Modes in a long period grating fabricated on dispersion shifted fiber

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ABSTRACT

In this work we present the modal study of a dispersion shifted fiber (4 layers) and also in a fabricated long period grating in the same fiber type using the RSoft Software ®. For the grating analysis, the refraction index and the diameters were varied to simulate the changes due to the diameter increment provided by the electrical arc discharges effect. The structural optical fiber change, due to the periodic fattening induced by the electric arc, is added to the grating analysis as a sinusoidal type variation in each optical fiber layer. Several wavelengths are considered for the analysis and some of them are the ones commonly used by operational lasers and diodes launched in optical fibers. Results depicted the existence of many excited light modes when working with a wide spectrum white light source. When these modes satisfy the phase matching condition, they will couple in the LPFG providing it of particular filtering characteristics because of the fiber type and technique (fattening) of fabrication.

Keywords: Optical fiber, long period grating, fattening, dispersion shifted fiber, modes.

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1. INTRODUCTION

Recently the fabrication of a long period grating, by using electric arc in a dispersion shifted optical fiber has been presented [1-2]. The special characteristic about these gratings is that by using the fattening technique the diameter's fiber is increased by applying electric arc discharges and by gradually compressing both fiber ends until filtering functions are observed in transmission. Currently, there are several methods to fabricate long period gratings using electric arc discharges from a standard splicer machine. A well known method is the one proposed by Kag Hwang in 1999 [3] which is based on the micro-bending technique induced by electric arc discharges. This is a simple method and could be applied to any type of standard optical fibers. Moreover, these LPGs present low insertion losses of about 0.2dB, high temperature sensitivity (76-180 pm/ºC) and flexibility in the optical parameters of the filter. In 2001, P. Palai et al. applied periodical electric arcs in a SMF-28 and a dispersion shifted fiber. A commercial splicer machine was used and no tension was applied to assure no deformation of the fiber. The fiber was moved from one point to another with a micro-controlled motor to adjust the grating periodicity after the electric arc discharges. The core and cladding index of refraction was modified by dopant diffusion. These LPGs show to have attenuation bands in transmission centered at different wavelengths which depicted the power coupling of 3 low order modes as LP_{01}, LP_{02}, and LP_{03} with band depths of approximately 12dB [4]. A variety of this technique consists in applying axial tension over the fiber with a death weight on a fiber end. This is one of the most used methods to fabricate long period gratings with electric arcs [5]. This method has some advantages, for instance, it is simple procedure of fabrication that does not need expensive laser equipment, neither photo sensitive and nor expensive optical fibers. However, due to the period length of the fabricated LPG, sometimes gratings about 10 cm in length are obtained which could be a fairly disadvantage depending on the application. Continuous research to improve the fabrication techniques with the electric arc method and the fabrication of cheaper and compact devices lead in 2008 to an alternative LPFG technique fabrication. This applied technique is usually used to reduce splices losses on optical fibers and is known as "fattening". For long period fiber gratings, it consists on the periodical and slowly enlargement of the optical fiber diameter until optical filtering functions are

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observed in transmission. In this study, a dispersion shifted fiber with a 4 layer structure was used. Band rejection filters with a 1250nm centered wavelength, an attenuation band depth of less than 20dB and up to 100nm in bandwidth were obtained. Outstanding grating length was achieved of less than 3mm [1]. We have not found in literature a modal study of several layered structures of optical fibers fattened long period gratings, neither of this kind of fiber. Hence, the need to perform an analysis for this type of fiber structure in order to understand its transmission behavior and to have a preliminary study that includes the ideal shaped structure of the fiber after applying electric arcs and fatten up the fiber diameter in punctual regions. Therefore, we present an introductory numerical study using the RSoft® software which will serve as a support for detailed theoretical studies where coupled mode theory might be applied.

2. PROCEDURE

The RSoft® software uses the beam propagation method to perform the necessary numerical computations to simulate light propagation in a waveguide or optical fiber. It is important to establish the refraction index profile of the optical fiber and introduce the necessary information to describe the waveguide parameters as refraction index, radius length, structure type, etc. The program shows the waveguide effective index and modal spectrum, thus, propagation modes information can be obtained. The effective index is describes as

$$\beta = n_{eff}\frac{2\pi}{\lambda} \tag{2.1}$$

The wavelength causes an indirect effect on the propagation constant, so different values of λ are proposed to be used in the analysis. These are 1.55µm, 1.31µm, 1.064µm, 1µm and 0.85µm which correspond to wavelength operation of common laboratory lasers, as well as a white light source on a range of 400-1700nm, that is used when fabricating these type of fattened gratings. In the simulation computation, and ideal index profile is considered for the DSF structure as depicted in figure 1.

