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Chapter

Theoretic Study of Cascaded Fiber Bragg Grating

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Abstract

The purpose of this chapter is to simulate and analyze the spectral characteristics of the fiber Bragg grating (FBG) to obtain narrow bandwidth and minimization side lobes in reflectivity. Fiber Bragg grating has made a big revolution in telecommunication systems. The existence of fiber Bragg grating is needed when an optical fiber amplifier and filter are used. They can be used as band reject filter or band pass filter for optical devices. The model equations of the cascaded uniform fiber Bragg grating and different cascaded apodization functions such as, Hamming apodized fiber Bragg grating, Barthan apodized fiber Bragg grating, Nuttall apodized fiber Bragg grating, Sinc apodized fiber Bragg grating and Proposed apodized fiber Bragg grating are numerically handled and processed via specially cast software to achieve maximum reflectivity, narrow bandwidth without side lobes.

Keywords: fiber Bragg grating (FBG), reflectivity, grating length and narrow bandwidth

1. Introduction

FBGs are typically used as a selective wave-length reflector. Fiber Bragg grating nuts are spectral filters based on the Bragg reflection principle. The light usually reflects the narrow wavelength and sends all other wavelengths. When light is spread by periodic rotation of regions of the upper and lower refractive index, it is partially reflected in each interface between those regions [1]. The power of coupling, and hence the reflection and transmission spectra at an angle of inclination, fiber geometry, and the refractive index (RI) of the surrounding medium are affected [2]. There are a number of parameters in which FBG spectra have been shown, such as change in refractive index, bending of fibers, period of grating, excitation conditions, temperature, and length of tree fibers [3]. The fiber Bragg grating separator (FBG) is an optical device that periodically changes the refractive index along the direction of propagation at the heart of the fiber. The basic property of FBGs is that they reflect the light in a narrow band centered around Bragg wave length. There is a different structure of FBG such as uniform, wet, peep, slanted and long period. When light diffuses through FBG in a narrow band of wavelength, the total reflection occurs at the Bragg wavelength and the other wavelength is not affected by the Bragg derivation except for some side lobes present in the reflection spectrum. These side lobes can be suppressed using the coding technique. The reflection range depends on the length and force of the refractive index formation. Wave reflection also depends on temperature and voltage [4]. In order to achieve

high-efficiency long-range fiber connections, WDM is introduced. Scattering is a key factor limiting the design of long-distance optical links. Several techniques have achieved effective dispersion compensation (DC). The widely used technologies are DCF and broken glass panels (CFBG). Although DCF is a large-scale unit, CFBG is superior to many faces [5]. Due to its excellent multicast capabilities, the fiber Bragg grating (FBG) sensors are particularly attractive for applications where a large number of sensors are desirable such as industrial process control, fire detection systems, and temperature conversion of power, since sensor FBG occupies a narrowband bandwidth that is very narrow and can easily create a distributed sensor matrix by writing several FBG sensors on a single fiber at different locations [6]. The refractive index of the nucleus is permanently changed. Germanium doped silica fiber is used in the manufacture of FBG because it is sensitive which means that the refractive index of the nucleus changes through exposure to light. The amount of change depends on the intensity and duration of exposure. It also depends on optical fiber sensitivity, so the level of fission with germanium should be high for high reflectivity [7]. Fiber Bragg grating nuts are spectral filters based on the Bragg reflection principle. The light usually reflects the narrow wavelength and sends all other wavelengths. When light is spread by periodic rotation of regions of the upper and lower refractive index, it is partially reflected in each interface between those regions [8]. This chapter is organized as follows. After the introduction in Section 1, Section 2 presents a basic model and analysis. In Section 3, we present the proposed system. The simulation results are displayed and discussed in Section 4. Finally we devoted to the main conclusions.

2. Basic model and analysis

In the present section, the basic model, governing equations and the analysis of the fiber Bragg grating are investigated to obtain a maximum reflectivity and minimum bandwidth, we discuss more than one case of different models of fiber Bragg grating; we will discuss in this section two models of fiber Bragg grating:

1. Uniform fiber Bragg grating
2. Apodized fiber Bragg grating

2.1 Uniform fiber Bragg grating

2.1.1 Fiber Bragg grating structure

The basic structure of the uniform fiber Bragg grating is illustrated in **Figure 1** [7, 9]. As shown in **Figure 1**, the refractive index of the core is modulated by a period of Λ. When light is transmitted through the fiber which contains a segment of FBG, part of the light will be reflected. The reflected light has a wavelength equals to the Bragg wavelength so that it is reflected back to the input while others are transmitted. The term uniform means that the grating period, Λ, and the refractive index modulation, δn, are constant over the length of the grating. A grating is a device that periodically modifies the phase or the intensity of a wave reflected on, or transmitted through it [10]. The equation relating the grating spatial periodicity and the Bragg resonance wavelength is given by $\lambda_B = 2n_{eff}\Lambda$. Where n_{eff} the effective mode is index and Λ is the grating period [11].

