Reflectivity and Braggs Wavelength in FBG

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Abstract

We have presented an analytical model of splitters based on Fiber Bragg Grating used to detect a Bragg wavelength from the number of wavelengths which are traveling in an optical fiber. The number of grids and grating length can be used as a wavelength shifter. This paper presents experimental results that are used to show the effect of number of grids, the length of the grating on the Bragg wavelength and reflectivity of Fiber Bragg Grating (FBG). The pitch of grating is directly proportional to the grating length and inversely proportional to number of grids. When the grating length is fixed and the number of grids is increased, the Bragg wavelength decreases resulting in increased reflectivity. This increased reflectivity is very small. Further when the number of grids is kept constant and the grating length is increased the Bragg wavelength increases. The effect of this increase in grating length on reflectivity is a very small. In our model, the effectiveness of the grating in extracting the Braggs wavelength is nearly 100%.

Keywords- Fiber Bragg Grating, Bragg Wavelength, Reflection, Number of Grids, Grating length, Pitch

1. INTRODUCTION

With the rapid growth of the Internet, capacity requirement is increasing day by day. This increase in the requirement of capacity can be easily met by the existing optical fiber communication technology. The transmission properties of an optical wave-guide are dictated by its structural characteristics, which have a major effect in determining how an optical signal is affected as it propagates along the fiber [1]. Light propagation occurs in the guiding region of waveguide on principle of total internal reflection at the material interfaces. For this to occur, the guiding region must have a refractive index of greater value than the materials surrounding it.

1.1 Fiber Bragg Grating

The Fiber Bragg Grating (FBG) was initially demonstrated by Ken Hill., K.O. [2]. FBG is a periodic perturbation of the refractive index along the fiber length in the fiber's core which is formed by exposure of the core to an intense optical interference pattern. Germanium, a dopant used in many optical fiber cores, is photosensitive to Ultraviolet (UV) light. A grating is a selective wavelength filter in the core of an optical fiber. It is made by exposing a section of the fiber to UV light through a phase mask. An interference pattern of maxima and minima is formed causing a permanent periodic change to the index of the core. A small amount of light is reflected at each index variation. At the "center wavelength" or "Bragg wavelength," all the reflections add coherently. The grating reflects light in a narrow wavelength range, centred at the so-called Bragg wavelength.

1.1.1 Grating Fabrication Technique

Many techniques have been developed for the fabrication of FBG i.e. transverse holographic (G.Meltz, 1989), phase mask (K.O.Hill, 1993) and point-by-point techniques [3]. When UV light radiates on an optical fiber, the refractive index is changed permanently; this effect is known as 'photosensitivity.' Out of these three, the phase mask is the most common technique due to its simple manufacturing process, great flexibility and high performance.

Transverse holographic technique: The light from an UV source is split into two beams that are brought together so that they intersect; the intersecting light beams form an interference pattern that is focused using cylindrical lenses on to the core of optical fiber [3]. The fiber cladding is transparent to UV light, whereas the core absorbs the light strongly. Due to this light beam the core is irradiated from the side, thus giving rise to its name transverse holographic techniques. The holographic technique for grating fabrication has two principal advantages.

- Bragg gratings could be photo imprinted in the core without removing the glass cladding.
- The period of the induced grating depends on the angle between the two interfering coherent UV light beams.

Phase Mask Technique: In this technique the phase mask is placed between the UV light source and the optical fiber. The shadow of the phase mask then determines the grating structure based on the transmitted intensity of light striking the fiber [4] & [5].

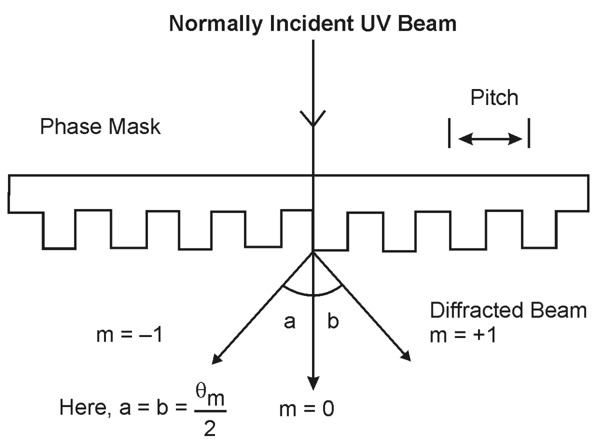

FIGURE1: Phase mask fabrication techniques of Grating

Point-by-Point technique: In this technique each index perturbation is written point by point. Here, the laser has a narrow beam that is equal to the grating period. This method of FBG inscription deep gratings have been written in a range of optical fibers at arbitrary wavelengths. It can be used to write gratings with periods of approximately 1 μm and above in a range of optical fibers [5]. In point by point technique, a step change of refractive index is induced along the core of the fiber at a time. A single pulse of the UV light passes through a mask to the core of the fiber containing a slit and thus the refractive index (n) of the corresponding core section increases locally. The fiber is then translated through a distance corresponding to the grating pitch (Λ) in parallel direction to the fiber axis, this process is repeated to form the grating structure in the fiber core.