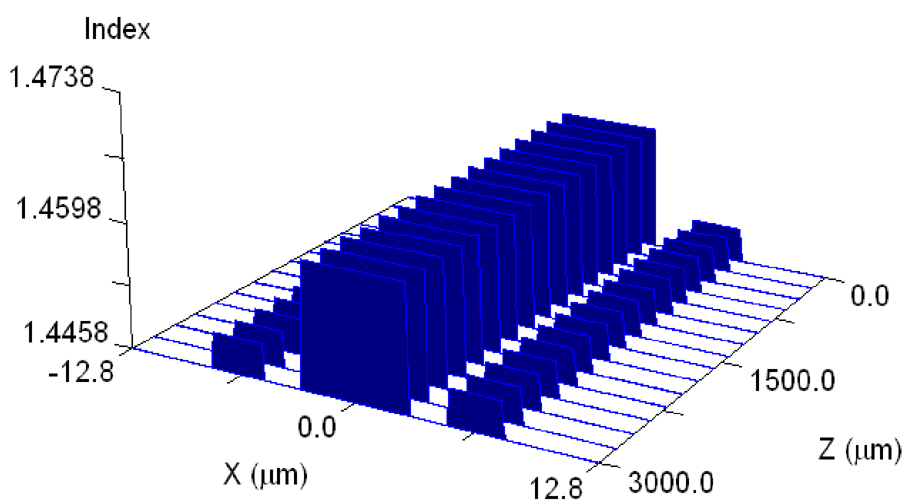

Fig. 1 Idealized step index profile of a dispersion shifted fiber.

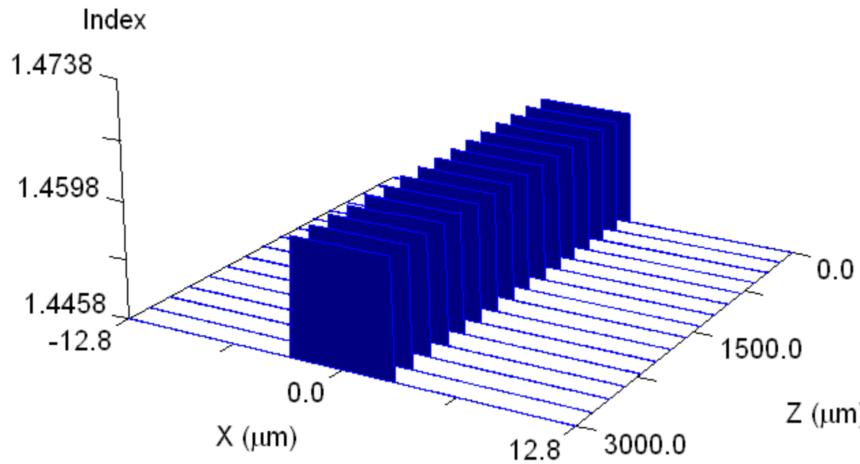

Fig. 2 Idealized step index profile of a dispersion shifted fiber central core.

The structure radii parameters considered were: $a=2.9\mu m$, $b=5\mu m$, $c=8\mu m$, and the index refraction values were: $n_1=1.4598$, $n_2=1.4498$, $n_3=1.4498$ *and* $n_4=1.4458$ [1]. The starting analysis wavelength is 1.55µm which is the operation wavelength of the fiber. In order to provide a complete analysis of the full structure, and considering that we are interested in the modal characteristics, we divided the optical fiber in two regions as in reference [2]. A central core region and a ring core region where light is confined and freely propagates. Such effect is given by the total internal reflection set by the higher refraction index. These regions are depicted in figures 2 and 3.

