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Hypolito J. Kalinowski
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Fiber Bragg Grating regeneration temperature in standard fibers

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ABSTRACT

In this work, the regeneration process of FBGs written into both standard and bend-insensitive fiber has been studied. Several dopants present in these fibers lead to different regeneration properties which, based on previous experiments, have been tested, paying special attention to the regeneration temperature. The achieved results suggest a reduction on the regeneration temperature for FBGs written into bend-insensitive fiber that favors mechanical properties of silica.

Keywords: High temperature, Fiber Bragg Gratings.

1. INTRODUCTION

Installation of optical fiber sensors have become more important currently. The growing amount of reported field applications of OFS technologies is an evidence [1] of the possibility of photonic devices. Within the widespread flavors of photonic devices that have been tested under field conditions, Fiber Bragg Gratings (FBGs) [2] have highlighted for their linearity when applied as physical sensing element.

Many monitoring scenarios traditionally have accepted FBGs as main OFS technology such as Structural Health monitoring of civil engineering, transportation infrastructure and even renewable energies [3]. Most part of these scenarios can squeeze the benefits exhibited by OFS techniques (their immunity to electromagnetic interference or their capability to operate into harsh environments) and particularly of FBGs, which can provide very linear measurements at several locations thanks to their multiplexing capabilities.

However, these “traditional” applications of FBGs usually are limited” to the “comfort-area” of silica gratings (temperatures under 500 °C) because structures to be monitored usually provide the mechanical limitations of both elements (structure and sensing elements). Nevertheless, beyond this working temperatures, there are still many scenarios where OFS and particularly FBGs can provide useful information. A clear example of this limitations is the extremely high temperature sensing using optical fiber such as for monitoring some industrial process.

Mechanical properties of silica have shown a remarkable good linearity (regarding their thermal expansion coefficient) at temperatures under 1000°C [4] However, despite the hosting material (silica for standard optical fiber) may be able to reach high temperatures from a mechanical point of view, its optical properties may not be maintained. This scenario is especially critical for UV-induced Fiber Bragg Gratings, where many different physical changes in silica caused at high temperatures may “erase” the modulation of the core refractive index, removing the Bragg reflection peak. Although certain temperature limits can be overcome by thermal stabilization techniques [5], a more interesting approach is based on FBG regeneration [6] that can increase the working temperature of Fiber Bragg Gratings.

Based on regenerated FBG technology, several proof-of-concept devices have been tested reaching temperatures up to 1295°C [7] exhibiting optical stability. However, this working temperature deteriorates drastically the mechanical properties of silica thus, achieving “low temperature” stabilization which weaken silica properties could be very interesting in order to achieve field-applicable sensing devices.

In this work, the thermal conditions to produce the regeneration of UV-written FBGs have been evaluated for two fiber types: standard SMF (G652) and bend-insensitive (G657). Similar seed FBGs have been written into these fibers before performing a thermal annealing process to achieve their regeneration. Different temperatures of regeneration have been empirically obtained, being lower into the bend-insensitive fiber, achieving a less-deteriorated sensing element.

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2. REGENERATED FIBER BRAGG GRATINGS

Different ideas have arisen during these years trying to explain the complex process of FBG regeneration. First explanation originated after this phenomenon was observed, rely on a diffusive interpretation [8], where the regeneration only happens when specific dopants are present in the fiber. Although many different process take place when the fiber is at very high temperatures, this interpretation gave way to another mechanical approach [9] where a seed grating becomes a permanent modification within the fiber structure because of the glass transformation. This permanent perturbation is mainly originated by the difference between thermal expansion of core (with different dopants) and cladding that, under very high temperature conditions, provoke a relevant stresses according to the period of the seed FBG [6].

Despite the complexity of FBG regeneration, last theories remark the mechanical transformation as the main contribution to achieve a regenerated FBG [6]. This phenomenon, makes possible an engineering approach to obtain reliable regenerated FBGs where, having strict control of regeneration conditions, many FBGs can be regenerated with high repeatability. Particularly, modifying the dopants within the optical fiber, the properties of the seed grating, the chosen UV-laser source and the thermal annealing, different methods can be empirically adjusted to achieve the regeneration. Any variation of these parameters may change the regeneration temperature, which can be reduced by changing the UV-laser source of the seed writing process or increased by employing different dopants [6].

3. EXPERIMENTS AND RESULTS

Two standard optical fibers from Draka Comteq (G652 and G657) have been studied paying special attention to their regeneration temperature. Main difference between the bend-insensitive (G657) fiber and the standard is regarding their refractive index profile. The bend-insensitive fiber exhibits a lower refractive index surrounding the core, to reduce the optical losses when an aggressive bend is applied. The refractive index reduction is provoked by other dopants in comparison to the standard G652 fibers that also may affect at very high temperatures, particularly during regeneration. In Fig. 1, the refractive index profiles of both tested fiber have been depicted.