1.1.2 Grating Structure

The structure of the FBG can vary via the refractive index, or the grating period. The grating period can be either uniform or graded or localized and distributed in a superstructure. The refractive index profile in FBG can be uniform or apodized, and the refractive index offset is positive or zero. There are six common structures for FBGs;

- Uniform positive-only index change,
- Gaussian apodized,
- Raised-cosine apodized,
- Chirped,
- Discrete phase shift, and
- Superstructure.

1.1.3 Grating Principle

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 Equation (1) [6].

$$\lambda_B = 2n_{eff}\,\Lambda \qquad (1)$$

Where n_{eff} and Λ are the effective refractive index of the fiber and the pitch of the grating respectively. 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. LITERATURE SURVEY

M.S. Ab-Rahman, *et al.* [7], investigated the effect of the refractive index of cladding (n_{cld}) to the Bragg wavelength and reflectivity of the grating. They found that the effect of the η_{cld} was not linear. The Bragg wavelength shifted periodically with the change of n_{cld}. The power also varied in a quadratic manner with a change of η_{cld}. D.W. Huang, *et al.* [8], worked on reflectivity-tunable FBG reflector with acoustically excited transverse vibration of the fiber. They observed that when the transverse vibration induced the coupling between the core and cladding, the Bragg reflectivity varied from its original value to zero. With this technique, they varied the Bragg reflectivity after a fiber grating was fabricated. C.Caucheteur, *et al.* [9], investigated the polarization properties of Bragg grating. They concluded that FBGs prepared by high-intensity laser pulse were characterized by high value polarization-dependent loss (PDL) and differential group delay (DGD). F.Z.Zhang, *et al.* [10], examined the effect of the zeroth-order diffraction of the phase masks on FBG in polymer optical fiber by observing and analysing the micrographs of the grating. When the strain was larger than 2%, the viscoelasticity of the polymer fiber was noticed. The 60 nm Bragg wavelength shift was observed when they investigated the strain response by stretching the polymer optical fiber up to 6.5%.of the polymer optical fiber. B.A.Tahir, *et al.* [11], described the FBG sensing system for strain measurement. They calculated the reflectivity by keeping the grating length constant and varying the index modulation amplitude of the Grating. In their model, the average reflectivity was 96% and negligible change in reflectivity was observed by variation in index modulation. Also, if applied strain was uniform then Bragg wavelength (λ_B) shift occurred without modification of initial spectrum shape. Good linear response was observed between applied strain and Bragg wavelength shift. F.Zeng, *et al.* [12], proposed an approach to implement optical microwave filters using an FBGS with identical reflectivity. The spectrum profile of the broadband light source can be controlled using an optical filter, which could be used to control the filter coefficients to suppress the filters side-lobes. M.ANDO, *et al.* [13], 2004, investigated the dependence of FBG characteristics on grating length. They concluded that under the standard FBG fabrication condition, the exposure time of the FBG to excimer laser irradiation for a given transmission time was inversely proportional to the length of the grating. During their investigation, they fixed the value of amplitude of refractive index modulation of the grating even when the length was varied. S.Ugale, *et al.* [14], found that the reflectivity increases with increase in grating length as well as index difference.

3. ANALYTICAL MODEL

In this paper, we have investigated the effect of number of grids and grating length which will be useful in designing the wavelength splitter with the help of FBG. The Analytical model has been proposed for the reflectivity of grating which is given by Equation (2).

$$R = \frac{\sinh^2\left[kl\sqrt{1-\left(\frac{\delta}{k}\right)^2}\right]}{\cosh^2\left[kl\sqrt{1-\left(\frac{\delta}{k}\right)^2}\right]-\left(\frac{\delta}{k}\right)^2} \quad (2)$$

