

Designing of a Long Period Fiber Grating (LPFG) using Optigrating Simulation Software

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Abstract:

In this paper we have first formulated a matrix for the coupled equations of Long Period Fiber Grating(LPFG) and then we have given a brief about the optigrating 4.2.2 software on which the simulations have been performed which is followed by designing of a Long Period Fiber Grating(LPFG) by simulating on software Optigrating 4.2.2. During simulation we have taken the parameters of the fiber as the refractive indices of the core and cladding 1.46 and 1.45 respectively while the radius of the core and cladding 4.1 μ m and 62.5 μ m respectively. In Long Period Fiber grating (LPFG) the fundamental guided mode couple light with co-propagating cladding modes at various wavelengths. We have designed a Long Period Fiber Grating(LPFG) of grating length 9cm with grating period 168.78 μ m for coupling fundamental core mode LP(00) to LP (08) mode at wavelength 1.525 μ m.

Keywords—Long Period Fiber Grating, Fundamental core mode, cladding modes, Refractive index, coupling

I. INTRODUCTION

Optical Fibers are the new alternatives and have provided an excellent choice to civil engineers because of their small dimensions, good[1] resolution and accuracy, and excellent ability to transmit signal over long distances. They are immune to electromagnetic and radio frequency interference and may incorporate a series of interrogated sensors multiplexed along a single fiber[2]. A long Period Fibre Grating (LPFG) is a periodic modulation of the optical characteristics of an optical fiber, obtained by either inducing a physical deformation in the fiber material or by modifying the refractive index of the fiber's core[3]. LPFGs typically have a grating period in the range from 100 μ m to 1 mm, which couples light from a fundamental guided core mode into co-propagating cladding modes at various wavelengths, was first reported by Vengsarkar and co-workers in 1996 [4]. LPFGs have also been used as gain-flattening filters for erbium-doped fiber amplifiers [5] and as optical fiber polarizer's[6]. LPFGs have a number of unique advantages such as the fact that simple techniques are required to fabricate them, their compact construction (they are

intrinsic fiber devices) and non conducting (dielectric) structure that is immune to electromagnetic interference (EMI) [7]. Long period fiber grating (LPFG) possesses a periodical refractive index (RI) modulation along the fiber length, which enables the light energy coupling from the fundamental mode to the cladding mode and hence creating resonant dips in its transmission spectrum [8]. The cladding mode is essentially the mode associated with the fiber of a very large core radius (~62.5 μ m) with the ambient as cladding. The cladding modes can be quickly attenuated. As we can see transmission spectrum of (a) an LPG of length 40 mm and period 400 μ m, fabricated in B-Ge co-doped photosensitive optical fibre with a cut-off wavelength of 644 nm [11]. (b) An LPG fabricated in Corning SMF-28 with period 320 μ m [12] in Fig2 below.

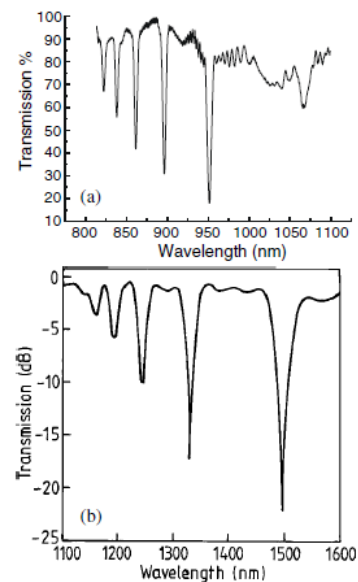


Fig 2 : Transmission Spectrum of (a) an LPG[11]. (b) An LPG fabricated in Corning SMF-28 with Period 320 μ m [12].

The basic principle of the LPG is to couple light from the fundamental guided mode (i.e. the LP01 mode present in the core) to other forward propagating cladding modes (LP0m mode with m =1, 2, 3, 4 ...) in the fiber with periodical variation of the RI is shown in Fig.1[10]

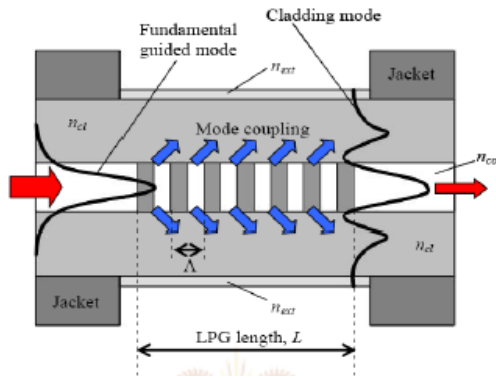


Fig 1: Coupling of a Fundamental Guided mode to a Cladding Mode in a Long-Period Grating[10]