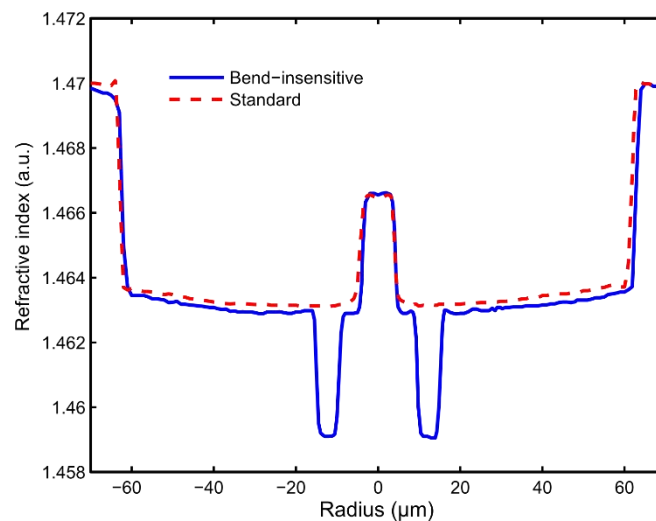


Figure. 1. Refractive index profile of both fibers standard (dotted line) and bend-insensitive (solid line).

Several FBGs have been written using a continuous laser emitting at 244 nm using the phase-mask technique. FBG writing parameters such as length and laser power have been maintained during the process. However, both fibers exhibit different photosensitivity after the hydrogen-loading process thus the visibility of written FBGs may differ. This does not have remarkable influence on the regeneration temperature, but the initial FBG erasing results slower.

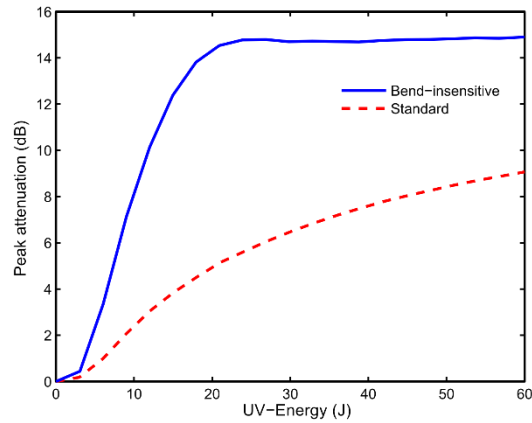


Figure. 2. Measured photosensitivity curves of both fibers for the employed UV-laser.

In Fig.2, the photosensitivity of both standard and bend-insensitive fibers has been empirically obtained. The continuous UV-laser Gaussian spot of approximately 0.8mm diameter has been passed through the phase mask to write a short FBG in each fiber. Several transmission spectra have been captured each 30 seconds, while the FBG reflectivity increases. As depicted in Fig. 2 the bend-insensitive fiber exhibit a higher sensitivity to the chosen UV source that can produce stronger FBGs.

The FBGs written in both fibers have been regenerated employing a pre-annealing step centered at 250°C for 1 hour. A controlled temperature ramp has been applied to both FBGs, reaching 900 °C for the standard fiber and 850°C for the bend-insensitive fibers. These temperatures have been empirically trimmed to where the FBG erasing process becomes more efficient, that matches the regeneration temperature.

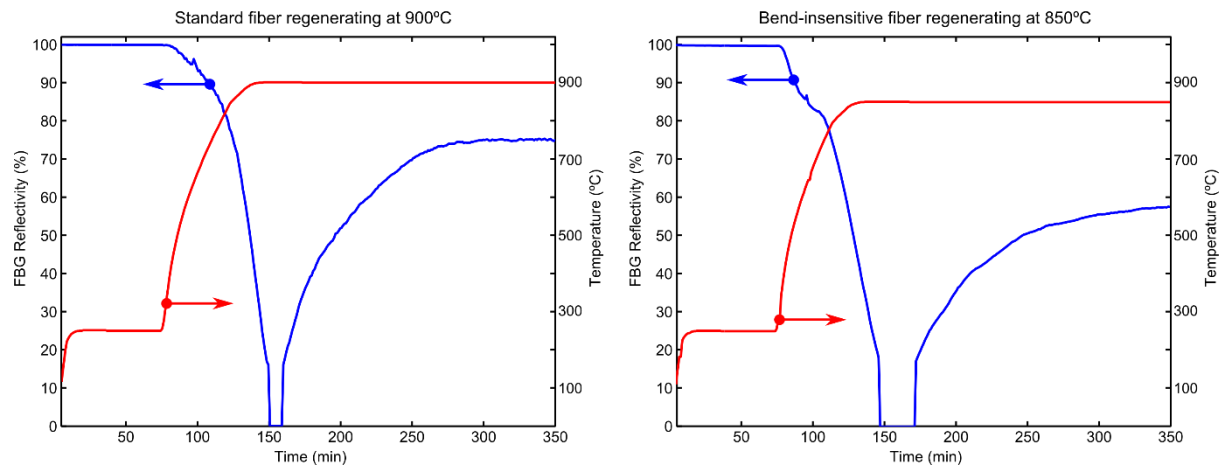


Figure. 3. Reflectivity of both FBGs during the regeneration process at different temperatures.