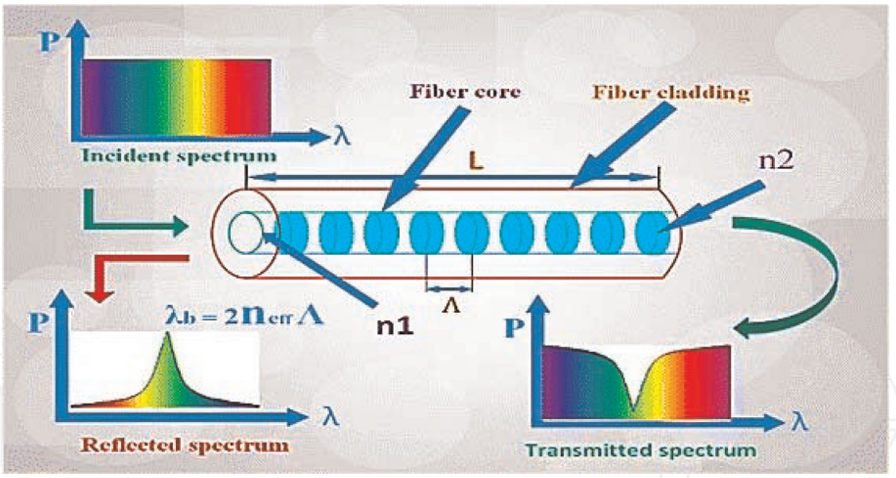


Figure 1.
Basic structure of fiber Bragg grating.

2.1.2 Theory and principle of operation

The study of the spectral characteristics of the uniform fiber Bragg grating is carried out by solving the dual mode equations. Dual mode theory is an important tool for understanding the design of fiber dividers from fiber Bragg grating [7]. FBG can be considered as a weak wave structure so that the pair mode theory can be used to analyze light propagation in a weak waveguide structure such as FBG. Dual-mode equations that describe the propagation of light can be obtained in FBG using the couple mode theory. The theory of marital status was first introduced in the early 1950s to microwave devices and later applied to optical devices in early 1970 [11].

For maximum reflectivity [12]:

$$R_{peak} = \tanh^2(kL) \tag{1}$$

Reflective bandwidth, $\Delta\lambda$ of uniform FBG is defined as wavelength bandwidth between the first zero reflective wavelength of both sides of peak reflection wavelength. It can be calculated by a general expression of the approximate bandwidth of the grating is:

$$\Delta\lambda = \lambda_B s \sqrt{\left(\frac{\Delta n_{ac}}{2n_{eff}}\right)^2 + \left(\frac{1}{N}\right)^2} \tag{2}$$

Where λ_B is the Bragg (center) wavelength, s is a parameter indicting the strength of the gratings ($\sim$1 for strong gratings and $\sim$0.5 for weak gratings), N is the number of grating planes, Δn_{ac} is the change in the refractive index and n_{eff} is the effective refractive index.

The forward propagated light is reflected at Bragg wavelength [13]:

$$\lambda_B = 2n\Lambda \tag{3}$$

Where λ_B is the Bragg wavelength (wavelength of the reflection peak amplitude), n is the effective refractive index of optical mode propagating along the fiber and Λ is the period of FBG structure. For a uniform Bragg grating formed within the core of an optical fiber with an average refractive index n_o. The index of the refractive profile can be expressed as [6, 14]:

$$n(z) = n_0 + \Delta n \cos\left(\frac{2\pi z}{\Lambda}\right) \tag{4}$$

Where Δn is the amplitude of the induced refractive index perturbation, Λ is the nominal grating period and z is the distance along the fiber longitudinal axis. Using coupled-mode theory the reflectivity of a grating with constant modulation amplitude and period is given by the following expression [6, 8, 12]:

$$R(l,\lambda) = \frac{k^2 \sinh^2(sl)}{\Delta\beta^2 \sinh^2(sl) + s^2 \cosh^2(sl)} \tag{5}$$

Where $R(l,\lambda)$ is the reflectivity, which is a function of the grating length L and wavelength λ, $\Delta\beta = \beta - \pi/\Lambda$ is the detuning wave vector, $\beta = 2\pi n_0/\lambda$ is the propagation constant and $s^2 = k^2 - \Delta\beta^2$ and $\kappa = \frac{\pi\Delta n}{\lambda} Mpower$.

Mpower is ac coupling coefficient, *Mpower* is the fraction of the fiber mode power contained by the fiber core.

In the case where the grating is uniformly written through the core, *Mpower* can be approximated by, $1 - V^2$, where $V = \frac{2\pi}{\lambda} a\sqrt{n^2_{c0} - n^2_{cl}}$ is the normalized frequency of the fiber, a is the core radius, n_{CO} and n_{CL} are the core and cladding indices, respectively. At the center wavelength of the Bragg grating the wave vector detuning is $\Delta\beta$ = 0, therefore the expression for the reflectivity becomes:

$$R(l,\lambda) = \tanh^2(kl) \tag{6}$$

The reflectivity increases as the induced index of refraction change gets larger. Similarly, as the length of the grating increases, so does the resultant reflectivity.