The phase matching condition between the fundamental[9] mode and the forward propagating cladding mode for the long-period grating (LPG), is given by

$$\lambda_{res} = (n_{co}(\lambda) - n_{cl}^m(\lambda))\Lambda \quad (1)$$

Where λ_{res} is the resonance wavelength, n_{co} is the effective refractive index of the core mode and $n_{cl,m}$ is the effective index of the m^{th} cladding mode. Λ is the grating period[10]. The core cladding mode interactions in a fiber grating can be understood by treating the coupling among the core mode and the multiple cladding modes. The most popular method for studying power exchange between core and cladding modes of a long period grating is the coupled mode theory. Coupled mode theory is essentially a perturbation analysis which assumes that the modal fields of the original fiber remain unchanged in the presence of the small periodic index variations. This approach leads to first order coupled differential equations for the z -dependent amplitudes of the coupled core and cladding modes. The corresponding matrix formulation of the LPFG (Long Period Fiber Grating) coupled mode equations can also be done.

II. THE MATRIX FORMULATION FOR LPFG

In order to put the results of the two mode coupled mode analysis in matrix form two new variables $R(z)$ and $S(z)$ are defined in terms of the amplitude terms $B_1(z)$ and $B_2(z)$ as

$$R(z) = B_1(z)e^{-j\frac{\Gamma}{2}z}$$

$$S(z) = B_2(z)e^{j\frac{\Gamma}{2}z} \quad (2)$$

On differentiating w.r.t. z , we get

$$\frac{dR}{dz} = \kappa_{12}S - j\frac{\Gamma}{2}R \quad (3)$$

$$\frac{dS}{dz} = -\kappa_{21}R + j\frac{\Gamma}{2}S \quad (4)$$

Again on Differentiating we obtain,

$$\frac{d^2R}{dz^2} = -\gamma^2R \quad (5)$$

Where $\gamma^2 = \frac{\Gamma^2}{4} + \kappa^2$,

$\Gamma(z) = \frac{2\pi}{\lambda} [n_e^{co} - n_e^{cl}] - \frac{2\pi}{\Lambda}$ the general solution of the equation of the form Eq. (5) can be written as

$$R = a_1 \sin \gamma z + a_2 \cos \gamma z \quad (6)$$

So we get,

$$S = \left(\frac{a_1\gamma}{\kappa_{12}} + j\frac{\Gamma a_2}{2\kappa_{12}} \right) \cos \gamma z - \left(\frac{a_1\gamma}{\kappa_{12}} + j\frac{\Gamma a_2}{2\kappa_{12}} \right) \sin \gamma z$$

Solving the equation with initial conditions $R=R_0, S=S_0$ at $z=0$, $R(z)$ and $S(z)$ can be obtained as

$$R(z) = \left(\cos \gamma z - j\frac{\Gamma}{2\gamma} \sin \gamma z \right) R_0 + \frac{|\kappa|}{\gamma} S_0 \sin \gamma z$$

$$S(z) = -\frac{|\kappa|}{\gamma} R_0 \sin \gamma z + \left(\cos \gamma z + j\frac{\Gamma}{2\gamma} \sin \gamma z \right) S_0 \quad (8)$$

This can be written in matrix form as

$$\begin{bmatrix} R(z) \\ S(z) \end{bmatrix} = \begin{bmatrix} \cos \gamma z - j\frac{\Gamma}{2\gamma} \sin \gamma z & \frac{|\kappa|}{\gamma} \sin \gamma z \\ -\frac{|\kappa|}{\gamma} \sin \gamma z & \cos \gamma z + j\frac{\Gamma}{2\gamma} \sin \gamma z \end{bmatrix} \begin{bmatrix} R_0 \\ S_0 \end{bmatrix} \quad (9)$$

or

$$\begin{bmatrix} R(z) \\ S(z) \end{bmatrix} = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} \begin{bmatrix} R_0 \\ S_0 \end{bmatrix} = T \begin{bmatrix} R_0 \\ S_0 \end{bmatrix} \quad (10)$$

Where the T matrix is referred as the transmission matrix.