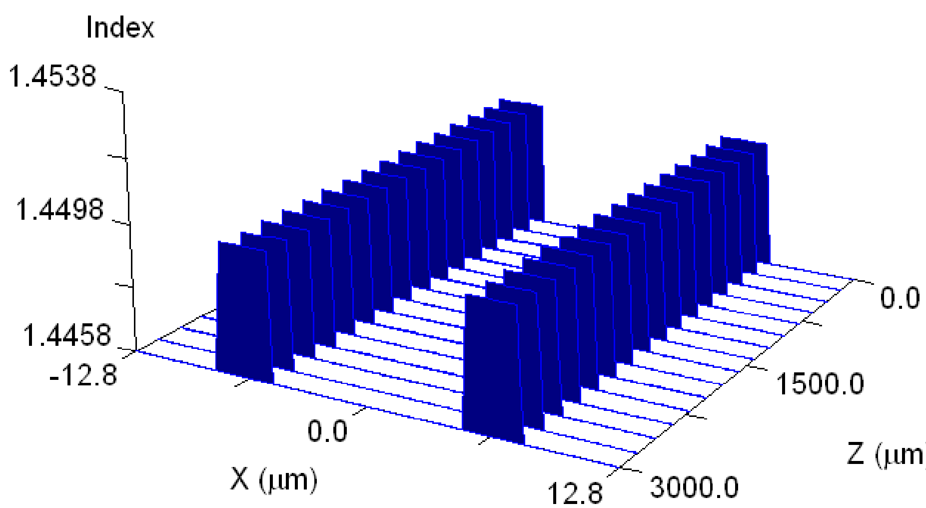

Fig. 3 Idealized step index profile of a dispersion shifted fiber ring core.

After the numerical computations of the plain dispersion shifted fiber, we proceed with the fiber modal analysis of the long period grating structure. For this purpose, a single sine periodic perturbation is simulated over a small region of the fiber structure to represent the ideally fattened points induced with the electric arc as depicted in figure 4.

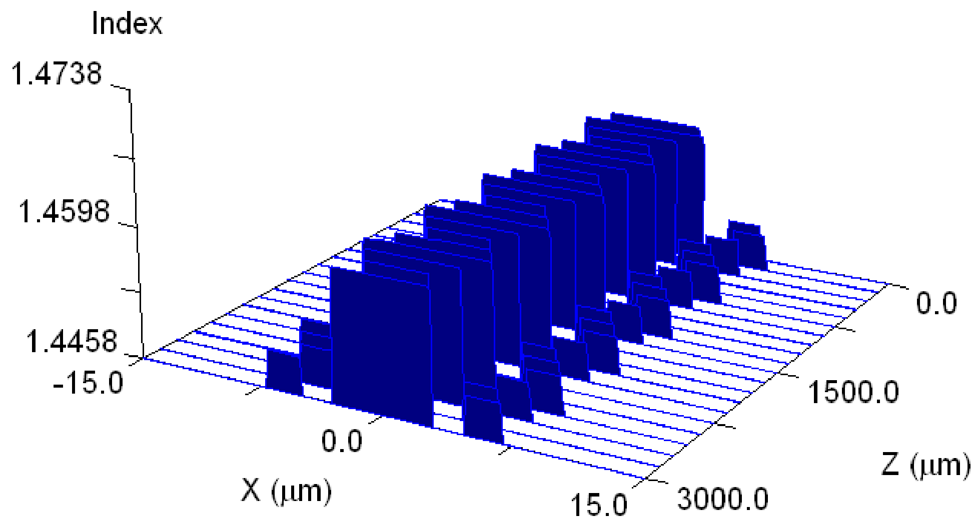

Fig. 4 Idealized step index profile of a dispersion shifted fiber fattened long period grating..

During the experimental process, this technique modulates the index of refraction of the different layers at a period rate of 150μm. Thus in the analysis, different index of refraction values are included besides the original ones. Since we do not know how much these parameters increase or decrease, with the induced changes produced by the electrical arc discharges over the glass, we presume values in a range of $\pm 10\%$ and ± 5. We also propose an increase variation of the fiber diameter proportional on the number of arc discharges and the times the fiber is compressed by an 11μm z-push manually produced by the splicer chucks. This process fattens up the fiber so we use 3 different diameter sizes to represent the parameter variation.

