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In-house fabrication and detailed analysis of fiber optic long period grating using electric arc discharge method

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Dedicated to Professor Bishnu P Pal for his enormous contributions to the advancement of research and education in science and technology through his unique vision and outstanding dedication

In this paper, we have demonstrated the recent results about the inscription and optimization of long-period grating (LPG) by means of the electric arc discharge (EAD) method. For these purposes, we have employed two different kinds of fibers such as single mode fiber (SMF) and a few modes fiber (FMF). We have optimized the proper combination of arc time and arc power which allows appropriate core and cladding modulation for desired LPG spectral features. These reported results may find potential applications in the field of sensing applications especially in biosensing and chemical sensing where miniaturization along with the higher intrinsic sensitivity is of paramount importance.

Keywords: Long period grating, Fiber optic sensors, Measurement.

1 Introduction

Long period gratings are periodic perturbations of refractive index in optical fiber, with periodicity ranging between 100μm – 1mm which rely on coupling the light from the fundamental core mode of a single-mode fiber to cladding modes. As a result, one or more attenuation bands are visible in the fiber transmission spectrum [1]. Such devices find wide applications for their sensing features since the position of the attenuation band depends on temperature, strain and surrounding refractive index. Many techniques have been reported for the fabrication of LPG, among which the Electric Arc Discharge (EAD) technique has gained much importance in recent years for its advantages of easy step-by-step fabrication, direct method, flexible and economical. There are some fiber dopants which perform a major role while designing a fiber with novel physical and optical properties such as refractive index contrast, melting properties etc. In case of doping fibers, the EAD technique is the most unique because it does not rely on such properties. EAD leads to point-by-point LPG inscription by localized thinning of the transversal size of the core and cladding region along with the fiber, and also by changing the refractive index of silica due to the stress relaxation induced by local hot spots. Few inherent effects in the fiber such as stress relaxation, dopant diffusion and geometrical deformations arise during the arc discharge technique while fabricating the gratings [2-9]. One of the most appealing features of this technique is the intrinsic possibility to write gratings in all kinds of optical fibers [10].

In this paper, we have reported our recent results on the fabrication and optimization of LPG in different kinds of optical fibers. Single mode fiber (SMF) and the few-mode fibers (FMF) have been taken

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into consideration for these purposes. We have optimized the proper combination of the arc power and the periodicity with optimized weight applied onto the grating along the length of the fiber.

2 Theory of long period grating

LPG fiber structure consists of two types of waveguides - the high refractive index core and the lower refractive index cladding. The phase-matching condition between the core mode and co-propagating cladding modes could be achieved at the wavelength λ by the equation [11]

$$\lambda = [n_{eff}(\lambda) - n^{i}_{clad}]\Lambda \tag{1}$$

where $n_{eff}(\lambda)$ is the effective refractive index of the core mode, n^{i}_{clad} is the refractive index of the i^{th} cladding mode at the wavelength λ and Λ is the periodicity of the grating.

The transmission dips in the attenuation band of the fabricated LPG could be expressed by the equation

$$T_i = 1 - \sin^2(k_i L) \tag{2}$$

where L is the length of the fabricated grating and k_i is the coupling coefficient of the i^{th} cladding mode.

Due to the larger diameter of the cladding (125 µm) compared to the core (9 µm), cladding supports a larger number of modes. LPG induces coupling between modes traveling in the same direction at the resonant wavelength. Therefore, LPGs promote the selective coupling between the core fundamental mode and the cladding modes. As the evanescent field overlaps in fiber, the coupling between the core and cladding modes of fibers may happen. Theoretically, it has been shown that efficient coupling would be possible if the core and the cladding modes have similar electric filed distribution characteristics [12]. As a result, a coupling of odd order between the circularly symmetric cladding and the propagating core mode is observed. This odd order coupling is due to the low field amplitude of the electric field of even order modes within the core, while a peak could be found corresponding to the electric field distribution of the odd order modes within the core [12].