III. INTRODUCTION TO OPTIGRATING 4.2.2 SOFTWARE

Optigrating 4.2.2[13] - a powerful and user-friendly design software for modeling integrated and fiber optic devices that are assisted by optical gratings. The operation of many telecom and sensor devices[13] is based on optical gratings which alter coupling between guided light modes. For example, waveguide grating technology has been used in WDM optical networks, laser stabilization, and temperature and strain sensing. A grating-assisted device can be analyzed and designed by calculating light propagation, reflection and transmission spectra, the phase group delay, and the dispersion. While the calculation results depend on waveguide and grating parameters, the design task can be greatly facilitated by the use of the appropriate computer software: Optigrating 4.2.2.

Optigrating 4.2.2 offers you different options for analyzing and designing typical grating assisted fibers and waveguides. You can select one of the options and set device parameters. For example, the design of a Bragg fiber grating filter involves adjustments of the grating shape, length, apodization, index modulation and chirp, according to the fiber diameter and refractive index. Once such a device setup is done, you can use the program to perform numerical simulations. Such simulations are based on solving coupled mode equations that describe the interaction of guided modes. The coupled mode equations are solved by the Transfer Matrix Method (a fundamental matrix method).

IV. OPTIGRATING MAIN AND PROJECT WINDOWS

A. Main Window

The main window of Optigrating is a multi-document interface which allows you to open several grating projects simultaneously. It can be shown as in Fig2 below

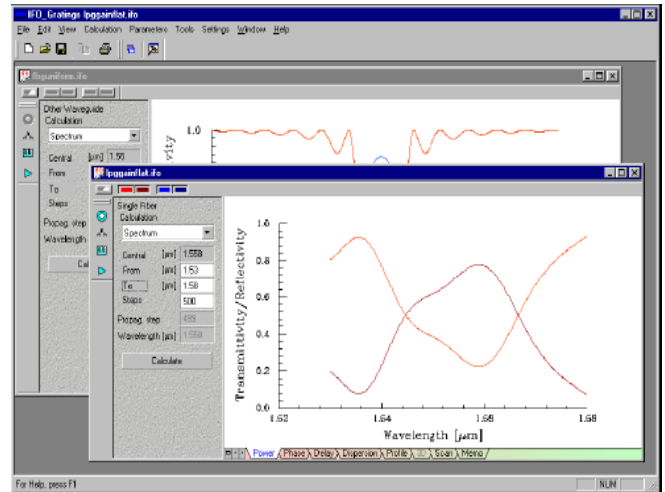


Fig2: Screenshot depicting the main window of the optigrating 4.2.2 software.

B. The Project Window

The Project Window contains the Data Entry Pane (on the left side of the window) and the graphic display (on the right side of the window). The Data Entry Pane enables you to select one of the calculation options, to set the range of the calculation variable, the number of calculation steps, etc[13]. The command buttons provide an easy access to the most often used commands. You can control the graphic display by using the Display tabs. It can be shown as below

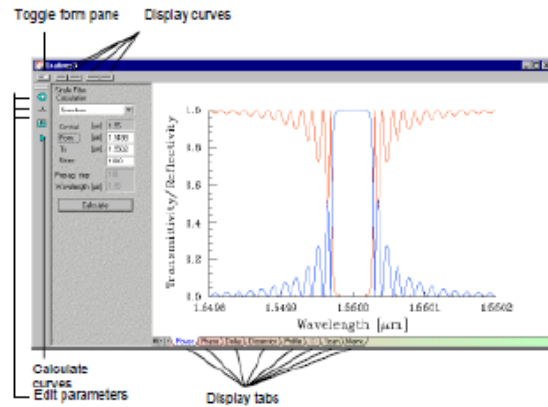


Fig3: Screenshot depicting the Project Window of the Optigrating 4.2.2 Software

V. DESIGNING OF A LPFG

As we know a Long Period Fiber Grating is formed typically by introducing a periodic refractive index modulation in the core of the optical fiber. It couples an incident fundamental core mode (LP_{01}) to forward propagating cladding modes (LP_{0m}) when the phase matching conditions are satisfied. The cladding modes are lossy and can be easily attenuated by introducing a bend. Hence, the guided core mode can be phase matched to a co-propagating LP_{02} , LP_{03} cladding modes and many more for a specific grating period. Depending upon the periodicity, coupling modes can be induced between the

fundamental core mode and further co propagating cladding modes The table1 below defines the various parameters for the fiber under such as grating period and propagation constant for coupling to various cladding modes.

Fiber Parameters	Values
Core refractive index (n_1)	1.46
Cladding refractive index (n_2)	1.45
Core radius (a_{co})	4.1μm
Cladding radius (a_{cl})	62.5μm
Grating Parameters	
Refractive index modulation(Δn)	0.0001

Table1: Various Fiber Parameters Under Study.

