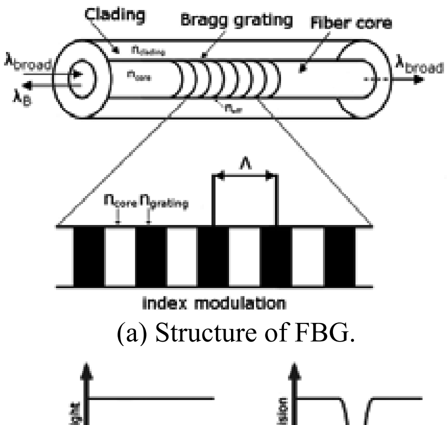
2. BASIC PROPERTIES OF FBG

FBG is an optical fiber whose core has the grating on it. The grating is made by using laser beam interference technique. Fundamental structure of FBG is shown in Fig. 1(a).

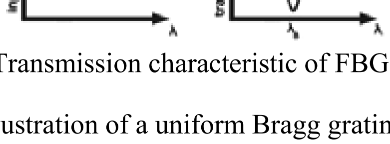
This type of FBG will reflect some area of wavelength shown in Fig. 1(b). λ_B is the reflected wavelength which satisfies by Bragg condition in Eq.(1).

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

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



(a) Structure of FBG.



(b) Transmission characteristic of FBG.

Fig. 1. Illustration of a uniform Bragg grating with constant index.

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3. NUMERICAL SIMULATION and RESULTS

In this research, the output characteristics of FBG based on the design parameter are examined numerically by using Finite Difference Time Domain (FDTD) methods.

FBG is assumed to be 2 dimensional periodic waveguide and uniform Bragg grating. Physical FBG structure considered here does not differ in thickness of the fiber.

Analytical process for FBG in this research is based only on numerical data.

As data for simulation, the analytical region for FDTD z=1.6mm and x=35μm, length of grating structure is 1mm, core width is 3μm. The refractive index of the cladding is n_3=1.46, while core refractive index is n_2=1.48. And $\Delta x=\Delta z=87.67\mu m$, $\Delta t=1.447\text{x}10^{-16}$s is used in FDTD method. Illustration of FBG structure simulated in this research is shown in Fig. 2.

Two kind of incident wave are applied. One is Gaussian pulse and another is sinusoidal. The Gaussian pulse is centered to wavelength of 1.55μm, while frequency of the sinusoidal wave is determined by corresponding frequency for FBG. With wavelength center of Gaussian pulse set to λ_0=1.55μm, we get Gaussian center frequency as follow:

$$f_0 = {}^{c}\!/_{\lambda_0} \tag{2}$$

where c is the speed of light.

To obtain frequency response for FBG output characteristics, the Fast Fourier Transform (FFT) technique is used to the data collected in time domain. This data is represented as transmission property of FBG.

Several groups of research are conducted here. These researches find how the differences of grating refractive index shapes, difference in grating refractive index, and difference of grating period affect the output characteristics of FBG.

In this paper, we set λ_B equal to 1.55nm. In this case, we aim the FBG will reflect the center frequency of the Gaussian pulse in frequency domain. With cladding refractive index n_3=1.46, core refractive index n_2=1.48 and core width 3μm, by using Bragg condition we can get the value of grating period Λ_0=526.19 nm.

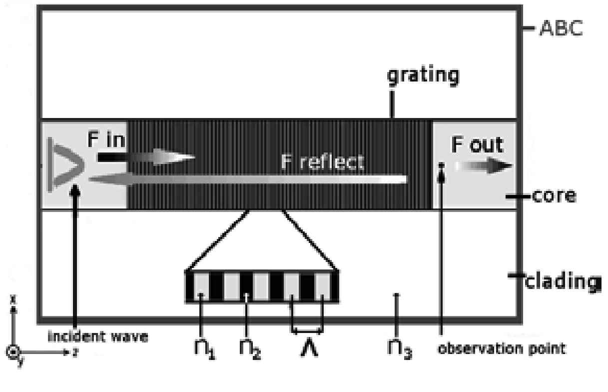
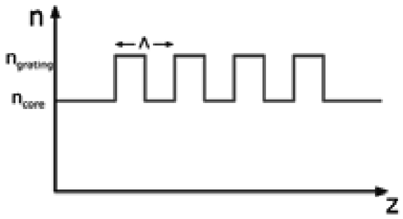
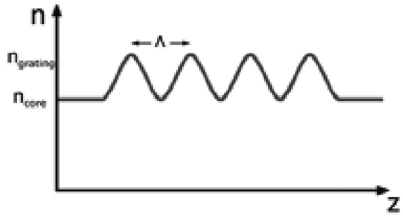


Fig. 2. Illustration of FBG structure.