Where 'l' is the length of the grating, 'k' is the coupling coefficient; δ is detuning factor and $\left(\frac{\delta}{k}\right)$ is the detuning ratio. The detuning parameter for FBG of period is $\delta = s - \left(\frac{\pi}{\Lambda}\right)$, Λ is known as pitch or grating period as in Equation (3).

$$\Lambda = \frac{l}{N} \quad (3)$$

N is number of grids or number of grating periods. Pitch of grating also depends upon the value of effective refractive index and Brag wavelength as shown in Equation (4).

$$\Lambda = \frac{\lambda_B}{2n_{eff}} \quad (4)$$

For sinusoidal variation in index perturbation, the coupling co-efficient for 1st order Bragg grating is $k = \frac{\pi\eta}{\lambda_B}$ where η is overlap integral between forward and reverse propagating mode. *V* is normalized frequency as given in Equation (5).

$$V = \frac{2\pi a n_{eff}\sqrt{2\Delta}}{\lambda_i} \quad (5)$$

Where

- n_{eff} is effective refractive index
- a is radius of core
- Δ is index difference

4. SIMULATION, RESULT & DISCUSSION

The work was carried out on Software MATLAB 7.2 of Mathworks. The analytical model thus constructed has investigated with variation of some of the design parameters of FBG. We have fixed some of the parameters i.e. index difference between core and cladding, radius of core and index amplitude of the grating. As per Equation (5), the pitch of grating is inversely proportional to the number of grids and directly proportional to grating length. Moreover, the number of grids also affects the reflectivity of grating. Table1. shows the relation between the number of grids and Braggs wavelength. Moreover, with the increase in number of grids, there is a negligible increase in reflectivity.

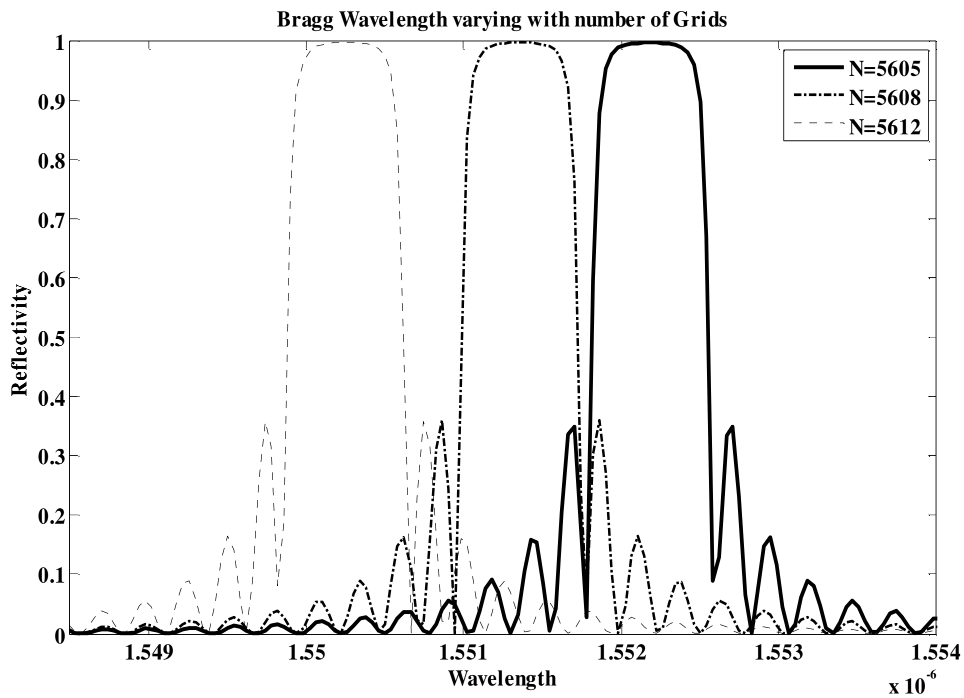

FIGURE 2: Bragg wavelength varying with number of grids of Grating N=5605, 5608 and 5612

