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Small fluence photosensitivity of high germanium doped core optical fibers from 266nm UV irradiation

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Abstract

The photosensitivity of high germanium content optical fiber was investigated with reference to UV laser of 266nm center wavelength. Bragg gratings were inscribed into the fiber using scanning phase mask method with a 266nm ultra short pulse laser and refractive index modulation due to irradiation was calculated from the parameters of the resulting fiber Bragg gratings. At small fluence, the high germanium content optical fibers seemingly experience competing photosensitivity mechanisms, dissimilar to the characteristics of common photosensitive optical fibers.

Keywords: term, term, term

1. Introduction

Germanosilicate optical fibers are known to be photosensitive to UV irradiation and a good gain medium for Raman fiber lasers. This photosensitive phenomenon is a contribution from multiple competing physical processes, dominant at different stage of irradiation. Standard Germanosilicate optical fibers (ie. SMF28) doped with low germanium concentration typically display two distinctive photosensitivity types, classified as Type I and Type II [1] photosensitivity. Type I and Type II photosensitivity results in refractive index (RI) increase and decrease of the doped fiber core, respectively. The absorption band in the UV region for such a fiber is centered at around 240nm. Hence, a 244nm Ar-ion laser is widely used for glass processing and grating inscription [2]. However, it has become increasingly popular for 266nm UV laser to be adopted due to the increasing technological maturity of solid state 266nm UV lasers[3, 4]. Despite significantly lower absorption at 266nm tail end of the UV absorption band of Germanosilicate fibers, practical benefit of a 266nm solid state laser system often outweighs this disadvantage.

The high UV photosensitivity of the optical fiber cores of these high germanium content optical fibers coupled with their high Raman gain characteristics give rise to the possibility of fabricating high finesse ultra-short Fabry-Perot (FP) cavities. These FP cavities are created by inscribing fiber Bragg gratings (FBG) in either a distributed Bragg reflector (DBR) [5] or distributed feedback (DFB) [6] configuration within short lengths of the Raman gain fiber itself, forming a single fiber Raman laser with no optical power lost from splicing mismatch fibers.

2. Photosensitivity characterization with fiber Bragg grating inscription

An approach to deposit consistent doses of irradiation and measure resulting RI change accurately is through the inscription of Bragg gratings into the fiber core [7]. Fiber Bragg grating, being periodic modulation of RI along the fiber, is a precision device fabricated through periodic exposure of fiber core to UV irradiation. Measurable parameters of the FBG can give insight to the degree of RI modulation arising from the UV dose.

Commonly, this process to characterize photosensitivity of optical fibers inscribes multiple uniform FBG of the same parameters but with different fluence into different lengths of the same optical fiber and measures reflectivity (R) and Bragg wavelength (λ_{Bragg}) from the spectral response. The resulting index modulation (Δn) can then be calculated using equation (1) with these measurements.

$$\Delta n = \frac{\kappa \lambda_{Bragg}}{\pi \eta} \tag{1}$$

$$\kappa = \frac{\operatorname{arctanh} \sqrt{R}}{L_{FBG}} \tag{2}$$

$$\eta = 1 - 2e^{-2 \log V^2} \tag{3}$$

where κ and L_FBG are the coupling constant, and length of grating. η and V are the mode overlap parameter and V number of the grating optical fiber host, respectively. Hence, for every grating written with known length, fluence, measurable reflectivity and Bragg wavelength, RI change due to the deposited UV fluence can be calculated.

An iteration of the method described above is to repeatably expose the same location on the same length of optical fiber with consistent dose of irradiation through a phase mask. The resulting Bragg grating can be measured and RI modulation calculated using the same method above between each additional dose of fluence [7]. Using a scanning phase mask method with controlled scanning speed, length and power, each scan of the phase mask over the optical fiber will result in the exposure of the fiber to approximately the same dose of fluence. Therefore, with each additional scan, the FBG grows with the addition of one dose of fluence. It is then possible to use measurements after each dose to calculate Δn and observe the evolution of RI from the UV irradiation.

3. Optical Fiber Characterization

Nine HGFs were gathered from three sources (commercial: Nufern, research institute: Optoelectronics Research Centre of University of Southampton and The Photonics Institute of Nanyang Technological University) and characterized for their photosensitivity with reference to a 266nm UV laser.

Table 1: List of high Germanium-doped optical fibers.

s/n	Fiber	%	φ_{core}	n_{core}^*	V*	Fabricator
1	A0020	25	1.1	1.478	1.400	UoS
2	UHNA4	29	2.2	1.485	3.152	NuFern
3	A0033	38	12.1	1.498	19.618	NTU
4	A0641	39	3.5	1.501	5.803	UoS
5	A0032	42	13.9	1.504	23.716	NTU
6	A0029	55	15.25	1.523	29.869	NTU
7	A0025	62	17.24	1.533	35.912	NTU
8	A0037	70	2.8	1.544	6.209	NTU
9	A0803	100	3	1.587	8.009	UoS

* with respect to 1550nm light

Bragg gratings were inscribed and RI modulation due to irradiation calculated from grating parameters. All the fibers were measured using an index profiler (IFA-100). The fibers were also inscribed with a Bragg grating with known grating pitch and measured to determine their effective index. It was found that most of the fibers are multimode at communication wavelength due to the large RI step between core and cladding and their core sizes. As only UHNA4, A0641 and A0037 are near single mode, these three fibers were selected for further investigation. However, A0037 exhibits low photosensitivity at small fluence doses of 50 J/cm2 and so was also excluded from the study. The cause of this observation is not well known but is believed to be the lack of defect states, since the fiber core is now essentially Germanium based, with over 70% concentration of Germanium, resulting in the unlikelihood for Ge-O defects to form.