2.2 Apodized fiber Bragg grating

In the present section, we cast the basic model and the governing equation to apodized fiber Bragg grating. Apodized FBG offer significant improvement in side lobe suppression but on the expense of reducing the peak reflectivity. Apodized gratings have variations along the fiber in the refractive index modulation envelope ($\Delta n \alpha c$) with constant grating period and constant DC refractive index function. The index of the refractive profile of Apodized can be expressed as [6]:

$$\mathrm{n(z)} = n_{c0} + \Delta n_0 \mathrm{A(z)} n_d(z) \tag{7}$$

Where n_{c0} is the core refractive index, Δn_0 is the maximum index variation, $n(z)$ is the index variation function and (z) is the Apodization function. Apodization profiles are [6, 13, 15]:

1. Uniform:

$$\mathrm{A(z)} = 1,\ 0 \le z \le L \tag{8}$$

2. Hamming Function

$$\mathrm{A(z)} = 0.54 - 0.46\cos\left(\frac{2\pi z}{L}\right), \text{ where } 0 \le z \le L \tag{9}$$

3. Barthan Function:

$$\mathrm{A(z)} = 0.62 - 0.48\left|\frac{z}{L} - 0.5\right| + 0.38\cos\left(\frac{z}{L} - 0.5\right), \text{ where, } 0 \le z \le L \tag{10}$$

4. Nuttall Function:

$$A(z) = 0.3635819 - 0.48917755\left(2\pi\frac{z}{L}\right) + 0.1365996\left(4\pi\frac{z}{L}\right) - 0.0106411\left(6\pi\frac{z}{L}\right), \tag{11}$$

where, $0 \leq z \leq L$

5. Sinc Function:

$$A(z) = \text{sinc}\left(2\pi\frac{z-\frac{L}{2}}{L}\right), 0 \leq z \leq L \tag{12}$$

6. Proposed ($\cos^8$) Function [8]:

$$A(z) = \left(\cos\left(\frac{2z}{L} - 1\right)\right)^8, 0 \leq z \leq L \tag{13}$$

3. The proposed system

This section shows a proposed model for cascaded n stages of FBGs. Analysis of this model is done by coupling theory [16]. T matrix 2 × 2 where FBG is divided into sections.

Each section is shown in **Figure 2** where T is the length of each section and ʌ is the space between reflected planes of each section where:

a_0: is the incident optical signal.
b_0: is the reflected optical signal.
a_m: is the output optical signal.
b_m: is the reflected optical signal at output of grating.
m: is number of sections.

The transfer matrix can be expressed by small multiplied matrixes as in:

$$\begin{bmatrix} a_0 \\ b_0 \end{bmatrix} = [T^1][T^2][T^3][T^4]...[T^m]\begin{bmatrix} a_m \\ b_m \end{bmatrix} \tag{14}$$

Replacing m matrix by whole matrix [**T**] where:

$$[\mathbf{T}] = \prod_{j=1}^{m}[T^m] \tag{15}$$

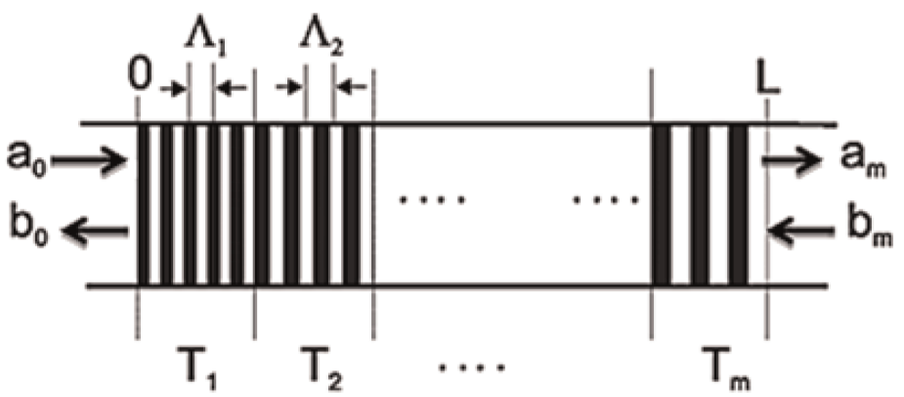


Figure 2.
Fiber Bragg grating sections.

The transfer matrix can be written as:

$$\begin{bmatrix} a_0 \\ b_0 \end{bmatrix} = [\mathbf{T}] \begin{bmatrix} a_m \\ b_m \end{bmatrix} \tag{16}$$

Where [**T**] can be written as:

$$\begin{bmatrix} a_0 \\ b_0 \end{bmatrix} = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} \begin{bmatrix} a_m \\ b_m \end{bmatrix} \tag{17}$$

In case of FBG reflection, There is no reflection at o/p at distance L so $b_m = 0$

3.1 In case of one grating

Transfer matrix can be written as:

$$\begin{bmatrix} a_0 \\ b_0 \end{bmatrix} = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} \begin{bmatrix} a_m \\ 0 \end{bmatrix} \tag{18}$$

Where Transfer matrix parameters T_{11} and T_{21} are:

$$a_0 = T_{11} a_m \tag{19}$$

$$b_0 = T_{21} a_m = \frac{a_0 T_{21}}{T_{11}} \tag{20}$$

Then reflectivity R can be calculated by:

$$\mathrm{R} = |\rho_1|^2 \tag{21}$$

Where,

$$\rho_1 = \frac{b_0}{a_0} = \frac{T_{21}}{T_{11}} \tag{22}$$

3.2 In case of two cascaded gratings

Figure 3 shows the connection between two FBGs where the output of the first on is connected to input of the second. In this case, the input optical signal for the second stage of the grating from (7) is:

$$b_0 = a_{02} = a_{01} \frac{T_{21}}{T_{11}} \tag{23}$$

Transfer matrix can be written as:

$$\begin{bmatrix} a_{01} \dfrac{T_{21}}{T_{11}} \\ b_{02} \end{bmatrix} = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} \begin{bmatrix} a_m \\ 0 \end{bmatrix} \tag{24}$$