(a) Square type grating refractive index



(b) Sinusoidal type grating refractive index

Fig.3. Grating refractive index.

To find the effect from the shape of grating refractive index to the output characteristics, we simulate two kinds of grating refractive index shapes as shown in Fig. 3 and analyze the transmission frequency response. The Gaussian pulse used as an incident wave, grating refractive index set to be n_1=1.485, and grating period Λ=526.19 nm.

By simulating FBG using FDTD and applying FFT to output data, result from both FBG structures shows similar frequency response. Both FBG reflect same wavelength and have similar shape of result. From this result, we could conclude that difference between square shape and sinusoidal shape of grating refractive index does not affect the output characteristic of FBG.

After simulating FBG with different grating refractive index shape, we try to find the effect of difference in grating refractive index to output characteristics. In this case, we simulate FBG structure with several grating refractive index and analyze the transmission frequency response. Several grating refractive indexes simulated here is n_l=1.48 (same with core, no grating structure). n_l=1.485, n_l=1.49, and n_l=1.495. The Gaussian pulse used as an incident wave, sinusoidal grating refractive type is used, and grating period $\Lambda=\Lambda_0$=526.19nm.

By observing output data, it shows that frequency response of FBG is changing following the changes of the grating refractive index. The transmittance of FBG is shown in Fig. 4. The transmittance is indicated in decibel (dB), and frequency is normalized by f_0.

We can see that if the grating refractive index is $n_1=1.48$ (no grating), there is no reflectance from the output of FBG. When we use $n_1=1.485$ we can see that some wavelength transmission was dropped and it shows that FBG reflecting wavelength at that area. If higher difference from grating refractive index and core refractive index are used ($n_1=1.49$ and $n_1=1.495$), it shows bigger reflectance, wider area of wavelengths reflected, and center of reflected frequency slightly shifted to smaller frequency.

In last group of research, we simulate several grating period and evaluate the corresponding frequency response in the output to find correlation between grating period and output characteristics. Two kinds of incident waves are used, but implemented alternately.

For first step, three difference grating periods simulated and using the Gaussian pulse as incident wave. The grating periods are $\Lambda_1=\Lambda_0=526.19$nm, $\Lambda_2=613.88$nm, and $\Lambda_3=701.58$nm. The sinusoidal grating refractive index is used, and grating refractive index $n_1=1.49$.

By using FDTD and FFT methods, we get three different center frequency reflected. FBG with $\Lambda_1=526.19$nm reflect frequency 1.202 f/f_0, FBG with $\Lambda_2=613.88$nm reflect frequency 1.022 f/f_0, And FBG with $\Lambda_3=701.58$nm reflect frequency 0.911 f/f_0.

Identical FBG structure analyzed by using three sinusoidal waves corresponding to three difference frequency mentioned above. The transmittance for three FBG with different grating period is shown in Fig. 5. The transmittance is indicated in decibel (dB), and frequency is normalized by f_0.