As we have defined the parameters of the fiber as shown in Table1. Now we will input these values into the fiber parameters of the optigrating software as. In our study we have taken the ambient medium as air and studied the coupling between LP(00) and LP(08) mode. Thus, defining core parameters shown in Fig 4 below

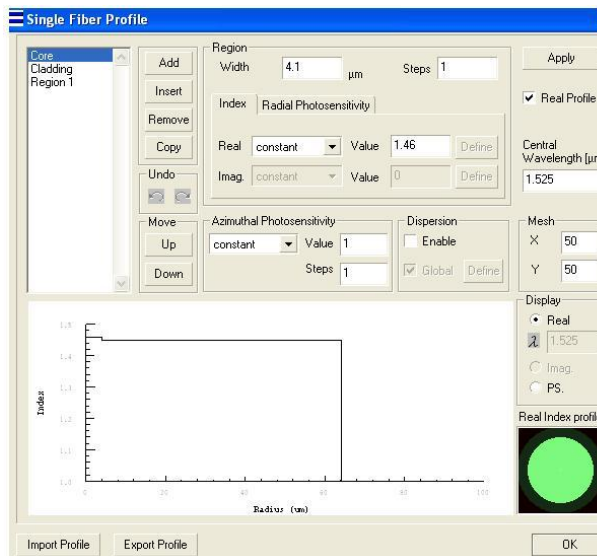


Fig4: Screenshot Depicting the Single Fiber Profile with Core Parameters Defined in the Optigrating 4.2.2 Software

The cladding parameters are defined in below Fig5 as

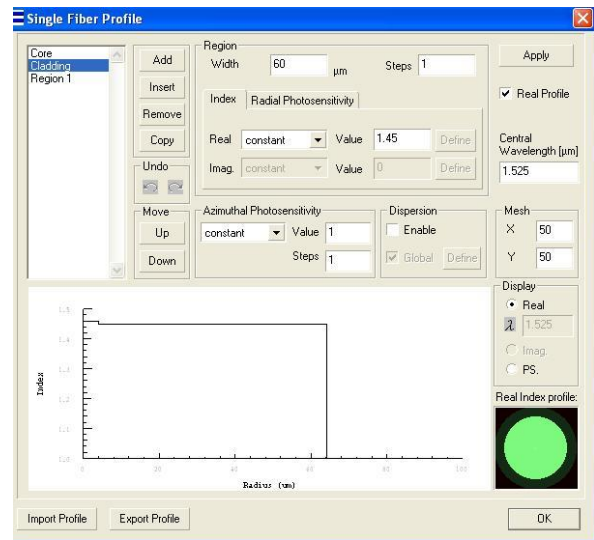


Fig5: Screenshot Depicting the Single Fiber Profile with Cladding Parameters as Defined in the Optigrating 4.2.2 Software

Defining the parameters for air as a ambient medium in fig6 as

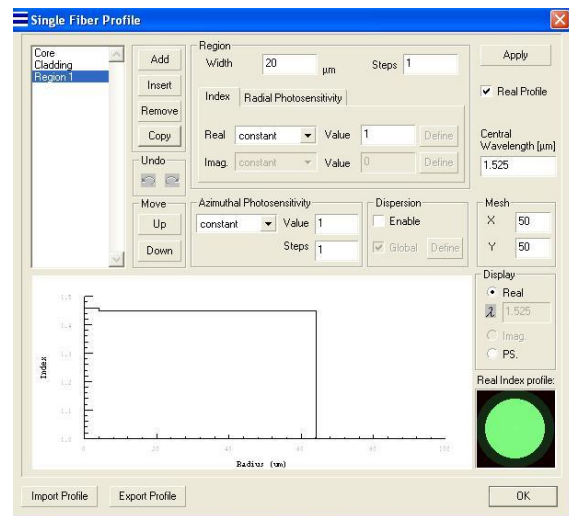


Fig 6: Screenshot depicting the single Fiber profile with ambient medium as air defined in the optigrating 4.2.2 Software

After defining the fiber parameters, the coupling between the modes LP(00) and LP(08) at wavelength 1.525 μ m can be shown as in fig7 below