Transfer matrix parameters T_{11} and T_{21} in two cascaded are:

$$a_{01} \frac{T_{21}}{T_{11}} = T_{11} a_m \tag{25}$$

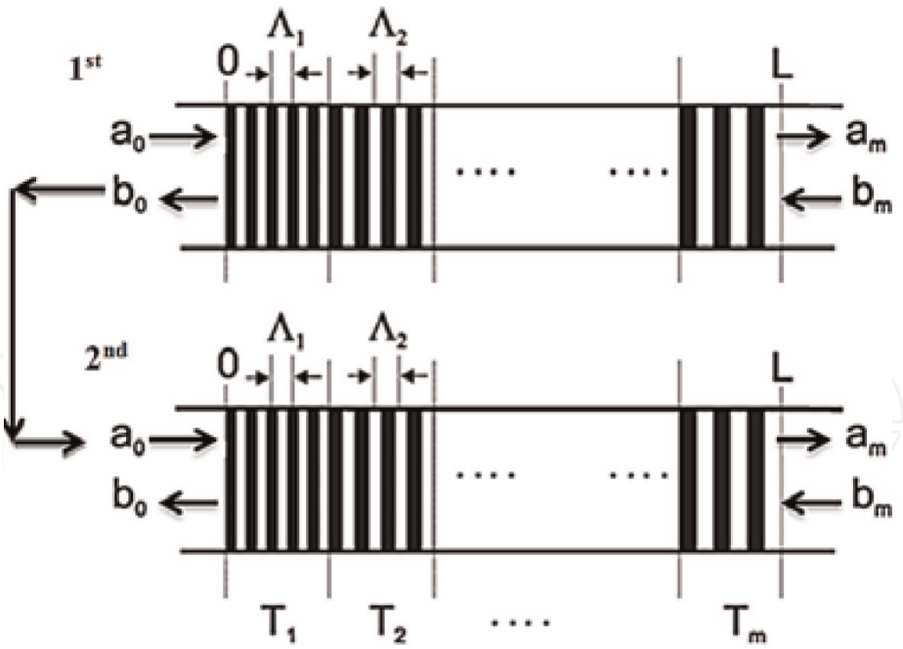


Figure 3.
Connection between two cascaded FBG.

Then from Eq. (12) we get:

$$a_{01} = \frac{{T_{11}}^2}{T_{21}} a_m \tag{26}$$

$$b_{02} = T_{21} a_m \tag{27}$$

We can calculate Reflectivity for the second grating by:

$$\mathrm{R} = |\rho_2|^2 \tag{28}$$

Where,

$$\rho_2 = \frac{b_{02}}{a_{01}} = \frac{T_{21} * a_m * T_{21}}{{T_{11}}^2 * a_m} \tag{29}$$

$$\rho_2 = \frac{{T_{21}}^2}{{T_{11}}^2} \tag{30}$$

$$\therefore \rho_2 = (\rho_1)^2 \tag{31}$$

3.3 In case of third cascaded gratings

The output of second grating b_{02} is equal to input of third grating:

$$a_{03} = b_{02} = a_{01} \frac{{T_{21}}^2}{{T_{11}}^2} \tag{32}$$

Transfer matrix can be written as:

$$\begin{bmatrix} a_{01} \dfrac{{T_{21}}^2}{{T_{11}}^2} \\ b_{03} \end{bmatrix} = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} \begin{bmatrix} a_m \\ 0 \end{bmatrix} \tag{33}$$

Transfer matrix parameters T_{11} and T_{21} in two cascaded are:

$$a_{01}\frac{{T_{21}}^2}{{T_{11}}^2} = T_{11}a_m \tag{34}$$

$$a_{01} = \frac{{T_{11}}^3}{{T_{21}}^2}a_m \tag{35}$$

$$b_{03} = T_{21}a_m \tag{36}$$

We can calculate reflectivity for the third grating by:

$$\mathrm{R} = \left|\rho_3\right|^2 \tag{37}$$

Where,

$$\rho_3 = \frac{b_{03}}{a_{01}} = \frac{T_{21} * a_m * {T_{21}}^2}{{T_{11}}^3 * a_m} \tag{38}$$

$$\rho_3 = \frac{{T_{21}}^3}{{T_{11}}^3} \tag{39}$$

$$\therefore \rho_3 = (\rho_1)^3 \tag{40}$$

From (23) we can prove that the reflectivity of three cascaded FBG at the same parameters is equal to cubic reflectivity of the first one. At n stages of cascaded FBGs have the same parameters and each of them have a reflectivity R; the reflectivity of all n groups is equal to R^n.

4. Simulation results and discussion

In this section we will display the simulation results of the cascaded uniform and cascaded different apodized fiber Bragg grating to obtain narrow bandwidth without side lobes and maximum reflectivity.

4.1 Cascaded uniform fiber Bragg grating

We will simulate the spectral characteristics of the cascaded uniform fiber Bragg grating as in **Figure 4**. In this simulation the modulation index,$d_n = 0.0003$ and grating length L = 5 mm. From **Figure 4** we noted that as the number of cascade of fiber Bragg grating is increased the bandwidth is decreased and the side lobes are also decreased but reflectivity is decreased.

We have obtained from simulation result for one unit of fiber Bragg Grating the reflectivity, R = 99% and bandwidth =0.23 nm but the side lobes is high, for two cascaded units from fiber Bragg grating the reflectivity, R = 98% and bandwidth =0.18 nm but side lobes in this case is decreased on one unit of fiber Bragg grating, for three cascaded units from fiber Bragg grating the reflectivity, R = 97% and bandwidth =0.17 nm but side lobes is decreased and for four cascaded units from fiber Bragg grating the reflectivity, R = 96%, bandwidth =0.16 nm and approximately no side lobes. Then we concluded that Reflectivity, R = 96%, bandwidth = 0.16 nm and the minimum side lobes is achieved at the fourth unit of cascaded fiber Bragg grating.