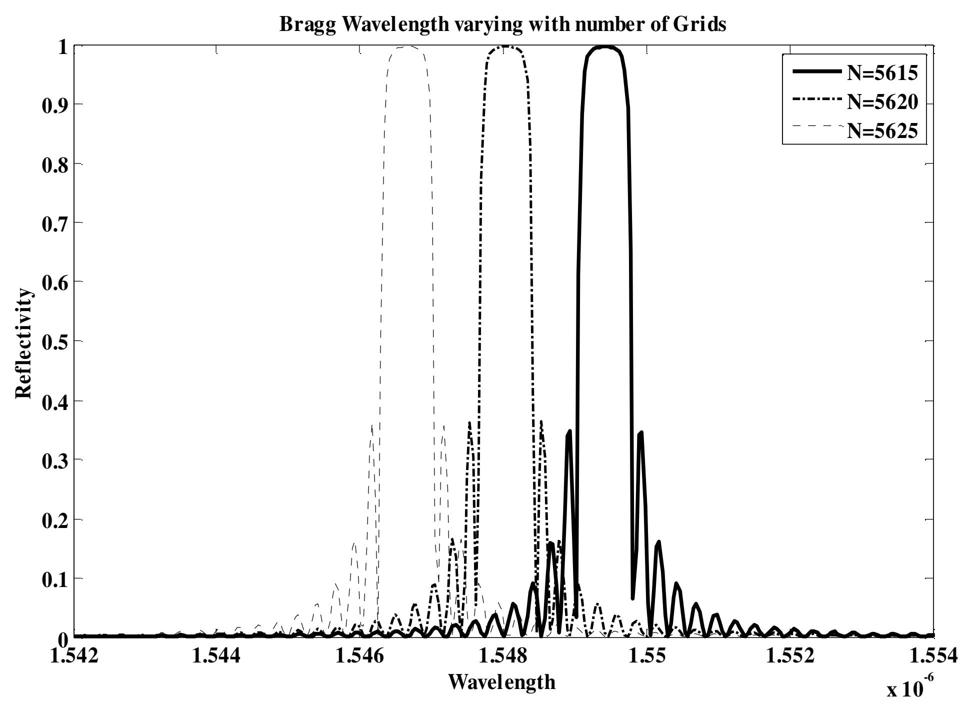

FIGURE 3: Bragg wavelength varying with number of grids of Grating N=5615, 5620 and 5625

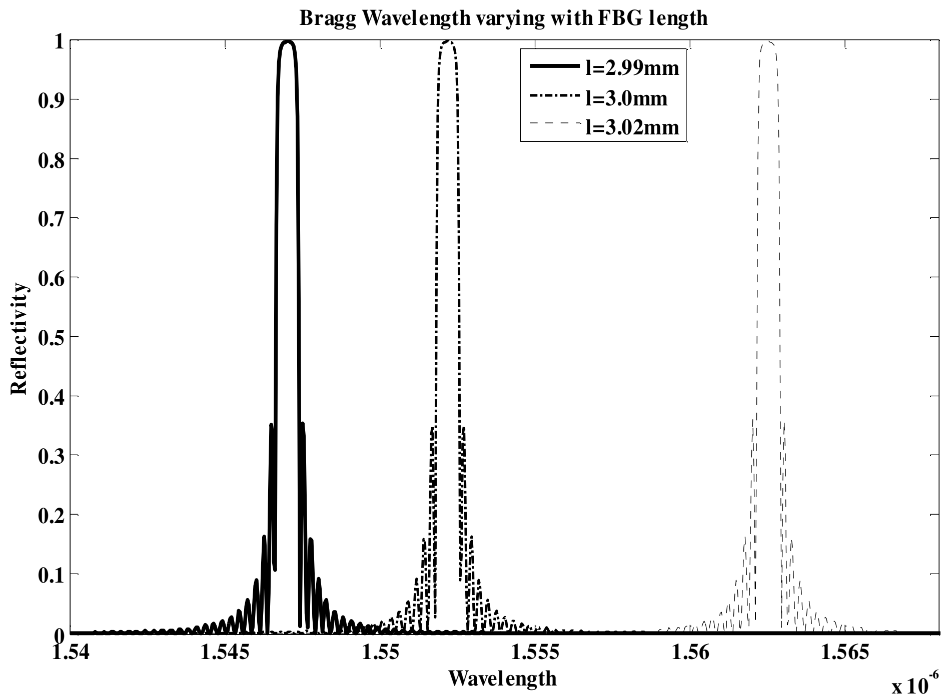

FIGURE 4: Bragg wavelength varying with Grating length l =2.99mm, 3.00mm and 3.02mm

