A Study on Uniform and Apodized Fiber Bragg Gratings

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Abstract— The design, simulation and analysis of an optical Fiber Bragg Grating for maximum reflectivity, minimum side lobe power wastage has been done using MATLAB software. The reflection spectra and side lobes strength were analyzed with different grating lengths, refractive index profiles and pitch values. The simulations are based on coupled mode equations and transfer matrix method that describes the interaction of guided modes.

Key words: Uniform and Apodized Fiber, Bragg Gratings, Grating Lengths

I. INTRODUCTION

Fiber Bragg Gratings (FBGs) have emerged as an important element, mostly in fiber optic communications and optical sensing fields. A fiber Bragg grating consists of a periodic modulation of the refractive index within the core of a single mode optical fiber, where the phase fronts are perpendicular to the longitudinal axis of the fiber and with grating planes having a constant period. Light gets scattered at each grating plane while being guided through the fiber core. The partially reflected light from each grating plane gets added up upon satisfying the Bragg condition. Thus the energy gets transferred from the forward propagating to the backward propagating mode [1]. The FBG therefore reflects certain wavelengths keeping propagation of other wavelengths practically unaffected. The refractive index profile may be uniform, apodized or chirped depending upon the induced change of core refractive index. Apodization refers to the minimization of power wasted in side lobes by the application of different index profiles. Chirped gratings have a linear variation in the grating period, which broadens the reflected spectrum.

II. METHODS FOR SIMULATION OF FBG

The most commonly chosen and accurate mathematical model for design of FBGs is the Coupled Mode Theory (CMT). In this paper, the equations of CMT are used to describe the spectral properties of FBG. Another fast and accurate technique is the Transfer Matrix Method (TMM), in which the whole grating is divided into sub-sections and the input and output fields of each sub-section is calculated and multiplied to get the total grating response. Parameters of FBG, such as period of refractive index perturbation, magnitude of refractive index, grating length and numbers of grids, give optical properties of FBG [2].

A. Equations Of Coupled Mode Theory

When light passes through the FBG, the narrowband spectral component at the Bragg wavelength is reflected by the FBG. The Bragg wavelength is given by the below equation:

$$\lambda_B=2n_{eff}\Lambda \qquad (2.1)$$

where neff and Λ are the effective refractive index of the fiber and the pitch of the grating respectively. The refractive index variations with a period Λ along the length of the fiber are generally expressed as:

$$n(z)=n_0+\Delta n(z)\cos(2\pi/\Lambda+\theta(z)) \qquad (2.2)$$

The functions $\Delta n(z)$ and $\theta(z)$ are slowly varying functions compared to the grating period Λ, n0 is the core refractive index, and $\Delta n(z)$ the envelope of the refractive index modulation. The parameter $\theta(z)$ defines locally, the phase of the effective index modulation, which is used to describe phase shifts or gating chirp. Considering only unchirped gratings, $\theta(z)=0$ [4].

$$\text{Coupling coefficient, } q(z)=\pi\,\Delta n(z) / 2n_0\,\Lambda \qquad (2.3)$$

$$\text{Detuning, } \delta = 2\,\pi n_0/\lambda - \pi/\Lambda \qquad (2.4)$$

Reflection Coefficient is given by:

$$\rho(\delta)= -q\sinh(\gamma L)/(\delta\sinh(\gamma L)+i\gamma\cosh(\gamma L)) \qquad (2.5)$$

Reflectivity,

$$R(\delta)= \sinh^2(\gamma L)/ [\cosh^2(\gamma L)- \delta^2/q^2] \qquad (2.6)$$

Maximum reflectivity R_{max} occurs when the resonance condition is observed; i.e., $\delta=0$ and is given by:

$$R_{max}=\tanh^2(qL) \qquad (2.7)$$

B. Apodization

The power wasted in side lobes can be minimized by applying different index profiles, called as Apodization. Doping concentration variation limits the index variation to maximum value Δn0. Index inside core after FBG has been printed can be expressed by the below equation.

$$n(z) = n_{co} + \Delta n_0.\ A(z).n_d(z) \qquad (2.8)$$

where n_{co} is the core refractive index, $n_d(z)$ is the index variation function, Δn0 is the maximum index variation and A(z) is the anodization function. For uniform FBG with no anodization index variation function A=1.

III. SIMULATION RESULTS

The simulation works presented in this paper are done using Matlab R2010a software.