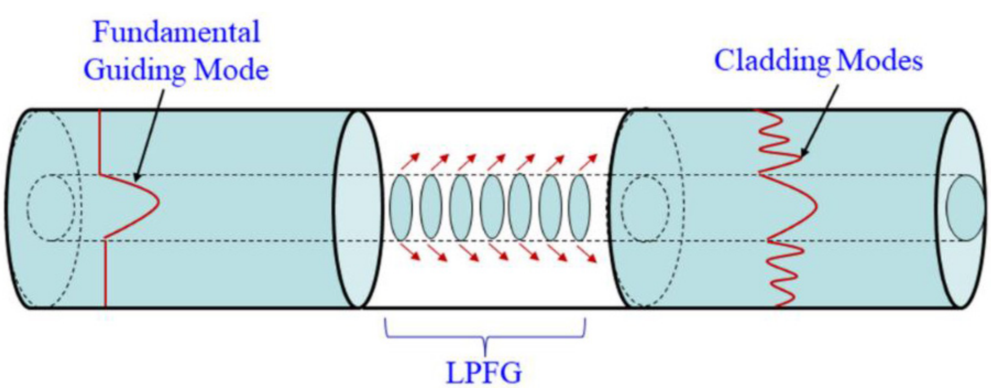


Fig 1. Schematic of the Long period grating

Figure 1 shows the schematic of the long period grating. The fundamental guiding mode inside the core and the copropagating cladding modes are shown in this figure.

3 Experimental Details

The operating principle behind this fabrication technique involves a certain stripped of optical fiber positioned inside a commercial fusion splicer (Fujikura 60S) between two electrodes which are electrically connected to a high voltage power supply that efficiently discharge. During the entire process, both sides of the stripped portion of the fiber is firmly fixed on two customized fiber holders ensuring the minimum tension and straightness of the fiber between two electrodes to maintain an even power distribution on the fiber. In order to create the perturbation, the arc discharge was applied to a specific section of the uncoated optical fiber. The arc discharge was repeated several times in order to induce a periodic perturbation until the desired spectral features are reached. The proper selection of power and duration of the arc time allows the control of modulation strength and thus LPG spectral features. Furthermore, the splicer is kept on a micro-translational stage platform connected with a single axis micro position controller, which was controlled by computer programming. The set up was designed to permit the fabrication of gratings without creating any bending in the fiber during the fabrication process of LPG.

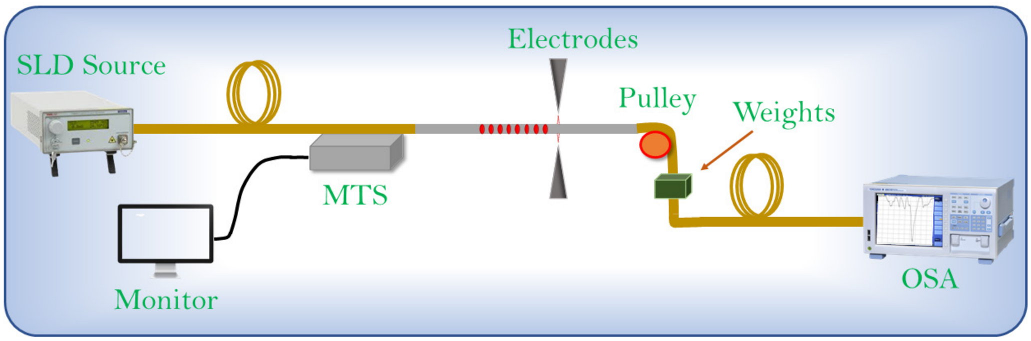


Fig 2. Schematic of the experimental set-up for fabricating the LPG; SLD: Super-Luminescence Diode, MTS: Micro-Translational Stage, OSA: Optical spectrum analyzer;

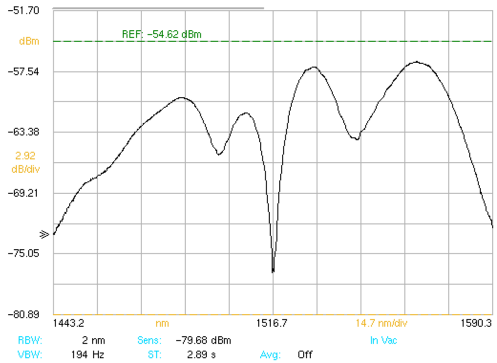
The LPG transmission spectra were recorded with an optical spectrum analyser (OSA - Agilent 86142B), while the illumination was provided by an SLD source of C band (Thorlabs).