This result shows that FBG with the same

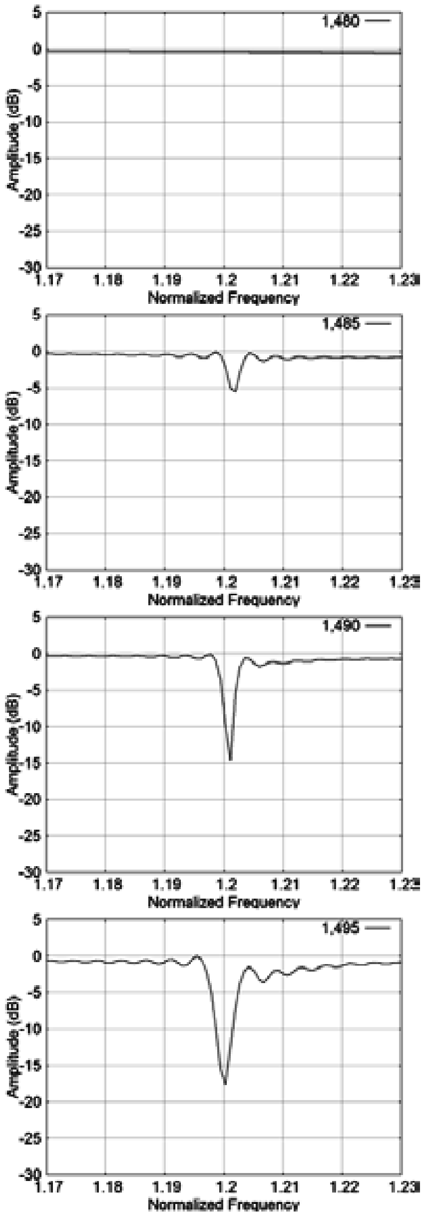


Fig. 4. Transmittance amplitude of FBG with several grating refractive index values n_1.

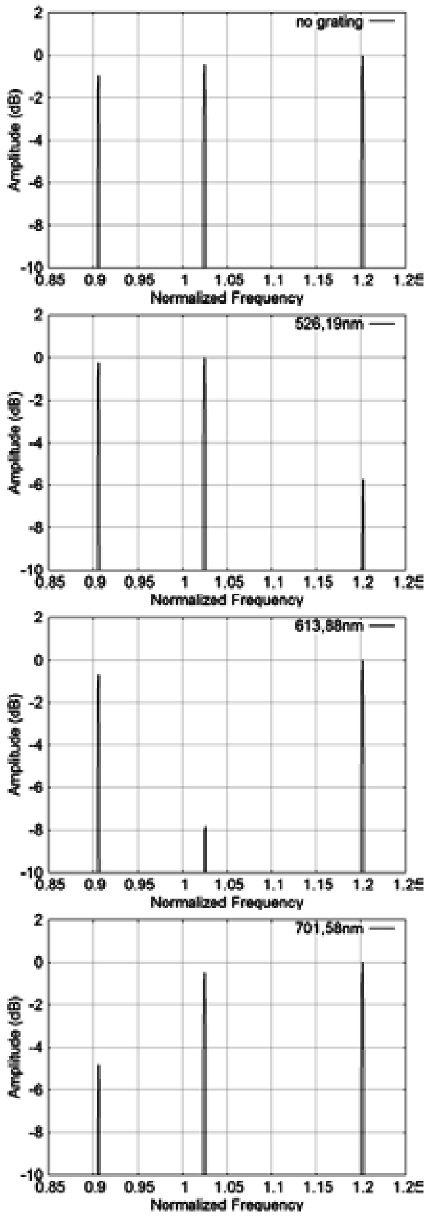


Fig. 5. Transmittance amplitude of FBG with three difference grating period Λ.

Table 1. Reflected frequency on several grating period.

No	Grating Period Λ (nm)	Λ/Λ_0	Frequency (f/f_0)
1	526.19	1.000	1.202
2	539.34	1.025	1.173
3	552.50	1.050	1.145
4	565.65	1.075	1.119
5	578.80	1.100	1.093
6	591.96	1.125	1.068
7	605.11	1.150	1.040
8	618.27	1.175	1.018
9	631.42	1.200	0.997
10	644.58	1.225	0.976
11	657.73	1.250	0.957
12	670.89	1.275	0.938
13	684.04	1.300	0.929

structure reflect the same frequency in different type of incident waves.

To see more precise correlation between grating period and output characteristic, more FBG structures with different grating period need to be simulated. In this case, we simulate several grating period ranged from $\Lambda=\Lambda_0$ to $\Lambda=1,3\Lambda_0$ with gap of 0,025 Λ_0.

By using Gaussian pulse as incident wave, refractive index of the cladding is $n_3=1.46$, core refractive index $n_2=1.48$, grating refractive index $n_1=1.485$, and sinusoidal grating refractive index used, we could see the list of grating period and its normalized reflected frequency in Table 1. Some of transmission characteristics are shown in Fig. 6. The transmittance is indicated in decibel (dB), and frequency is normalized by f_0.

