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Thermal activation of regenerated fiber Bragg grating in few mode fibers

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ABSTRACT

This work demonstrated for the first time, the thermal regeneration of two and four modes graded index fiber Bragg gratings using high temperature tube furnace. During the regeneration process, the seed grating is erased and a new grating with lower index contrast is formed. The thermal calibration shows that the temperature sensitivity of regenerated grating is slightly higher for fiber with larger core. On the other hand, the regeneration temperature is lower for fiber with smaller core. The temperature sustainability up to 900 °C is observed for the produced regenerated gratings in few mode fibers.

1. Introduction

The development of optical fiber-based temperature sensors with good sensitivity, robustness, high temperature sustainability and durability remains a challenge. Several types of fiber optic temperature sensors have been reported. For instance chemical composition gratings(CCG) [1], sapphire fiber gratings [2,3], laser micro-machined cavity-based sensors [4], chemically etched sensors [5] and regenerated fiber Bragg grating (RFBG) [6]. Regenerated fiber Bragg gratings (RFBGs) are well established as temperature sensors for harsh environments particularly for high temperature environments [7]. Much effort has been put into the research of RFBGs due to their interesting properties, in particular the high operating temperature, simple fabrication technique and cost effective production of RFBGs. Canning et al. proposed a model based on thermal and internal stress induced glass crystallization in B/Ge codoped fibers to explain the phenomenon of grating regeneration [8]. High temperature annealing of the FBGs induces periodic variation in the stress of the fiber which leads to crystallization at the interface of the periodic index modulation region. However, more research is still ongoing in order to reveal more information about the mechanism of the thermal regeneration in FBG covering different aspects including fiber types [9], photosensitization techniques (Eg. hydrogen/deuterium/helium gas loading) [10], grating inscription laser source [11] and regeneration procedure [12].

Few mode fibers (FMF) have a relatively larger core diameter than the single mode fiber and sustain few transverse modes. These fibers have higher resistance to mode coupling compared to normal multimode fiber (MMF), but less nonlinearity compared to single-mode fiber (SMF), whilst the dispersion and attenuation characteristics are similar to a standard SMF [13]. Bragg grating inscribed on FMF produces more than one Bragg wavelength, where each Bragg wavelength corresponds to a transverse mode or a coupling of two transverse modes [14]. Therefore, few mode gratings (FMG) can be used for multi parameter sensing, such as temperature, strain, and refractive index. However, a FMG is not thermally stable at high temperature operation conditions. Thermal regeneration has been proven to be a viable solution for improving the performance of FBGs in high temperature environments. To date, there is still lack of investigation of thermal regeneration in FMG temperature sensors.

In this work, the thermal regeneration of FMG is demonstrated using two mode, four mode graded-index and single mode fiber Bragg gratings. High temperature annealing is performed on each grating using a programmed high temperature tube furnace. The annealing temperature is increased in steps up to the regeneration temperature of the grating. The reflection spectra are recorded using optical spectrum analyzer (OSA) in conjunction with a fiber optic circulator and an amplified spontaneous emission (ASE) broadband light source. During the thermal regeneration process, the FMG is fully erased before a new grating with lower strength emerges from the noise level and stabilizes. The higher order modes are unobservable in regenerated gratings due to the weak grating strength. The thermal sensitivity of regenerated two mode

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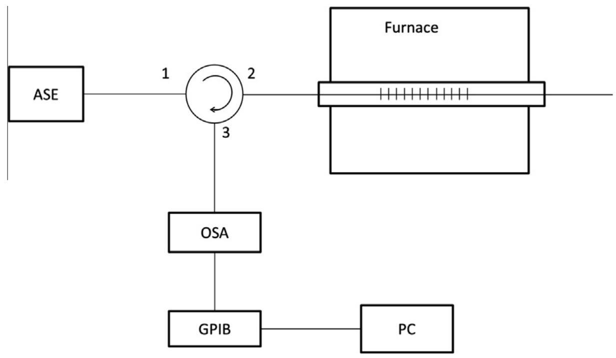

Fig. 1. The schematic diagram of fiber annealing using high temperature tube furnace for regeneration and thermal calibration purpose. ASE: amplified spontaneous emission broadband light source, OSA: optical spectrum analyzer, GPIB: general purpose interface bus, PC: personal computer.

and four mode gratings are similar to that of a regenerated single mode grating. The results indicate that FMG is suitable for thermal regeneration. Regenerated FMG improves the sensing temperature limit of FMG, which makes them potential candidates for multi parameter sensing in high temperature environments.