In Fig. 3, the FBG evolution during the regeneration process has been depicted for FBGs written into both fibers: standard (left) and bend-insensitive (right). As suggested, FBGs written into the bend-intensive fiber exhibit full regeneration at lower temperatures: 850°C in comparison to the 900°C required for standard fiber. Obtaining lower regeneration temperature reduces the mechanical degradation of silica, that suggest a better performance

Both regeneration temperatures have been empirically verified writing several FBGs with different properties (length and UV exposure) in both fibers. It has been confirmed that the regeneration temperature does not depend on FBG writing parameters but does depend on UV laser source and employed fiber. However, writing speed has been trimmed according to the photosensitivity of each fiber trying to obtain similar visibility in both FBGs: starting peak attenuation of the “standard” FBG was 35 dB vs the “bend-insensitive” of 32dB). However, several regeneration tests have been performed using FBGs with different visibilities and the same regeneration temperatures have been obtained. Fiber photosensitivity

only affect to the visibility of seed gratings (and, therefore, to the regenerated FBG reflectivity [6]) but it does not affect to the regeneration temperature.

Although, FBGs regenerated at lower temperatures may improve the mechanical response of silica fiber, their optical properties are less stable at high temperatures, particularly beyond their regeneration threshold. In Fig. 4, reflectivity of regenerated FBGs have been depicted during two heating pulses, reaching 850°C and 900°C respectively. FBG regenerated in standard fiber maintains its optical properties even at 900°C. On the contrary, optical properties of the regenerated FBG written into bend-insensitive fiber starts to re-erase at temperatures beyond its regeneration threshold (850°C).

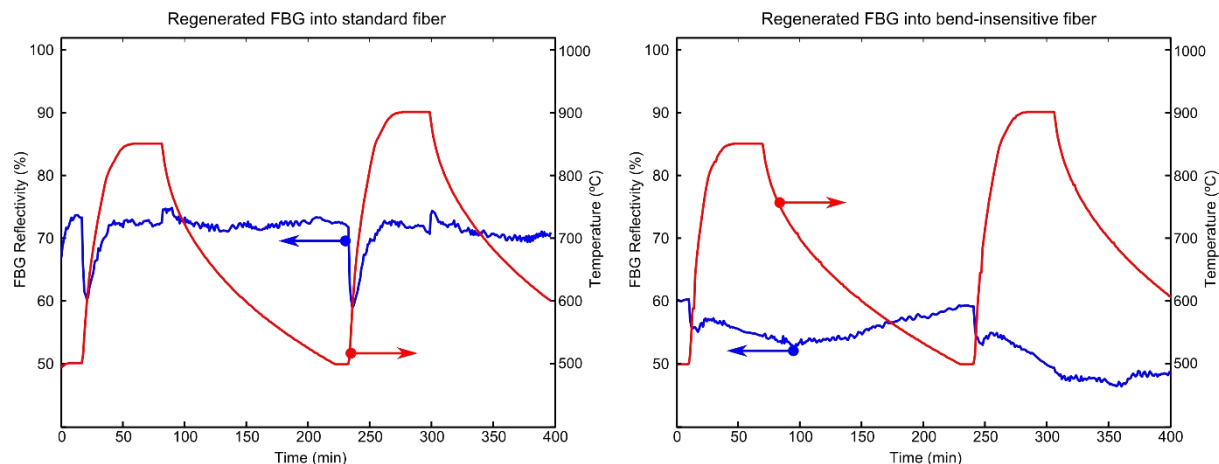


Figure. 4. Several heating pulses have been applied to reg. FBGs written into standard (left) and bend-insensitive (right) fibers.

4. CONCLUSION

Although many parameters have influence on FBG regeneration, several of these have been isolated to achieve a better understanding of the regeneration process of FBG written into different standard fibers. Several experiments have been completed employing the standard and bend-insensitive fibers to write several FBGs before regenerating them. The achieved results confirm a reduction on the temperature threshold when regenerating FBGs written into bend-insensitive fibers. However, since this temperature reduction may be less aggressive to mechanical properties of silica, optical stability of regenerated FBG can be only guaranteed up to their regeneration temperature, being more limiting for bend-insensitive fibers. Special thanks to Javier Arozamena for his valuable collaboration with the experimental works. This work has been supported by the project TEC2013-47264-C2-1-R.

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