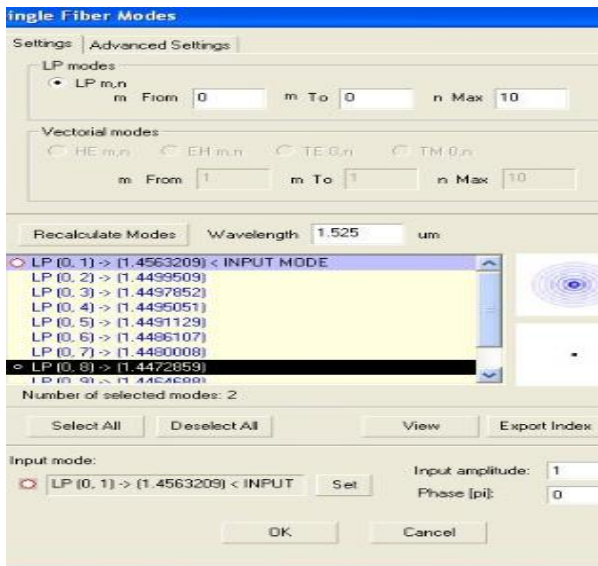


Fig7: Screenshot Depicting the Single Fiber Modes with Coupling Between the Modes LP(00) and LP(08) At Wavelength 1.525μm Defined in the Optigrating 4.2.2 Software.

Now to design Long Period Fiber Grating, the parameters defined in Fig 8 and Fig 9 are

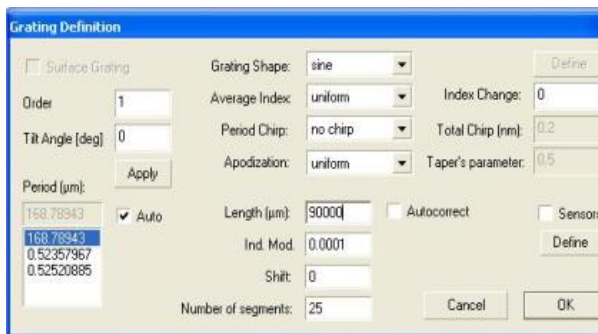


Fig8: Screenshot Depicting the Grating Parameters As Defined in the Optigrating 4.2.2 Software

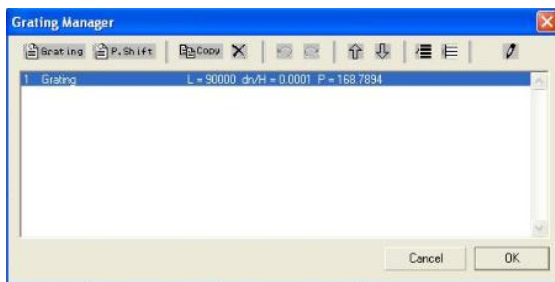


Fig9: Screenshot Showing the Grating of Length 9 Cm and Period 168.7894 μm As Defined in the Optigrating 4.2.2 Software

Thus it can be seen that we had designed the grating for fixed length of 9cm (90,000 μm) and grating period 168.7894 μm with parameters no chirp, no sine shape, uniform average index[13] and uniform apodization[13] as shown above in Fig 8.

VI. OBSERVATION

After defining the grating parameters we found the coupling length by plotting the propagation of the wave in terms of Transmittivity/ Reflectivity along the grating length as shown below in Fig 10

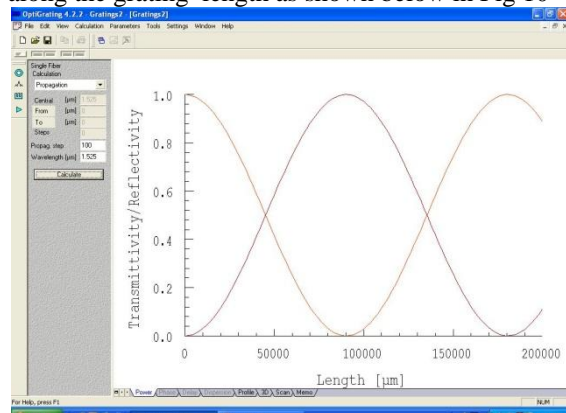


Fig10: Screenshot Showing the Propagation of the Wave in Terms of Transmittivity/ Reflectivity Along the Length of the Fiber As Seen in the Optigrating 4.2.2 Software

By looking at the table of the points of above graph (Fig 10) we found that the coupling length of the fiber is 9cm (90,000μm) for which we designed the LPFG. Thus, it matched with the required results so obtained. Now, we will plot the transmission spectrum of the LPFG for the central wavelength of 1.525um with air as a ambient medium, as shown below in Fig 11