A. Spectrum Of Uniform Fiber Bragg Grating

Device Parameters	
Length	3mm
Pitch	0.499µm
Refractive Index Modulation	5.15e-4
Maximum Reflectivity	100%

Table 1: Uniform FBG.

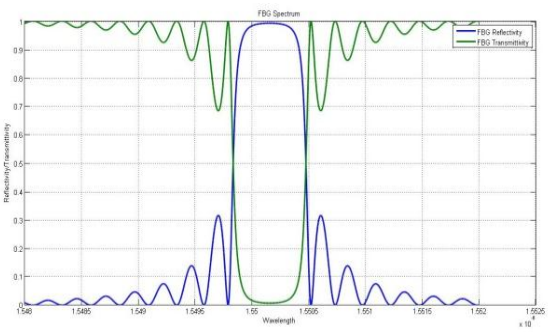

Fig. 1: Reflectivity/Transmittivity of UFBG.

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It can be seen that the uniform FBG spectrum has a peak reflectivity at the Bragg wavelength along with side lobes on either sides of it.

Device Parameters	
Pitch	0.5µm
Refractive Index Modulation	1e-4
Maximum Reflectivity	99%

Table II: Spectrum Of Ufbg Varying The Grating Length.

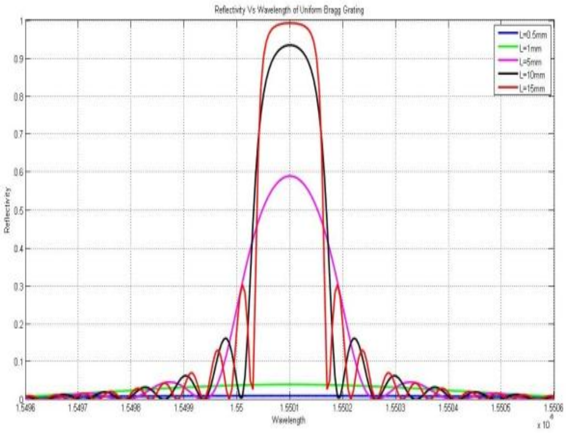

Fig. 2: Reflectivity of UFBG varying the grating length.

The reflectivity of UFBG has been plotted for grating lengths 0.5mm, 1mm, 5mm, 10mm, and 15mm. It can be seen that as the grating length increases, the reflectivity also increases whereas bandwidth decreases as length increases.

Device Parameters	
Pitch	0.5µm
Length	1mm
Maximum Reflectivity	93.27%

Table III: Spectrum Of Ufbg Varying The Index Modulation.

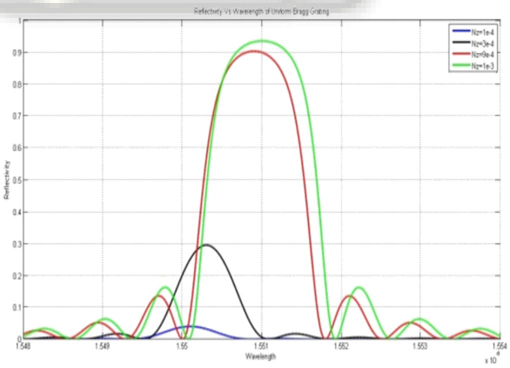

Fig. 3: Reflectivity of UFBG varying the index modulation.

As the index modulation increases, the reflectivity increases, bandwidth increases, the Bragg wavelength gets slightly shifted towards the higher wavelength regime.

Device Parameters	
Refractive Index Modulation	1e-4
Length	1mm
Maximum Reflectivity	40%

Table Iv: Spectrum of UFBG Varying the Pitch.

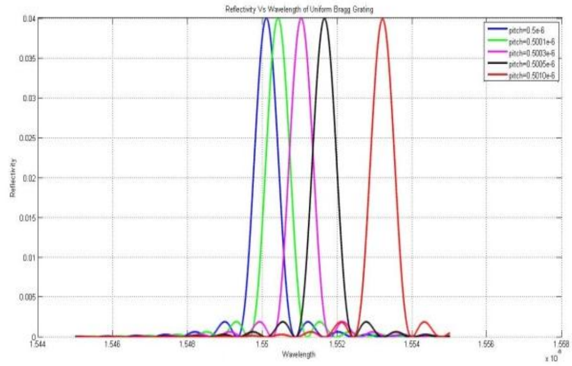

Fig. 4: Reflectivity of UFBG varying the pitch.