4. Experiment and result

Phase mask scanning method was employed to inscribe 5mm gratings into two high germanium doped fibers, UHNA 4 from Nufern and A0641 from Optoelectronics Research Centre, under identical conditions. RI profile of the fibers presented in figure 1 were taken with IFA-100 Fiber Index Profiler, giving insight on the RI distribution across the fibers and their fiber core sizes.

UHNA 4 fabricated by Nufern is a commercial fiber with n_{core} of 1.485, n_{eff} of 1.456, NA of 0.347 and 28:3% GeO_2 in core. A0641 fabricated by Optoelectronics Research Centre is a special fiber with n_{core} of 1.501, n_{eff} of 1.482, NA of 0.409 and 39:7% GeO_2 in core. All RI were measured with respect to 1550nm light.

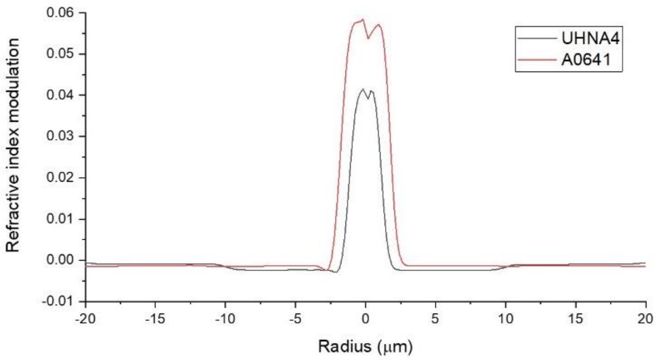

Figure 1: Refractive index profiles of two high germanium content optical fibers under test.

The UV irradiation is from a 266nm 20 Hz, 5ns pulsed laser of average power 15mW. Speed of translation and focus of beam is adjusted to deposit a fluence of 50J/cm^2 per scan. Both optical fibers underwent the same process with 100 UV irradiation scans amounting to a total fluence of 5kJ/cm^2 deposited. After each scan, the Bragg wavelength and reflectivity were immediately measured before commencing the next dose of irradiation. From the Bragg wavelength and reflectivity of the resulting FBG measured on the Optical spectrum analyzer, index modulation was calculated. Figure 2 plots the RI evolution of the fibers throughout the process.

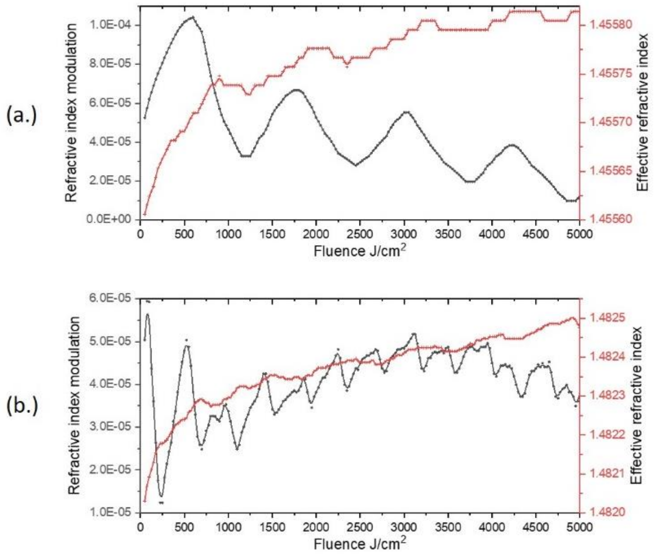

Figure 2: Refractive index modulation and effective index evolution of a.) UHNA 4 and b.) A0641.

There is a clear periodic positive and negative RI modulation for both fibers. When compared to the evaluation of effective RI of the grating fiber, it is obvious that effective RI evolution follows the trend of RI modulation. Every period exhibits close to identical shape. This is not observed for large fluence irradiation [8] in extremely high germanium dopant level of over 90%. To eliminate the influence of any environmental factors, the experiment was isolated on the optical table shielded from any potential air draft and laser power was measured every 5 scan and was found to be stable with no measurable power drift. Experiment was repeated on different segments of the optical fibers yielding identical results.

5. Conclusion

An interesting phenomenon was observed with RI evolution of silica fibers doped with a high concentration of germanium in its core. All care was taken to eliminate the possibility of external influence and measurement errors. The periodic behavior seemingly indicates that there are competing photosensitivity mechanisms at work when the fibers were irradiated with small doses of 266nm UV irradiation. It reasonable to postulate that this phenomenon is due to closely competing Type I (positive index change) and Type II (negative index change) photosensitivity. Type I photosensitivity is believed to be caused by optically induced densification of the glass structure whereby Type II photosensitivity is believed to be due to GeO2 defect resulting in glass molecular structure dilation when irradiated with UV light. At higher concentration of GeO2 of 30-40% in core, it is possible that contribution by both photosensitivity mechanisms resulted in the observed results.

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