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

Mr. Puneet Sehgal¹, Ms. Himani Dua²

¹Department of Electronics, Assistant Professor, A.R.S.D. College, University of Delhi, India
²Department of Instrumentation, Assistant Professor, Shaheed Rajguru College of Applied Sciences for Women, University of Delhi, India

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 4.1µm and 62.5 µm 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 168.78µm for coupling fundamental core mode LP(00) to LP (08) mode at wavelength 1.525 µm.

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 µm 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 (~62.5µm) 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 µm, 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 µm [12] in Fig2 below.

Fig 2 : Transmission Spectrum of (a) an LPG[11]. (b) An LPG fabricated in Corning SMF-28 with Period 320 µm [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]
The core cladding mode of the long period grating (LPG), is given by

\[ \lambda_{re} = (n_{co} - n_{cl}^m(\lambda))\Lambda \]  

(1)

Where \( \lambda_{re} \) 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. \( \Lambda \) 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 LPGF (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

\[ R(z) = B_1(z)e^{-\frac{\Gamma}{2}z} \]

\[ S(z) = B_2(z)e^{\frac{\Gamma}{2}z} \]  

(2)

On differentiating w.r.t. \( z \), we get

\[ \frac{dR}{dz} = \kappa_{12}S - j\frac{\Gamma}{2}R \]  

(3)

\[ \frac{dS}{dz} = -\kappa_{21}R + j\frac{\Gamma}{2}S \]  

(4)

Again on Differentiating we obtain,

\[ \frac{d^2R}{dz^2} = -\gamma^2R \]  

(5)

Where \( \gamma^2 = \frac{\Gamma^2}{4} + \kappa^2 \).

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

\[ \lambda_{re} = (n_{co} - n_{cl}^m(\lambda))\Lambda \]  

(1)

Where \( \lambda_{re} \) 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. \( \Lambda \) 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 LPGF (Long Period Fiber Grating) coupled mode equations can also be done.

\[ \begin{bmatrix} R(z) \\ S(z) \end{bmatrix} = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} \begin{bmatrix} R_0 \\ S_0 \end{bmatrix} \]  

(2)

or

\[ \begin{bmatrix} R(z) \\ S(z) \end{bmatrix} = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} \begin{bmatrix} R_0 \\ S_0 \end{bmatrix} \]  

(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 Fig 2 below

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

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 table 1 below defines the various parameters for the fiber under such as grating period and propagation constant for coupling to various cladding modes.

<table>
<thead>
<tr>
<th>Fiber Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core refractive index (n₁)</td>
<td>1.46</td>
</tr>
<tr>
<td>Cladding refractive index (n₂)</td>
<td>1.45</td>
</tr>
<tr>
<td>Core radius (a₁)</td>
<td>4.1μm</td>
</tr>
<tr>
<td>Cladding radius (a₂)</td>
<td>62.5μm</td>
</tr>
</tbody>
</table>

Table 1: Various Fiber Parameters Under Study.

As we have defined the parameters of the fiber as shown in Table 1. Now we will input these values into the fiber parameters of the Optigrating software. 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.

![Fig 4: Screenshot Depicting the Single Fiber Profile with Core Parameters Defined in the Optigrating 4.2.2 Software](image)

Defining the parameters for air as a ambient medium in Fig 6 as

![Fig 6: Screenshot depicting the single Fiber profile with ambient medium as air defined in the optigrating 4.2.2 Software](image)

After defining the fiber parameters, the coupling between the modes LP(00) and LP(08) at wavelength 1.525μm can be shown as in Fig 7 below.
Now to design Long Period Fiber Grating, the parameters defined in Fig 8 and Fig 9 are

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.

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 1.525µm with air as a ambient medium, as shown below in Fig 11.

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 optigrating 4.2.2. 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 1.525µm is designed.

ACKNOWLEDGEMENT

The authors are thankful to University of Delhi and their respective colleges. Thanks are also due to Department of Electronic Sciences, South Campus, University of Delhi and our colleagues for their constant guidance and unconditional support.

REFERENCES


