New Simulation of Fiber Bragg Grating: Maximum Reflectivity and Narrow Bandwidth without Side Lobes

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Abstract: The purpose of this paper 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, Nuttal 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 [1]. 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 [2]. The basic property of FBGs is that they reflect the light in a narrow band centered on Brag 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 [3]. 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 [4]. 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 [5]. Nazmi A. Mohammed, Ayman W. Elashmawy and Moustafa H. Aly choice the raised cosine profile DFB-F with grating length (L = 30 mm) and modulation depth (no = 10^{-5}) this provides a Full Width at Half Maximum (FWHM) of 0.044 nm [6]. Before 2005, most of literatures uses CFBG as a narrow band unit covering a maximum full width half maximum (FWHM) of 2 nm of C-Band [7]. Yobani Mejía using an optical setup that includes a square array of 3×3 holes, he used nine meridional rays to measure the effective focal length of a lens, also he observed the selected meridional rays as a spot pattern on a diffuse screen. First, he generated a regular square spot pattern (reference pattern) without a lens to test, and then he generated two spot patterns in two different axial positions when the lens being tested refracts the rays. By selecting two sets of four rays of each spot pattern, he was able to measure the difference of the longitudinal (primary) spherical aberration in two positions [8]. Y. Chen et al. designed eight narrow band FBGs each with a maximum FWHM of 0.45 nm [9]. Zhi-Gang Zang and Yu-Jun Zhang propose a new optical bistable device (OBD), which is constructed by connecting two symmetrical fiber Bragg gratings with a ytterbium-doped fiber to form a nonlinear Fabry–Perot cavity. The principle of this new OBD is described using the transfer-matrix method, and the two groups of transmitted and reflected optical bistability loops under different parameters are investigated symmetrically [10].

In this paper 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 without 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, also minimization in side lobes achieved by increasing number of cascaded units from FBG.

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 FBG
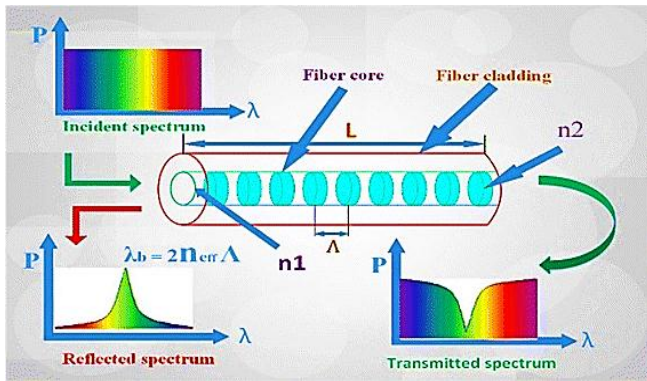2.Apodized FBG

2.1 Uniform FBG

A. FBG Structure

Fig. 1 Basic structure of fiber Bragg grating

The basic structure of the uniform fiber Bragg grating is illustrated in Fig.1 [5] [6]. As shown in Fig.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 [7]. 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 [8].

B. 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 [5]. 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 [8].

For maximum reflectivity [9]:

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

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 (~1 for strong gratings and ~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 [10]:

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

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 [4] [11]:

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

Where Δn is the amplitude of the induced refractive index perturbation, ∧ 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 [4] [9] [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,λ) 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 (Δnαc) with constant grating period and constant DC refractive index function. The index of the refractive profile of Apodized can be expressed as [4]:

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

Where n_{c0} is the core refractive index, Δn_0 is the maximum index variation, $nd\ (z)$ is the index variation function and (z) is the Apodization function. Apodization profiles are [4] [10] [13]:

1-Uniform:

$$A(z) = 1\ , \qquad 0 \leq z \leq L \qquad (8)$$

2- Hamming Function

$$A(z) = 0.54 - 0.46 \cos\left(\frac{2\pi z}{L}\right), \qquad (9)$$

where,

$$0 \leq z \leq L$$

3- Barthan Function:

$$A(z) = 0.62 - 0.48 \left|\frac{z}{L} - 0.5\right| + 0.38 \cos\left(\frac{z}{L} - 0.5\right), \quad (10)$$

where,

$$0 \leq z \leq L$$

4- Nuttall Function:

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

where,

$$0 \leq z \leq L$$

5- Sinc Function:

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

6- Proposed (cos^8) Function [8]:

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

3. THE PROPOSED SYSTEM

The proposed system aims to achieve maximum Reflectivity, narrow bandwidth without side lobes by using cascaded FGBs. It consists of four cascaded FBGs with four units. The reflectivity of each unit is derived related to of the first unit, where the reflected signal of each unit is the input signal for the new unit. This section shows a proposed model for cascaded n stages of FBGs. Analysis of this model is done by coupling theory [14]. T Matrix 2×2 where FBG is divided into sections.
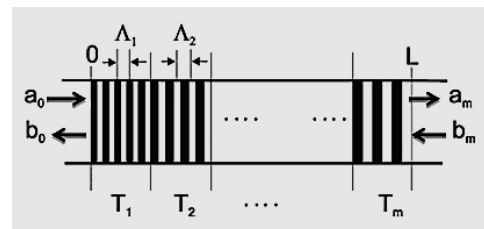

Fig. 2 Fiber Bragg grating sections

Each section is shown in Fig. 2 where T is the length of each section and ∧ 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:

$$\begin{bmatrix} a_0 \\ b_0 \end{bmatrix} = [T^1][T^2][T^3][T^4]\dots[T^m]\begin{bmatrix} a_m \\ b_m \end{bmatrix} \qquad (14)$$

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

$$[\mathbf{T}] = \prod_{j=1}^{m} [T^m] \qquad (15)$$

The transfer matrix can be written as:

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

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

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

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

A. In case of one grating:

Transfer matrix can be written as:

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

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

$$a_0 = T_{11}\, a_m \qquad (19)$$

$$b_0 = T_{21}\, a_m \; = \; \frac{a_0\, T_{21}}{T_{11}} \qquad (20)$$

Then reflectivity R can be calculated by:

$$R = |\rho_1|^2 \qquad (21)$$

Where,

$$\rho_1 = \frac{b_0}{a_0} = \frac{T_{21}}{T_{11}} \qquad (22)$$

B. In case of two cascaded gratings:

Fig. 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:

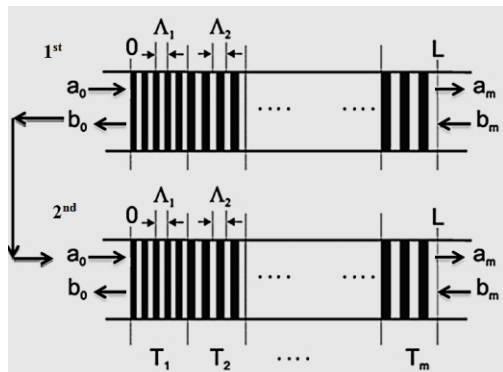$$b_0 = a_{02} = a_{01}\frac{T_{21}}{T_{11}} \qquad (23)$$

Fig. 3 Connection between two cascaded FBG

Transfer matrix can be written as:

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

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

$$a_{01}\frac{T_{21}}{T_{11}} = T_{11}a_m \qquad (25)$$

Then from equation (12) we get:

$$a_{01} = \frac{T_{11}^{\,2}}{T_{21}}\, a_m \qquad (26)$$

$$b_{02} = T_{21}\, a_m \qquad (27)$$

We can calculate Reflectivity for the second grating by:

$$R = |\rho_2|^2 \qquad (28)$$

Where,

$$\rho_2 = \frac{b_{02}}{a_{01}} = \frac{T_{21}*a_m*T_{21}}{T_{11}^{\,2}*a_m} \qquad (29)$$

$$\rho_2 = \frac{T_{21}^{\,2}}{T_{11}^{\,2}} \qquad (30)$$

$$\therefore \rho_2 = (\rho_1)^2 \qquad (31)$$

C. In case of third cascaded gratings:

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

$$a_{03} = b_{02} = a_{01}\frac{T_{21}^{\,2}}{T_{11}^{\,2}} \qquad (32)$$

Transfer matrix can be written as:

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

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

$$a_{01}\frac{T_{21}^{\,2}}{T_{11}^{\,2}} = T_{11}\, a_m \qquad (34)$$

$$a_{01} = \frac{T_{11}^{\,3}}{T_{21}^{\,2}}\, a_m \qquad (35)$$

$$b_{03} = T_{21}a_m \qquad (36)$$

We can calculate Reflectivity for the third grating by:

$$R = |\rho_3|^2 \qquad (37)$$

Where,

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

$$\rho_3 = \frac{T_{21}^{\,3}}{T_{11}^{\,3}} \qquad (39)$$

$$\therefore \rho_3 = (\rho_1)^3 \qquad (40)$$

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 Fig. 4. In this simulation the modulation index, $d_n = 0.0003$ and grating length L=5mm. 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.
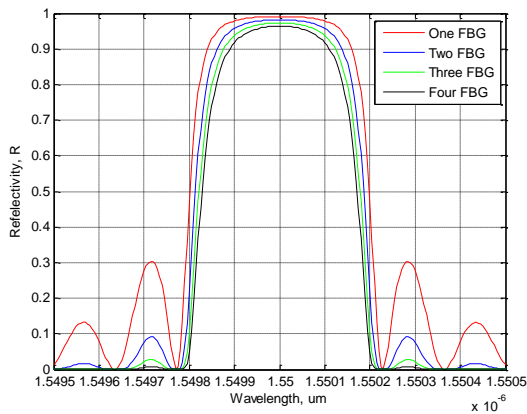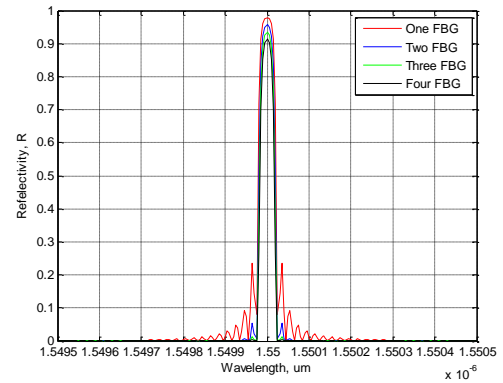

Fig. 4 Reflectivity spectrum for four stage uniform fiber Bragg grating.

We have obtained from simulation result for one unit of fiber Bragg Grating, R=99 % and BW =0.22 nm but the side lobes is high, for two cascaded units from fiber Bragg grating, R=98 % and BW =0.17 nm but side lobes in this case is decreased on one unit of fiber Bragg grating, for three cascaded units from fiber Bragg grating, R=97 % and BW =0.168 nm but side lobes is decreased and for four cascaded units from fiber Bragg grating, R=96 % , BW =0.16 nm and approximately no side lobes. Then we concluded that, R=96 %, BW =0.16 nm and the minimum side lobes is achieved at the fourth unit of cascaded fiber Bragg grating also, minimization in side lobes achieved by increasing number of cascaded units from FBG.

4.2 Hamming Apodized Cascaded Fiber Bragg Grating

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

Fig. 5 Reflectivity spectrum for four stage Hamming Apodized fiber Bragg grating.

In this simulation, $d_n = 0.0003$ and L=5mm. 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.

We have obtained from simulation result for one unit of fiber Bragg Grating, R=98 % and BW =0.026 nm but the side lobes is high, for two cascaded units from fiber Bragg grating the, R=96 % and BW=0.02 nm but side lobes in this case is decreased on one unit of fiber Bragg grating, for three cascaded units from fiber Bragg grating, R=93 % and BW=0.018 nm but side lobes is decreased and for four cascaded units from fiber Bragg grating, R=92 % , BW =0.017 nm and approximately no side lobes. Then we concluded that, R=92 %, BW =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 Fig. 6.
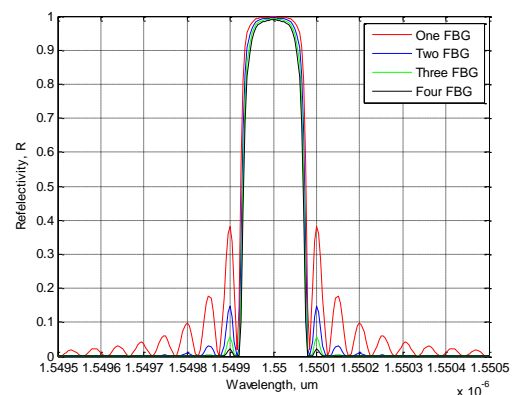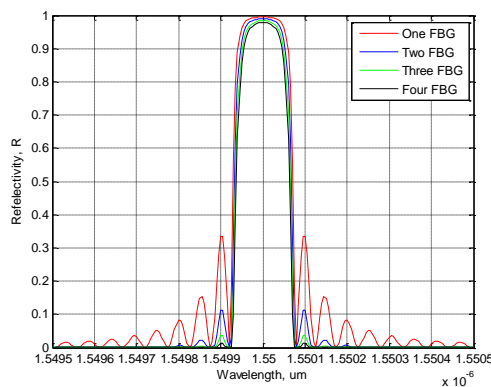

Fig. 6 Reflectivity spectrum for four stage Barthan Apodized fiber Bragg grating.