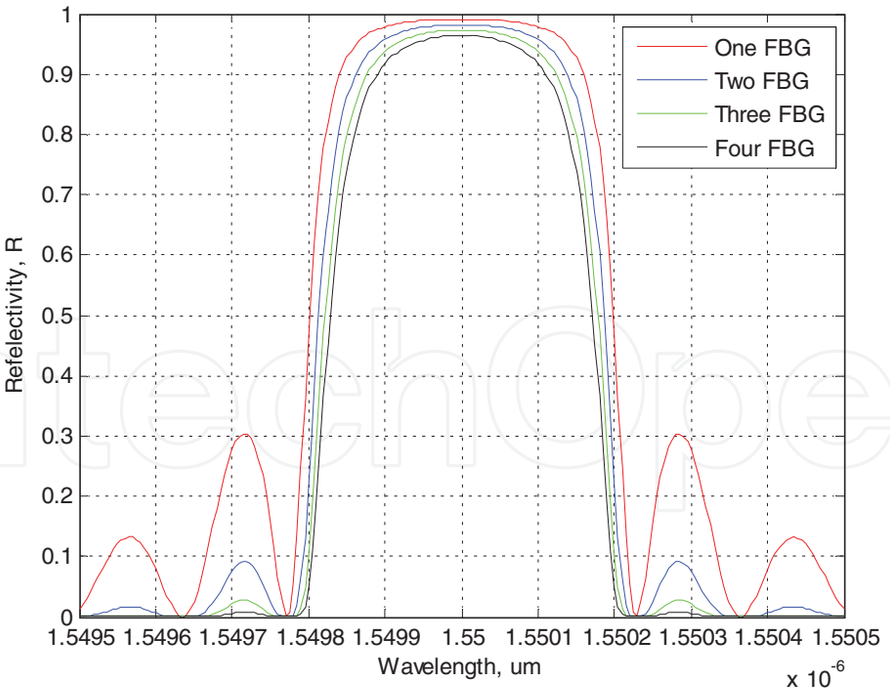


Figure 4.
Reflectivity spectrum for four stage uniform fiber Bragg grating.

4.2 Hamming apodized cascaded fiber Bragg grating

We will simulate the spectral characteristics of the cascaded Hamming apodized fiber Bragg grating as in **Figure 5**.

In this simulation the modulation index, $d_n = 0.0003$ and grating length L = 5 mm. From **Figure 5** we noted that as the number of cascade of fiber Bragg grating is increased the bandwidth is decreased and the side lobes are also decreased but reflectivity is decreased.

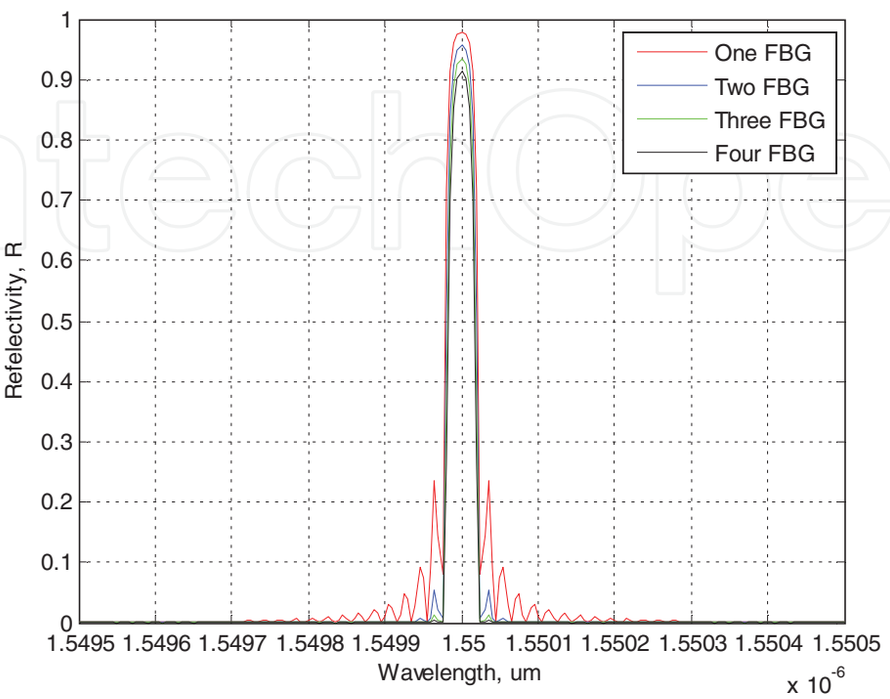


Figure 5.
Reflectivity spectrum for four stage hamming apodized fiber Bragg grating.

We have obtained from simulation result for one unit of fiber Bragg grating the reflectivity, R = 98% and bandwidth =0.026 nm but the side lobes is high, for two cascaded units from fiber Bragg grating the reflectivity, R = 96% and bandwidth =0.020 nm but side lobes in this case is decreased on one unit of fiber Bragg grating, for three cascaded units from fiber Bragg grating the reflectivity, R = 93% and bandwidth =0.018 nm but side lobes is decreased and for four cascaded units from fiber Bragg grating the reflectivity, R = 92%, bandwidth =0.017 nm and approximately no side lobes. Then we concluded that Reflectivity, R = 92%, bandwidth =0.017 nm and the minimum side lobes is achieved at the fourth unit of cascaded fiber Bragg grating.