5 Results and Discussion

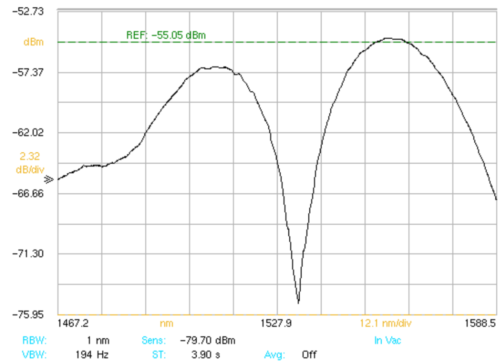
In this section, we report the fabrication of long-period gratings by means of the EAD method and also optimize the proper combination of arc time and arc power to get the expected spectral features of LPG. For this purpose, we have taken two different kinds of fibers namely single-mode fiber (SMF 28e+) and a few modes fiber (980 HP and 1310 BHP).

1. *Fabrication of LPG in Single-mode fiber* (*SMF 28e+*)

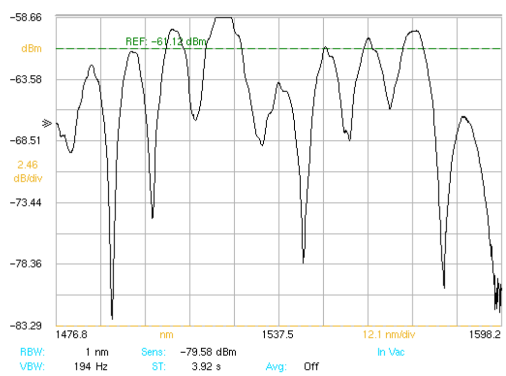
In the case of SMF fiber, results show that as the grating length is increased, the power of the transmission spectrum decreases. The observed powers at grating lengths of 3.2 cm, 4 cm and 4.65 cm are 19 dB, 15 dB and 11 dB, respectively. This indicates that as we increases the length of grating, the depth of attenuation of the spectrum becomes less. The strength of the LPG fully depends on the proper combination of arc power and arc time. With standard arc power for the arc time 300 ms and periodicity of 500 µm beyond 4 cm length, the achieved LPG spectrum is shown in Fig 3(a). Whereas, Fig 3 (b) shows the spectrum of designed grating for the lowest grating length of 0.5 cm with arc power of standard +2 bit, arc time of 300 ms and periodicity of 500 µm. This is because of the combination of arc time and arc power which affect the coupling modes of the core and cladding and also the coherence length. We have achieved the highest grating length of around 10cm using the combination of arc time and arc power 300ms and 500µm, respectively with the standard +2 bit power. Also, it is noticed that the spectrum is repeated after a certain periodic length of grating. Figure 3(c) shows the LPG spectrum with the higher-order mode excitation. In this figure, up to 8th order mode could be observed. As the arc time increases, higher-order modes are getting excited at lower grating length.



(a)

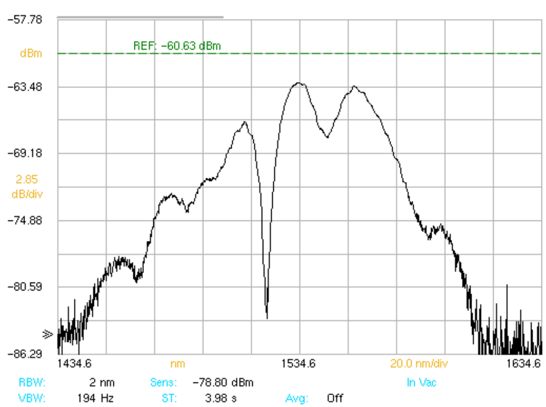


(b)