2. Experiment

In the preparation, two types of few mode optical fibers, namely two mode graded-index (2G) (NA: 0.14, core diameter: 16 μm) and four mode grade-index (4G) (NA: 0.14, core diameter: 24 μm) supplied by OFS, Denmark, together with single mode optical fiber (OFS ZWP-SMF) were hydrogen loaded at ~16 MPa using purified hydrogen gas at room temperature for a week. Subsequently, a 20 mm long type-I uniform seed grating was inscribed on each fiber using a KrF excimer laser (248 nm) at an average pulse energy of 30 mJ. Subsequently, these gratings were dehydrogenated in an oven at 80 °C for ~8 h. During thermal regeneration, the FBGs were annealed in a high temperature tube furnace (LT Furnace STF25/150-1600). The schematic of the experimental setup is shown in Fig. 1. The annealing temperature was incremented continuously from room temperature to the regeneration temperature, where the grating reflectivity decays rapidly until the Bragg reflection is totally erased. The grating was annealed at this temperature until the regeneration process was completed. The reflection spectra were recorded continuously using an OSA controlled by a LABVIEW program via GPIB interface card. The observed regeneration temperatures of SMF, 2G, and 4G are ~950 °C, ~920 °C, and ~900 °C respectively. The annealing temperature was ramped up from room temperature to regeneration temperature in ~100 min (see Fig. 2 green line). As shown in Fig. 2, the refractive index changes of each type of FBG degrade rapidly once the annealing temperature reached the regeneration temperature. The total annealing time for the refractive index change of SMF, 2G, and 4G FBG to degrade and eventually diminish is ~100 min (before regeneration). The refractive index change of the grating was calculated based on the grating reflectivity (R), Bragg wavelength (λ_C), mode overlap parameter (η), and grating length (L) using the equation below [15,16].

$$\Delta n_{\text{mod}} = \frac{\lambda_C \tanh^{-1}(\sqrt{R})}{\eta \pi L}$$

During thermal regeneration, a continuous variation in the grating reflectivity and Bragg wavelength was observed throughout the process. An Optical Spectrum Analyzer (OSA) was used to continuously record the reflection spectra of the grating and the measurement of the grating refractive index change during the regeneration process.

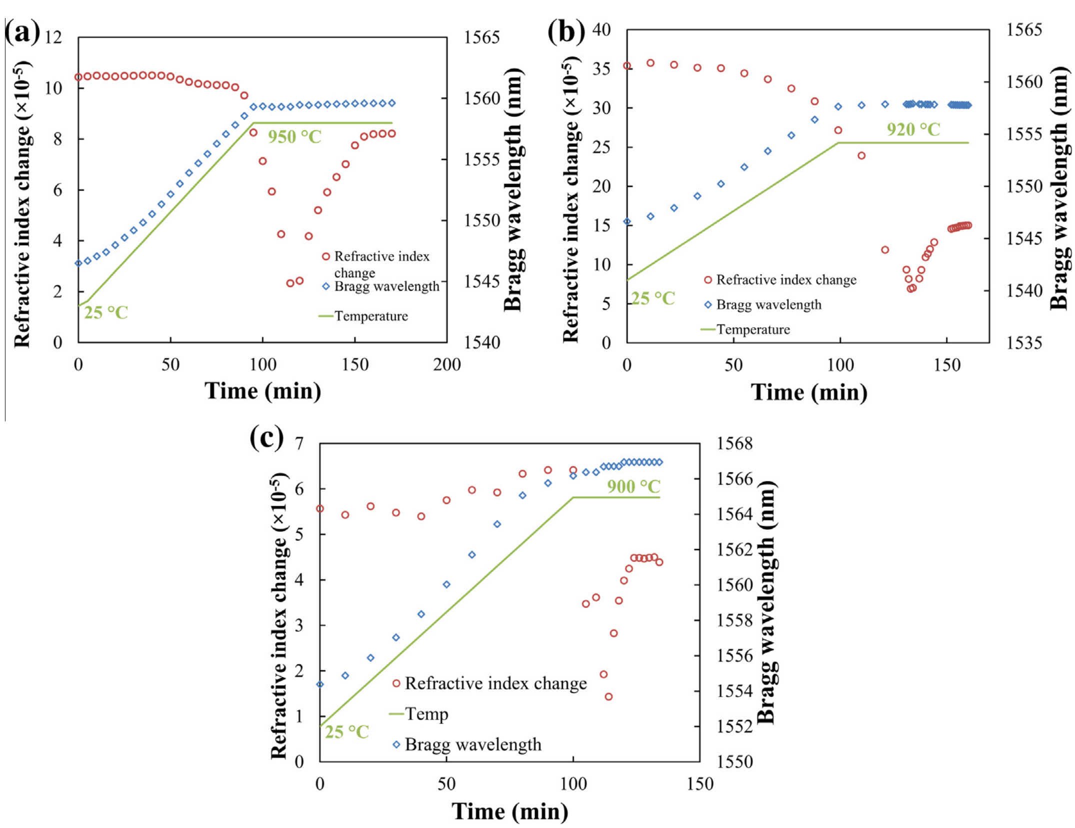

Fig. 2. Output response of (a) SMF, (b) 2G and (c) 4G FBGs during regeneration process.