4.3 Barthan apodized cascaded fiber Bragg grating

We will simulate the spectral characteristics of the cascaded Barthan apodized fiber Bragg grating as in **Figure 6**.

In this simulation the modulation index, $d_n = 0.0003$ and grating length L = 5 mm. From **Figure 6** we noted that as the number of cascade of fiber Bragg grating is increased the bandwidth is decreased and the side lobes are also decreased but reflectivity is decreased. We have obtained from simulation result for one unit of fiber Bragg Grating the reflectivity, R = 100% and bandwidth = 0.083 nm but the side lobes is high, for two cascaded units from fiber Bragg grating the reflectivity, R = 99% and bandwidth =0.069 nm but side lobes in this case is decreased on one unit of fiber Bragg grating, for three cascaded units from fiber Bragg grating the reflectivity, R = 99% and bandwidth =0.066 nm but side lobes is decreased and for four cascaded units from fiber Bragg grating the reflectivity, R = 99%, bandwidth = 0.064 nm and approximately no side lobes. Then we concluded that Reflectivity, R = 99%, bandwidth =0.064 nm and the minimum side lobes is achieved at the fourth unit of cascaded fiber Bragg grating.

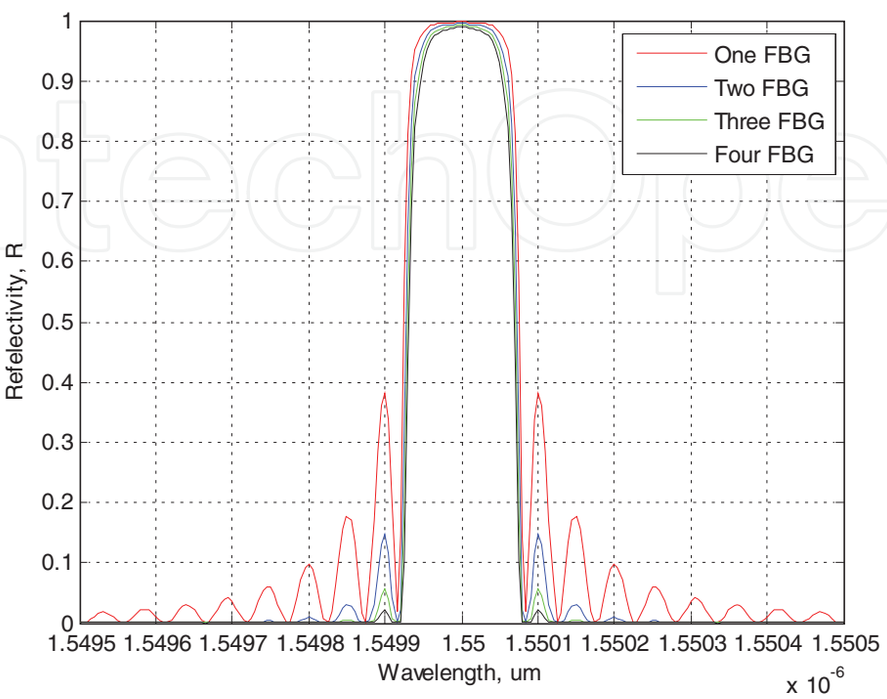


Figure 6.
Reflectivity spectrum for four stage Barthan apodized fiber Bragg grating.

4.4 Nuttall apodized cascaded fiber Bragg grating

We will simulate the spectral characteristics of the cascaded Nuttall apodized fiber Bragg grating as in **Figure 7**.

In this simulation the modulation index, $d_n = 0.0003$ and grating length L = 5 mm. from **Figure 7** we noted that as the number of cascade of fiber Bragg grating is increased the bandwidth is decreased and the side lobes are also decreased but reflectivity is decreased. We have obtained from simulation result for one unit of fiber Bragg grating the reflectivity, R = 99% and bandwidth = 0.08 nm but the side lobes is high, for two cascaded units from fiber Bragg grating the reflectivity, R = 99% and bandwidth =0.063 nm but side lobes in this case is decreased on one unit of fiber Bragg grating, for three cascaded units from fiber Bragg grating the reflectivity, R = 98% and bandwidth = 0.061 nm but side lobes is decreased and for four cascaded units from fiber Bragg grating the reflectivity, R = 98%, bandwidth = 0.059 nm and approximately no side lobes. Then we concluded that Reflectivity, R = 98%, bandwidth = 0.059 nm and the minimum side lobes is achieved at the fourth unit of cascaded fiber Bragg grating.