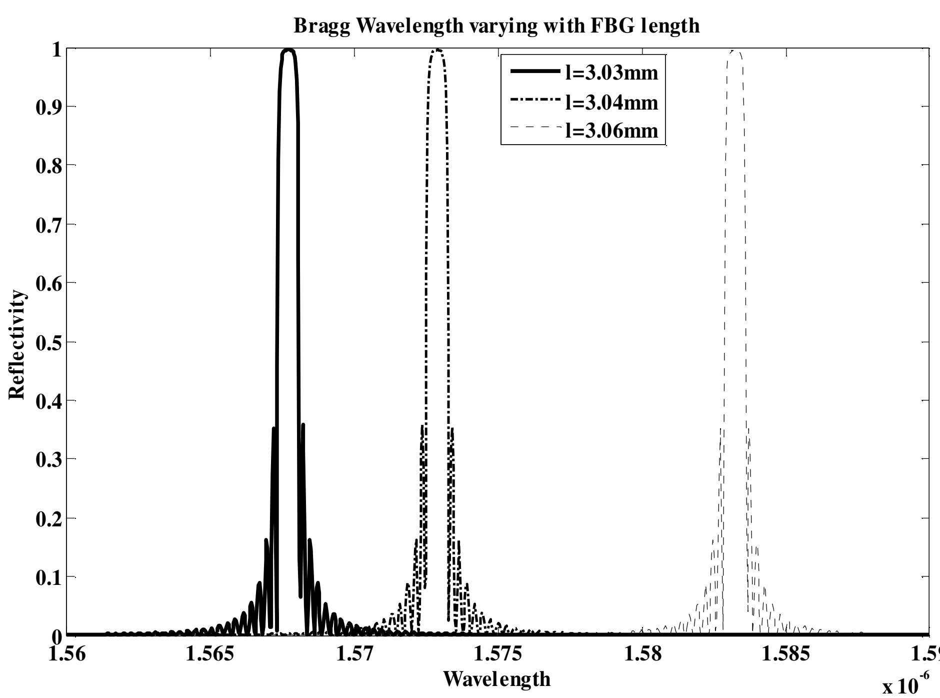

FIGURE 5: Bragg wavelength varying with Grating length l=3.03mm, 3.04mm and 3.06mm

The results shown in Figure 2 and Figure 3 depict the reflectivity and Bragg wavelength variation with the number of grids. It has been shown in Figure 2 also, that the Bragg wavelength varies with the number of grids and it decreases with the increase in number of grids. Bragg wavelength was calculated to be 1552nm for 5605 number of grids, when grating length was fixed at 3mm. It was found that the Braggs wavelength decreased with the increase in number of grids. It decreased to 1551nm and 1550nm when the effective number of grids was increased to 5608 and 5612. For a fix value of grating, there is no change in Reflectivity with the increase in the number of grids. In Figure 3 the results show that Bragg wavelength of the grating was calculated to be 1549 for the number of grids as 5615, which was decreased to 1548, 1547, when the number of grids of grating was increased to 5620 and 5625 respectively. Moreover, with the increase in the number of grids, there was a little increase in the reflectivity of FBG. The reflectivity was increased to 99.65% with 5650 grids when the grating length was 3mm and to 99.61% for number of grids up to 5612.

N(Number of Grids)	**Bragg Wavelength(nm)**	**Reflectivity (%)**
5605	1552	99.61
5608	1551	99.61
5612	1550	99.61
5615	1549	99.62
5620	1548	99.62
5625	1547	99.63
5640	1545	99.63
5650	1540	99.65

TABLE 1: Characteristics of FBG with the Variation of number of Grids

Now, on same model of FBG splitter, we have fixed the number of grids (N) and studied the effect of varying grating length on Bragg wavelength and reflectivity. As per Equation (3), $\Lambda = l/N$ the pitch of grating is directly to the grating length. In this section, the number of Grids (N) is fixed at 5605 and the grating length is varied to observe the effect on Bragg wavelength and reflectivity of the grating.

Grating length(mm)	**Bragg Wavelength(nm)**	**Reflectivity (%)**
2.99	1547	99.6
3.00	1552	99.6
3.02	1563	99.59
3.03	1568	99.58
3.04	1573	99.58
3.05	1583	99.56
3.06	1599	99.52
3.07	1630	99.45

TABLE 2: Characteristics of FBG with the Variation of Grating length

In Figure 5, the Bragg wavelength calculated was 1568 nm for 3.03mm grating length. With increase in the grating length, the pitch of grating increased but the Bragg wavelength of the FBG decreased and at the same time the reflectivity of the FBG also decreased. For the grating length of 3.04mm and 3.06mm, the Bragg wavelength noted was 1573 nm and 1583nm respectively. The Table 2 also showed that for increase of 0.02mm in the grating length, the Bragg wavelength shifted from 1573nm to 1583nm. The reflectivity also decreased with the increase in grating length. It was 99.60 % for 2.99mm grating length and 99.45% for 3.15mm grating length.