Table 1 and Fig. 6 show that increasing of grating period affect in lower frequency reflected. This phenomena suit to Bragg condition in Eq. (1) which mention that reflected wavelength proportional to grating period, while wavelength have inverted correlation to frequency.

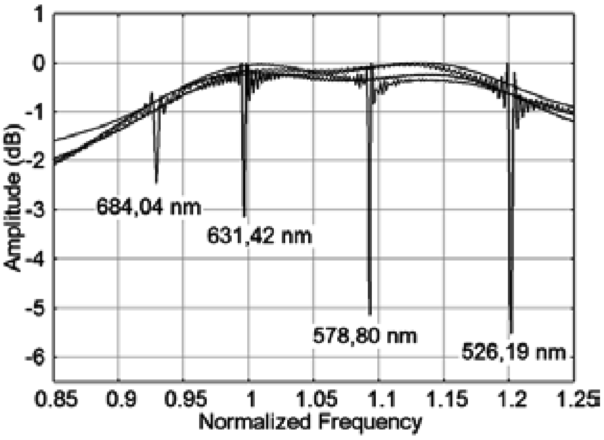


Fig. 6. Transmittance amplitude of FBG with several grating period.

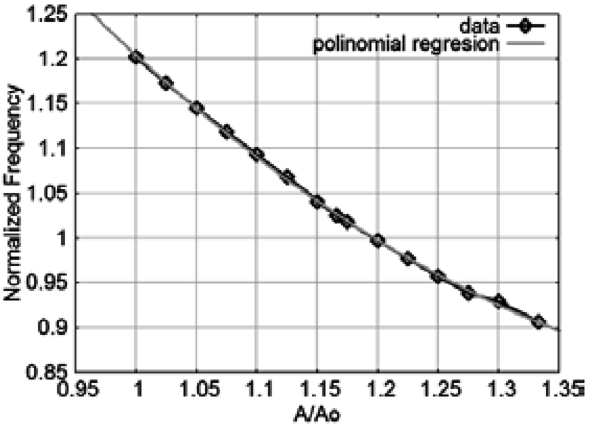


Fig. 7. Transmittance amplitude of FBG with several grating period.

Summary chart between grating period and reflected frequency is shown in Fig. 7. Horizontal axis show grating period relatively to Λ_0=526.19nm and vertical axis show frequency normalized by f_0.

From Fig. 7 it can be seen that correlation between the grating period and reflected frequency is not linear. Afterward, 2nd order of polynomial regression applied to the chart. The formula from polynomial regression is as follow:

$$y = 1.03607x^2 - 3.3122x + 3.47997 \qquad (3)$$

4. CONCLUSION

Several FBG structures have been analyzed with several different parameters. When we change the shape of grating refractive index, similar result shows that grating refractive index shape does not affect output characteristic.

We also simulate different grating refractive index to find the affect to output characteristic. From this simulation show that higher value of grating refractive index will affect in higher value of reflectance in specific wavelength transmission, and reflected wavelength area is widening.

In other simulation, FBG with same grating period will reflect same value of wavelength in both sinusoidal wave and Gaussian pulse. By using Gaussian pulse as incident wave in more FBG with difference grating period, we could get correlation between grating period and reflected frequency. This correlation is not a linear correlation, but it match with 2nd order polynomial regression.

Based on our experiment, we conclude that:

1) FBG could be simulated and analyzed using FDTD method.
2) Changing in FBG parameter will affect in output characteristic of FBG.
3) Grating refractive index shape does not affect the output characteristic of FBG.

4) Higher grating refractive index value will affect in stronger reflection in specific wavelength and widen area of wavelength reflected.
5) Longer period of grating will affect in smaller frequency reflected. The correlation between them is not linear.

From this experiment, there are some ideas to be used for future work:

1) Analyze FBG structures in 3 dimensional approaches.
2) Analyze FBG with more type of grating structures.
3) Developing program with higher resolution for analysis.
4) Developing program to use GPU computation.
5) Analyze non real FBG structure that impossible to fabricate yet.

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