3. RESULTS

Results show that the complete structure supports the LP_{01} and LP_{11} modes for all tested wavelengths, effect in agreement with reference 2. Calculation depicts that for any wavelength the modal power fraction changes for all modes. It is observed that the central core power decays according to λ and the power of the LP_{11} mode increases. For the divided structure into the central core and the ring core the following results were found. The LP_{01} mode is always excited in the central core region and the power fraction is preserved at 99.9%. The ring core shows single mode characteristics for λ up to 1.064um so only the fundamental mode LP_{01} is excited at a power fraction of less than 100%. For $\lambda = 1.0\mu m$ the LP_{01} and LP_{11} modes are excited and for smaller wavelengths the ring core region depicts a multimodal behavior because several modes like the LP_{01}, LP_{03}, LP_{11}, LP_{21} are excited. It is worth to remember that in this part, the radii values and index of refraction are not changed in any simulation and they are the same of the original waveguide.

Simulations for the fattened long period gratings with diameter sizes of $a = 4.98\mu m$, $b = 8.59\mu m$ and $c = 13.74\mu m$ with changes in the index of refraction of ± 10, ± 5 units, indicates that even though the changes of the index of refraction, the LP_{01} and the LP_{11} modes will be excited at any wavelength. Small changes on the radii sizes like $a = 6.64\mu m$, $b = 11.46\mu m$, and $c = 18.33\mu m$ exhibit the same modes for all wavelengths. Greater changes on radii sizes like $a = 8.31\mu m$, $b = 14.32\mu m$ and $c = 22.91\mu m$ show that for λ values up to 1um, the LP_{01} and LP_{11} modes are always excited. Shorter wavelengths excite the LP_{01}, LP_{11}, LP_{21} and the LP_{03} modes for any index of refraction variation. Figure 5 depicts some of the modes found to be excited on the fattened LPFG structure.