In this simulation, $d_n = 0.0003$ and L=5mm. 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, R=100 % and BW=0.083 nm but the side lobes is high, for two cascaded units from fiber Bragg grating, R=99 % and BW =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, R=99 % and BW =0.066 nm but side lobes is decreased and for four cascaded units from fiber Bragg grating, R=99 % and BW=0.064 nm and approximately no side lobes. Then we concluded that, R=99 %, BW =0.064 nm and the minimum side lobes is achieved at the fourth unit of cascaded fiber Bragg grating.

4.4 Nuttal Apodized Cascaded Fiber Bragg Grating

We will simulate the spectral characteristics of the cascaded Nuttal apodized fiber Bragg grating as in Fig. 7. In this simulation, $d_n = 0.0003$ and L=5mm. 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.
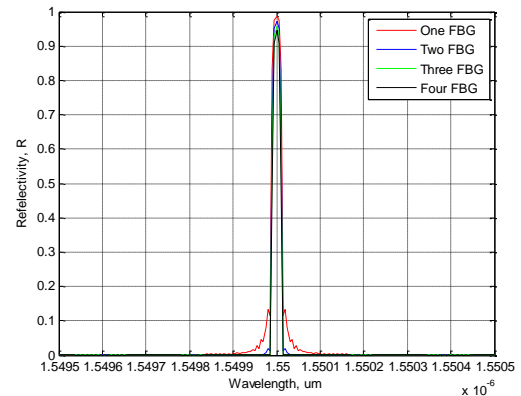

Fig. 7 Reflectivity spectrum for four stage Nuttal Apodized fiber Bragg grating.

We have obtained from simulation result for one unit of fiber Bragg Grating, R=99 % and BW =0.08 nm but the side lobes is high, for two cascaded units from fiber Bragg grating the, R=99% and BW =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, R=98 % and BW =0.061 nm but side lobes is decreased and for four cascaded units from fiber Bragg grating, R=98 % , BW =0.059 nm and approximately no side lobes. Then we concluded that, R=98 %, BW =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 Fig. 8. In this simulation we choose, $d_n = 0.0003$ and L=5mm. 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.
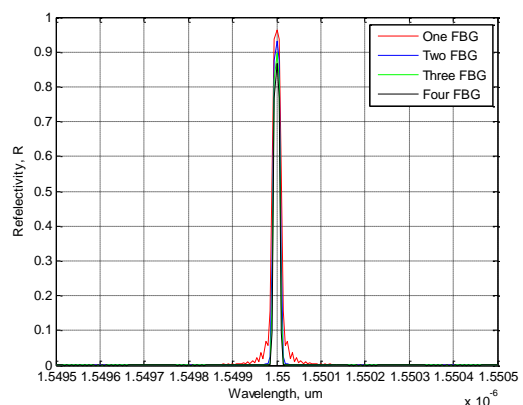

Fig. 8 Reflectivity spectrum for four stage Sinc Apodized fiber Bragg grating.

we have obtained from simulation result for one unit of fiber Bragg Grating, R=99 % and BW =0.013 nm but the side lobes is high, for two cascaded units from fiber Bragg grating the, R=97 % and BW =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, R=96 % and BW =0.0098 nm but side lobes is decreased and for four cascaded units from fiber Bragg grating, R=95 % , BW =0.0096 nm and approximately no side lobes. Then we concluded that, R=95 %, BW =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 Fig. 9.

Fig. 9 Reflectivity spectrum for four stage Proposed Apodized fiber Bragg grating.

In this simulation, $d_n = 0.0003$ and L=5mm. 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, R=96 % and BW =0.013 nm but the side lobes is high, for two cascaded units from fiber Bragg grating, R=93 % and BW =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, R=90 % and BW =0.0084 nm but side lobes is decreased and for four cascaded units from fiber Bragg grating, R=87 % , BW =0.0081 nm and approximately no side lobes. Then we concluded that, R=87 %, BW =0.0081 nm and

the minimum side lobes is achieved at the fourth unit of cascaded 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.

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

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

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 also, we can cancelled side lobes by increasing number of cascaded units from FBG more than fourth units..

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= 0.22nm and exist side lobes but for fourth unit R=96%, BW=0.16nm with minimum side lobes.

2- For Hamming, Barthan and Nuttal 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=0.0081nm in fourth unit without side lobes.

6- We can delete side lobes by using more than fourth units from FBG in all apodized fiber Bragg grating.

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