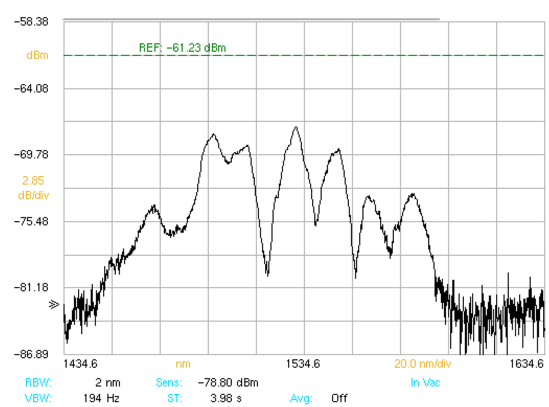


(c)

Fig 3. Transmission spectra of LPG fabricated SMF 28e+ for (a) arc time=300ms, Λ = 500µm, std power; (b) grating length of 0.5cm; (c) LP_{01}-LP_{08} modes. Up to eight order modes have been observed at the lowest length of the 5.3 cm of grating length for arc time and periodicity of 300ms and 450µm respectively with standard power.



(a)



(b)

Fig 4. Transmission spectra of fabricated LPG on FMF (a) 1310 BHP and (b) 980 HP fiber.

2 Fabrication of LPG in few-mode fiber (*FMF*)

Here, we describe the LPG fabrication in two different types of FMF fibers. One fiber has the core diameter of 8.5 µm (1310 BHP) and another fiber has a core diameter of 3.6 µm (980HP).

From Fig 4, it can be seen that for a few modes fiber many transmission dips are observed. In the case of 980HP fiber, many spectra can be observed compared to the 1310 BHP fiber. It can be concluded that such peaks are caused by the coupling between the core modes and cladding modes, rather than caused by the self-coupling between the core modes. Such transmission spectra were achieved for the arc time = 200 ms, arc power = std +5 and periodicity = 600 µm.

Table 1. Experimental aspects for different types of fiber

Fiber Type	D_{core} (µm)	$D_{cladding}$ (µm)	Grating Period (µm)	Arc Step	Arc Time (ms)	Highest Depth (dB)
SMF 28e+ (Corning)	8.6	125	450	+2-bit	300	~21
1310 BHP	8.5	125	600	+5-bit	200	~17
980 HP	3.6	125	600	+5-bit	200	~12

6 Conclusions

In conclusion, we have optimized the proper combinations of arc time, arc power and periodicity to get the desired LPG spectrum in single-mode optical fiber (SMF-28e+). We have achieved the highest grating length of around 10cm using the combination of arc time and arc power 300ms and 500µm respectively with the standard +2-bit power. Whereas, the lowest grating length of 0.5cm has been achieved using the combination of arc time and arc power 500ms and 500µm, respectively. Grating length in terms of periodicity has an adverse effect on the transmission spectrum of the LPFG. There will be a noticeable shift in the resonance dip as well at the number of different coupling modes. These short and large types of gratings are very useful for sensor application purposes and can be employed in the measurement of surrounding environment changes due to strain, temperature and refractive index. The highest slope region of ~19nm is achieved for arc time and periodicity of 300ms and 450µm, respectively with standard power. This larger slope region is useful for interrogation techniques as well as in-band rejection filter applications. This work can further be extended to optimize the depth of the attenuation bands for a different combination of arc time, arc power and periodicity. Furthermore, we have fabricated the LPG on two different types of few-mode fibers. For this purpose, 980 HP and 1310 BHP fibers have been taken into consideration. Different types of higher-order modes were observed in the former case. This is because of the coupling between the core modes and cladding modes, rather than caused by the self-coupling between the core modes. This analysis may find a wide range of applications in multiparameter sensing, generation of optical vortices, etc. To characterize the LPFG, different tests could be performed such as temperature, strain, refractive index, etc. By performing these tests, different informations like shifts of the resonance wavelength, transmission depth, etc can be monitored. Furthermore, the high sensitivity, the simple structure would enable the FM-LPFG sensor to be used in various applications such as chemical and biological sensing fields.

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