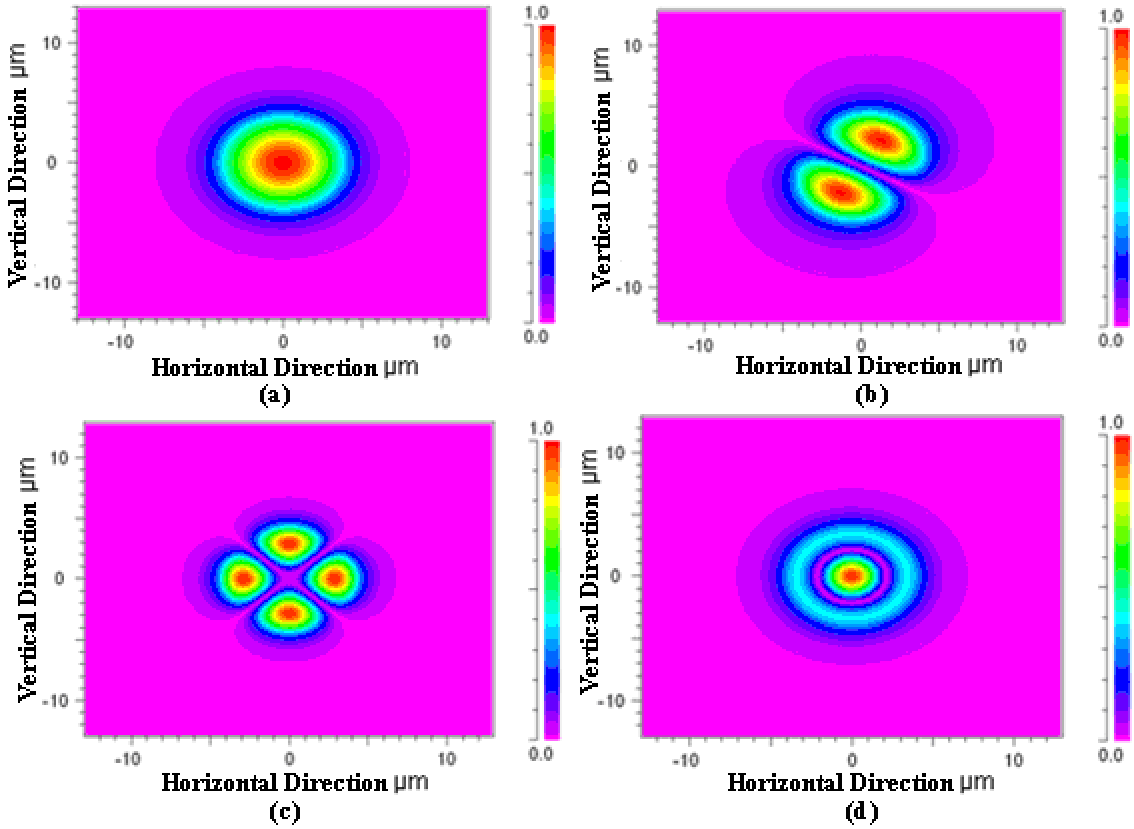

Fig. 5 Computed modes possible to couple in a fattened LPG, a) LP_{01}, b) LP_{11}, c) LP_{21} and d) LP_{03}.

The mode spectrum figures show one or two peaks of the guided modes supported by the fiber in different regions as the central core, the ring core, the complete structure and the long period grating structure. The height of the peaks is equal to the power fraction of the input field that is contained by each mode. Thus, we can observe how they change due to the wavelength and other considered parameters. See figure 6.

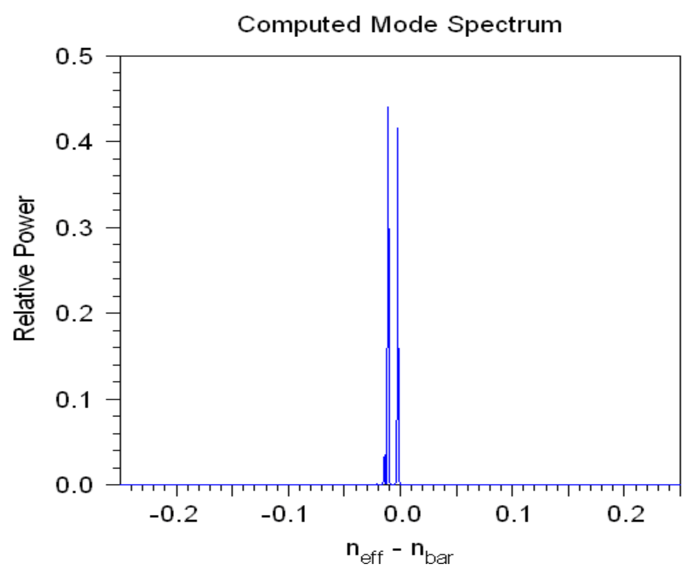

Fig. 6 Modal spectrum computed for the complete structure of a dispersion shifted fiber.

4. CONCLUSIONS

We have presented the modal study of a 4 layered optical fiber and a fattened long period grating with the same type of fiber. It has been convenient to make the analysis or simulation of the fiber separating it in two different regions as the central core and the ring core. This is appropriate because the full structure always shows the excitation of two modes, the fundamental LP_{01} and the asymmetric mode LP_{11}. The ring core resulted multimodal at wavelengths below the cutoff wavelength of $\lambda = 1.26\mu m$ and single mode up to this wavelength. The analysis of the fattened long period grating was realized with the complete structure considering its basic operation, this is, that it couples light from the central core to the ring core. The size of the fattened point, or wider diameter, on the fiber, influences on the number of excited modes. There are more modes with bigger diameters than the ones observed in the original fiber. The variation of the refractive index induced with the electric arc, does not affect notably in the quantity and mode orders.

In general, it is the wavelength and the fattened diameter that induces the modal excitation. The period (>100nm) of the long period grating, permits the mode coupling if the phase matching condition is accomplished. The simulations depict that there are many excited modes that can couple when a wide spectrum white light source is used. Besides, the asymmetric structure, due to the electric arc, seems to influence in the bandwidth of the loss band which explains the more than 100nm width. This could be corroborated with a detailed analysis using coupled mode theory. Specifically, the fattening method achieved by using electric arc discharges contributes with the many excited modes at different wavelengths, known as low and high order modes. The effective index variation and the periodicity of the grating contribute to the number of modes that are coupled to achieve an attenuation band in transmission with a resonance wavelength. To lower the insertion losses, according to the distributed power fraction between modes, it could be convenient to fabricate them and use them at wavelengths up to the cutoff wavelengths. Also, to avoid an excess of excited modes and reduce the bandwidth, it could be convenient to use medium or low spectral range light sources so this flexibility can be exploited for sensing applications.

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