The experimental results show the effect of number of grids, the length of the grating on the Bragg wavelength and reflectivity of FBG. It is clear that the pitch of grating is directly proportional to the grating length and inversely proportional to number of grids. When the grating length is fixed and the number of grids is increased, the Bragg wavelength decreases resulting in increased reflectivity. This increased reflectivity is very small. Further when the number of grids is kept constant and the grating length is increased the Bragg wavelength increases. The effect of this increase in grating length on reflectivity is a very small. The effectiveness of the grating in extracting the Braggs wavelength is nearly 100%.

6. CONCLUSION

In our work, we have analyzed the effect of number of grids and grating length of FBG on reflectivity and Bragg wavelength by keeping other parameters constant. The pitch of grating is directly proportional to grating length and inversely proportional to number of grids. On increasing the number of grids, keeping the grating length as fixed, the Bragg wavelength decreases and at the same time, the reflectivity increases. The reflectivity increases by 0.02% with increase in the number of grids by 25 and at the same time, Bragg wavelength shifted by 7nm. Also, when the grating length is varied by 0.02mm, keeping the number of grid constant, the Bragg wavelength shifts by 10nm and reflectivity decreases by 0.02%. The effectiveness of the grating in extracting the Braggs wavelength is nearly 100%.

7. REFERENCES

[1]. G.Keiser, “Optical Fiber communication”, Second Edition, Singapore, McGraw-Hill series in Electrical Engineering, 1991.

[2]. K.O.Hill, Y.Fujii, and D.C.Johnson, “Photosensitivity in optical fiber waveguides: Application to reflection filter fabrication”, *Applied Physics Letters*, VOL. 32, 647-649, 1978.

[3]. Z.Zhou, T.W. Graver, L. Hsu and J.Ou, “Techniques of Advanced FBG sensor: fabrication, demodulation, encapsulation and their application in the structural health monitoring of Bridges”, *Pacific Science Review*, VOL.5, 116-121, 2003.

[4]. K.O.Hill, and G. Meltz, “Fiber Bragg Grating Technology Fundamentals and Overview”, *Journal of Light wave technology*, VOL. 15, NO.8, 1997.

[5]. G.D.Marshall, M. Arms and M.J. Withford, “Point by point femtosecond laser inscription of fiber and waveguide Bragg grating for photonic device fabrication”, *Proceeding of the 2nd Pacific international conference on Application of Lasers and optics*, 2006.

[6]. Z.Zhou and J.Ou, “Techniques of temperature compensation for FBG strain sensors used in long-term structural monitoring”, *Proceeding of Asian pacific fundamental problems of Opto- and Microelectronics* (APCOM 2004) Russia, 465-471, 2004.

[7]. M.S.Ab-Rahman and M.Fauzi, “Effect of Refractive index of cladding on Bragg wavelength and reflection –the Application”, *Australian Journal of Basic and Applied Science*, VOL.3, NO.3, 2876-2882, 2009.

[8]. D.W.Huang, W.F.Liy, C.W. Wu and C.C.Yang, “Reflectivity Tunable fiber Bragg Grating Reflectors”,*IEEE Photonics Technology letters*, VOL.12, NO.2, 2000.

[9]. C.Caucheteur, P. Megret, T. Ernst and D.N.Nikogosya, “Polarization properties of FBG inscribed by high intensity femtosecond 264 nm pulses”, *Science Direct*, Optical Communication 271, 303-308, 2007.

[10]. F.Z. Zhang, C. Zhang and M.T.Xiao, "Inscription of polymer Optical Fiber Bragg grating at 962 nm and its potential in strain sensing", *IEEE photonics technology letters*, VOL.22, NO.21, 2010.

[11]. B.A.Tahir, J. Ali and R.A.Rahman, "Strain measurement using FBG sensor", *American Journal of Applied Science* (special Issue), 40-48, 2005.

[12]. F.Zeng and J.Yao, "All optical microwave filters using uniform FBG with Identical Reflectivity", *Journal of Lightwave Technology*, VOL.23, NO.3, 2005.

[13]. M.Ando, M.Yamauchi, K.Nakayama, K. Moriyama and Y.Masuda, "Dependence of FBG Characteristics on its Length", *Japanese Journal of Applied Physics*, VOL.43, NO.7A, 4234-4235, 2004.

[14]. S.Ugale and V.Mishra, "Fiber Bragg Grating modeling", Characterization and Optimization with different index profiles", *International Journal of Engineering Science and Technology*, VOL.2, NO. 9, 4463- 4468, 2010.