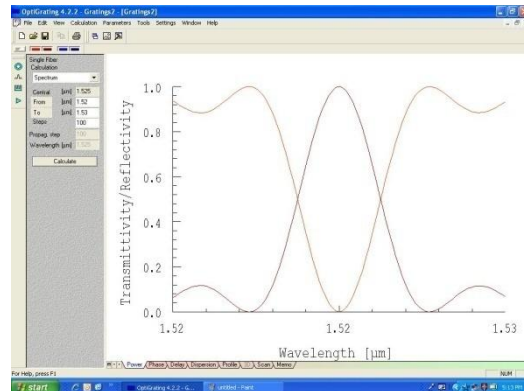


Fig11: Screenshot Showing the Transmission Spectrum Of The LPFG Withnotch at the Central Wavelength Of 1.525μm With Air as a Ambient Medium as Seen in the Optigrating 4.2.2 Software.

Hence, from the above obtained graph Fig 11 it can be seen that power at all wavelengths except the central wavelength passes without attenuation and hence a notch appears at wavelength 1.525μm.

VII.RESULT AND CONCLUSION

Thus we have studied about Long Period Fiber Grating (LPFG) and formulated a matrix of the set of coupled mode equations of LPFG which are used in simulation software optigrating4.2.2. We also got familiar with the basics of the simulation software under which the whole designing of the LPFG is performed and analysed with set of curves obtained. Thus transmission spectrum of a LPFG for a grating period of 168.78 μm for coupling between the LP(00) and LP(08) mode at grating length of 9cm(90,000 μm) at wavelength 1.525 μm is designed.

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REFERENCES

- [1] Ahmed.M.Maleej, Kuang.S.F.U, and Paramasivam, P. (2004), "Fiber optic sensing for monitoring corrosioninduced damage", *Structural Health Monitoring*, 3(2), 165-176.
- [2] Study of Long Period Grating as Strain Sensor Anish Sharma¹, Derick Engles², Amit Singh³, Dept. of Electronics Technology, G.N.D.U. Amritsar. *International Journal of Engineering Research & Technology (IJERT)* Vol. 1 Issue 4, June – 2012 ISSN: 2278-0181.
- [3] Bhatia, V. & Vengsarkar, A.M. "Optical fiber longperiod grating sensors"*Optics Letters* 21(9), pp 692-694, 1996.
- [4] Vengsarkar A M, Lemaire P J, Judkins J B, Bhatia V, Erdogan T and Sipe J E 1996 Long-period grating asband-rejection filters . **14** 58– 64.J. Light wave Technol.
- [5] Qian J R and Chen H E 1998 Gain flattening fibre filters usingphase shifted long period fibre grating **34** 1132–3*Electron. Lett.*
- [6] Ortega B, Dong I, Lic W E, Sandro J P, Reekie I, Tsygina S I,Bagratashvile V N and Laming R I 1997 High performance.
- [7] Study of Long Period Grating as Strain Sensor Anish Sharma¹, Derick Engles², Amit Singh³, Dept. of Electronics Technology, G.N.D.U. Amritsar. *International Journal of Engineering Research & Technology (IJERT)* Vol. 1 Issue 4, June – 2012 ISSN: 2278-0181 www.ijert.
- [8] 1. A. M. Vengsarkar, P. J. Lemaire, J. B. Judkins, V. Bhatia, T. Erdogan, and J. E. Sipe, "Long-period fiber gratings as band rejection filters," *J. Lightwave Technol.* 14(1), 58–65 (1996).
- [9] Bhatia, V "Applications of long-period gratings to single and multi-parameter sensing" *Optics Express* 4(11), pp457-466, 1999.
- [10] Study of Long Period Grating as Strain Sensor Anish Sharma, Derick Engles, Amit Singh, Dept. of Electronics Technology, G.N.D.U. Amritsar. *International Journal of Engineering Research & Technology (IJERT)* Vol. 1 Issue 4, June – 2012 ISSN: 2278-018.
- [11] Khaliq S, James S W and Tatam R P 2002 Enhanced sensitivity fibre optic long period grating temperature sensor *Meas. Sci. Technol.* **13** 792–5.
- [12] Bhatia V, Campbell D K, Sherr D, D'Alberto T G, Zabaronick N A, Ten Eyck G A, Murphy K A and Claus R O 1997 Temperature-insensitive and strain insensitive long-period grating sensors for smart structures *Opt. Eng.* 36 1872.
- [13] <http://optigrating.software.informer.com/4.2/>