4.5 Sinc apodized cascaded fiber Bragg grating

We will simulate the spectral characteristics of the cascaded Sinc apodized fiber Bragg grating as in **Figure 8**. In this simulation we choose modulation index, $d_n = 0.0003$ and grating length L = 5 mm. From **Figure 8** we noted that as the number of cascade of fiber Bragg grating is increased the bandwidth is decreased and the side lobes are also decreased but reflectivity is decreased.

we have obtained from simulation result for one unit of fiber Bragg grating the reflectivity, R = 99% and bandwidth =0.013 nm but the side lobes is high, for two cascaded units from fiber Bragg grating the reflectivity, R = 97% and bandwidth =0.01 nm but side lobes in this case is decreased on one unit of fiber Bragg grating, for three cascaded units from fiber Bragg grating the reflectivity, R = 96% and bandwidth =0.0098 nm but side lobes is decreased and for four cascaded units from

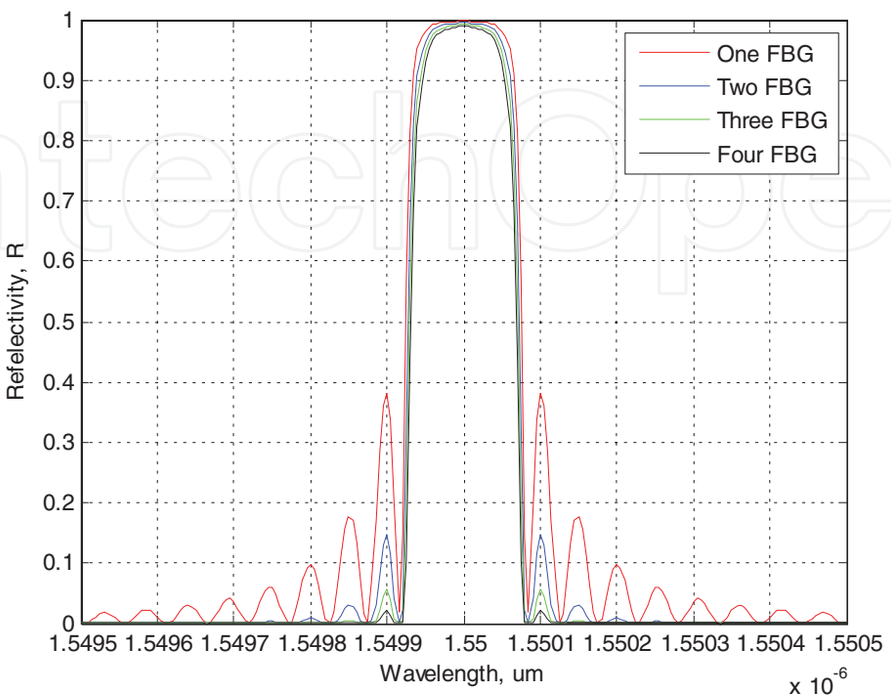


Figure 7.
Reflectivity spectrum for four stage Nuttall apodized fiber Bragg grating.

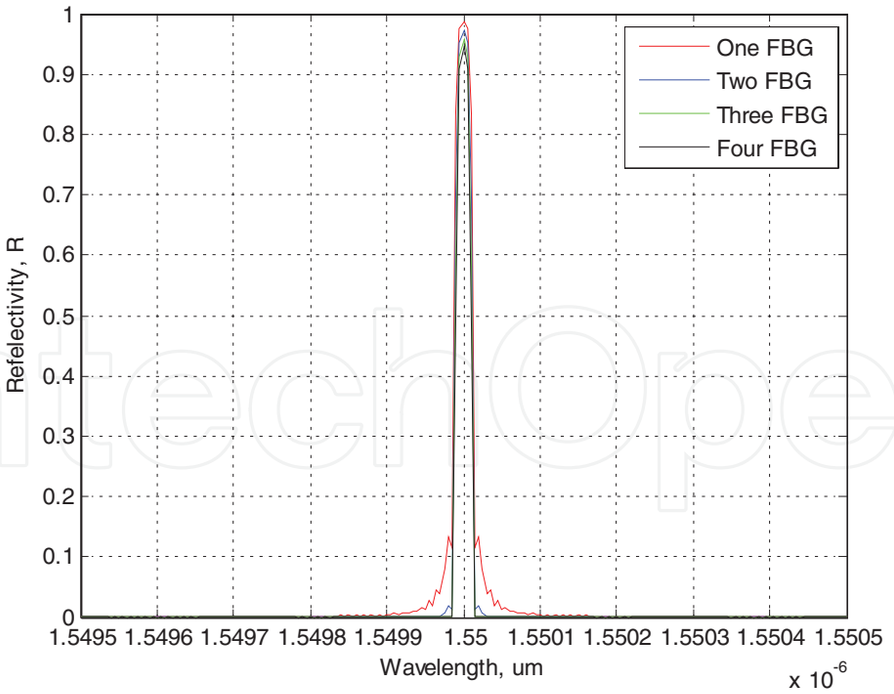


Figure 8.
Reflectivity spectrum for four stage sinc apodized fiber Bragg grating.

fiber Bragg grating the reflectivity, R = 95%, bandwidth =0.0096 nm and approximately no side lobes. Then we concluded that Reflectivity, R = 95%, bandwidth =0.0096 nm and the minimum side lobes is achieved at the fourth unit of cascaded fiber Bragg grating.

4.6 Proposed apodized cascaded fiber Bragg grating

We will simulate the spectral characteristics of the cascaded proposed apodized fiber Bragg grating as in **Figure 9**.