A slight change in pitch value causes a noticeable change in Bragg wavelength. The Bragg wavelength shifts towards higher wavelengths as the pitch of the grating is increased.

B. Spectrum of Apodized Gratings

Apodization functions can reduce the side lobes present in the FBG spectra at the expense of power reflected/transmitted. In applications where wavelength selectivity is most important, apodized FBGs are to be preferred than uniform FBGs.

Device Parameters	
Length	5mm
Pitch	0.5µm
Refractive Index Modulation	2.8e-4
Maximum Reflectivity	60%

Table V: Gaussian Apodized FBG.

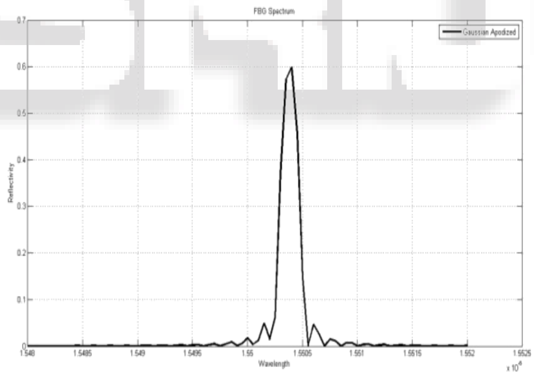

Fig. 5: Reflectivity of Gaussian Apodized FBG.

The apodization function used for Gaussian apodized FBG is given below:

$$A(z) = \exp(-4*((z-L/2)/L)^2) \quad (3.1)$$

Device Parameters	
Length	5mm
Pitch	0.5µm
Refractive Index Modulation	2.8e-4
Maximum Reflectivity	57%

Table VI: Sinc Apodized FBG

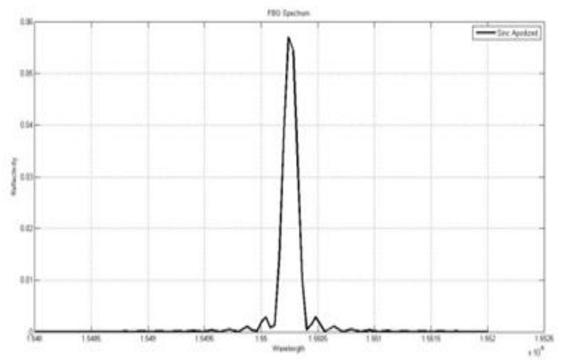

Fig. 6: Reflectivity of Sinc Apodized FBG.

The apodization function used for Sinc apodized FBG is given below:

$$A(z)= 2*sinc(2*pi/L*(z-L/2)) \qquad (3.2)$$

Device Parameters	
Length	5mm
Pitch	0.5µm
Refractive Index Modulation	2.8e-4
Maximum Reflectivity	11.8%

Table VII: Raised Cosine Apodized FBG.

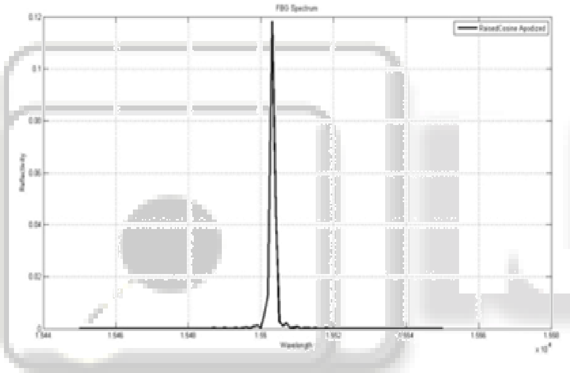

Fig. 7: Reflectivity of Raised Cosine Apodized FBG.

The apodization function used for Raised Cosine apodized FBG is given below:

$$A(z) =1.05*(1+cos((pi*z-0.5*L)/L)) \qquad (3.3)$$

IV. CONCLUSION

The spectral properties of FBG are affected by changes in grating length, refractive index modulation and pitch of the grating. The reflectivity increases with increase in length whereas bandwidth decreases as length increases. Apodization functions can reduce the side lobes present in the FBG spectra at the expense of power reflected/transmitted. The reflectivity is very less for raised cosine apodized gratings, but very good suppression of side lobes is achieved. In applications where wavelength selectivity is most important, apodized FBGs are to be preferred than uniform FBGs.

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