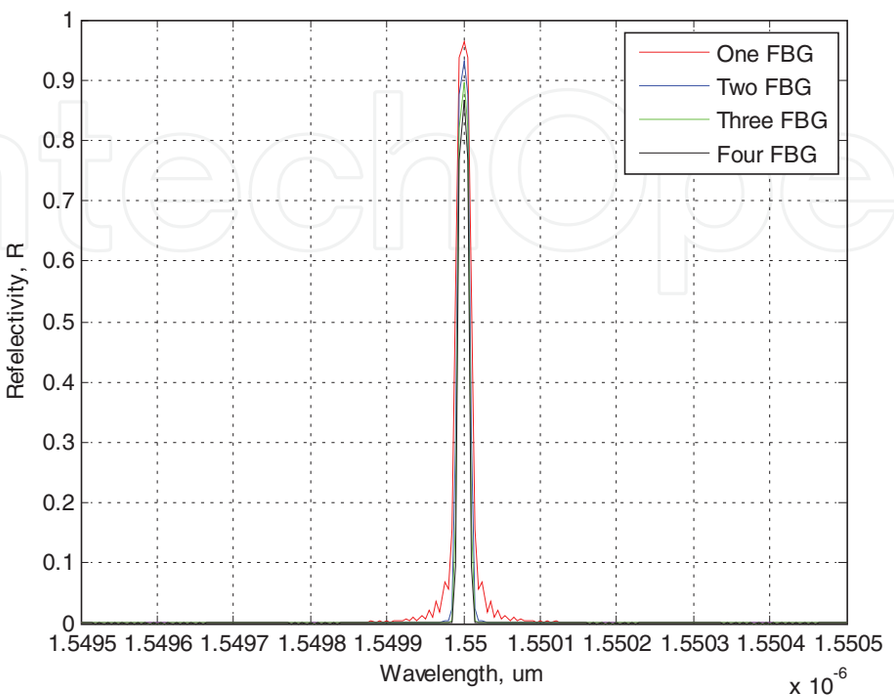


Figure 9.
Reflectivity spectrum for four stage proposed apodized fiber Bragg grating.

In this simulation the modulation index, $d_n = 0.0003$ and grating length L = 5 mm. From **Figure 9** we noted that as the number of cascade of fiber Bragg grating is increased the bandwidth is decreased and the side lobes are also decreased but reflectivity is decreased. We have obtained from simulation result for one unit of fiber Bragg Grating the reflectivity, R = 96% and bandwidth =0.013 nm but the side lobes is high, for two cascaded units from fiber Bragg grating the reflectivity, R = 93% and bandwidth =0.0092 nm but side lobes in this case is decreased on one unit of fiber Bragg grating, for three cascaded units from fiber Bragg grating the reflectivity, R = 90% and bandwidth =0.0084 nm but side lobes is decreased and for four cascaded units from fiber Bragg grating the reflectivity, R = 87%, bandwidth =0.0081 nm and approximately no side lobes. Then we concluded that Reflectivity, R = 87%, bandwidth =0.0081 nm and the minimum side lobes is achieved at the fourth unit of cascaded fiber Bragg grating.

Apodization profile	Grating length and refractive index modulation	Stage number	Reflectivity, R (%)	Bandwidth (nm)
Uniform	L = 5 mm, dn = 0.0003	1st stage	99	0.22
		2nd stage	98	0.17
		3rd stage	97	0.168
		4th stage	96	0.16
Hamming	L = 40 mm, dn = 0.0004	1st stage	98	0.026
		2nd stage	96	0.02
		3rd stage	93	0.018
		4th stage	92	0.017
Barthan	L = 15 mm, dn = 0.0001	1st stage	100	0.083
		2nd stage	99	0.069
		3rd stage	99	0.066
		4th stage	99	0.064
Nuttall	L = 15 mm, dn = 0.0003	1st stage	99	0.08
		2nd stage	99	0.063
		3rd stage	98	0.061
		4th stage	98	0.059
Sinc	L = 80 mm, dn = 0.0004	1st stage	99	0.013
		2nd stage	97	0.010
		3rd stage	96	0.0098
		4th stage	95	0.0096
Proposed	L = 80 mm, dn = 0.0002	1st stage	96	0.013
		2nd stage	93	0.0092
		3rd stage	90	0.0084
		4th stage	87	0.0081

Table 1.
Comparison between reflectivity, R and bandwidth for different cascaded units of apodized fiber Bragg grating.

4.7 Comparisons between reflectivity and bandwidth for different cascaded units of apodized fiber Bragg grating

Table 1 show different cascaded apodized fiber Bragg grating variations of reflectivity, R and bandwidth with the increase of number of stages.

From **Table 1** we noted that as the number of cascaded units of fiber Bragg grating is increased the reflectivity is slightly decreased and the bandwidth decreased with minimum side lobes.

5. Conclusions

In this work the model equations of the cascaded uniform fiber Bragg grating and different cascaded apodization functions are numerically handled and processed via specially cast software to achieve maximum reflectivity, narrow bandwidth and minimum side lobes. For better performance the proper values for grating length and refractive index modulation must be chosen to achieve maximum reflectivity and narrow bandwidth. The minimization in side lobes achieved by using cascaded units from FBG. From this study we concluded that:

1. Uniform FBG in case one unit R = 99%, BW = 0.22 nm and exist side lobes but for fourth unit R = 96%, BW = 0.16 nm with minimum side lobes.

2. For Hamming, Barthan and Nuttall FGB achieved high reflectivity and narrow bandwidth with minimum side lobes in fourth unit FBG.

3. For sinc and proposed FBG achieved narrow bandwidth without side lobes.

4. High reflectivity achieved in case of Barthan apodization function where, R = 99% in fourth unit.

5. Narrow bandwidth achieved in case of proposed apodization function where, BW = 0.0081 nm in fourth unit without side lobes.

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Acronyms and abbreviations

FBG	fiber Bragg grating
RI	refractive index
DC	dispersion compensation

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