Behavior of Tilted Fiber Bragg Gratings at High Temperature

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Tilted fiber Bragg gratings are exposed to thermal essays and some aspects related to their behavior are highlighted. The discussion pays special attention to the cladding mode resonances conservation and stability in high temperature environments, as well as to the possibility of their regeneration and improvement.

Introduction

Tilted fiber Bragg gratings (TFBGs) are widely used for optical sensing [1]. They differ from standard fiber Bragg gratings (FBGs) in their ability to couple part of the light out of the core, into the cladding of the optical fiber. This fact, along with some specific coatings added to the fiber, allows plasmon wave generation and their use for sensing the refractive index of the medium surrounding the fiber, which has led to several kinds of chemical sensors [2].

Fiber gratings present stability issues when the ambient temperature gets increased, which sometimes limits their operability for certain applications. This document focuses on some thermal experiments realized on TFBGs with the aim of studying their behavior, and check if they can be used for chemical sensing applications in high temperature environments.

TFBG fabrication and measurement equipment

Several 8 to 10 mm long TFBGs have been photo-inscribed in the core of a hydrogen-loaded photosensitive single-mode optical fiber. An Argon Ion laser emitting at 244 nm has been used for the inscription, together with a 1070 nm pitch phase mask. The phase mask has been tilted 6° with respect to the fiber longitudinal axis, in order to obtain the desired angle in the grating pattern. The inscription process has been permanently monitored with an optical vector analyzer from Luna Technologies®.

The thermal cycles have been configured in a furnace from Carbolite®, able to reach up to 1200 °C. The instant temperature data have been obtained with a thermocouple from Pico Technology® placed in the middle of the furnace (in the same place as the TFBGs) and the measurements of the gratings were carried out with a FBG interrogator from FiberSensing®, capable of working both in transmission and in reflection.

Experimental results

Experiments have been conducted to study the behavior of TFBGs when their temperature gets highly increased. The thermal cycle was configured as a simple ramp from ambient temperature to 1000 °C, with the increasing rate imposed by the furnace. Figure 1.a displays the TFBG spectrum at some specific moments of the cycle, with the most prominent minima of the cladding mode resonances highlighted to improve the visual analysis. As expected, the wavelength of every TFBG resonance gets increased at a rate of ~10 pm/°C, as a result of the temperature change induced in the grating.

As can be seen, the grating resonances are still present in the spectrum at temperatures of 500 °C or even higher, especially the ones related to the cladding modes. However, their peak-to-peak amplitude gets reduced as soon as the temperature increases, so definitely the TFBG gets erased from the fiber core. Figure 1.b shows the evolution of the peak-to-peak amplitudes of some mode resonances measured in transmission in a more accurate way. It is important to highlight the fact that the deeper the resonances are, the longer they last in the spectrum.

At the same time, some measurements in reflection were carried out, taking into account that the only resonance that is possible to analyze this way is the one due to the Bragg mode. Figure 1.c presents the evolution of the reflected optical power of this mode, divided into three main phases: first the power decreases due to the erase of the Bragg mode, then it increases between 720 °C and 780 °C approximately, and finally it falls again. This is the trace of the weak regeneration of the Bragg resonance that took place in a short period of time of 3-4 minutes.

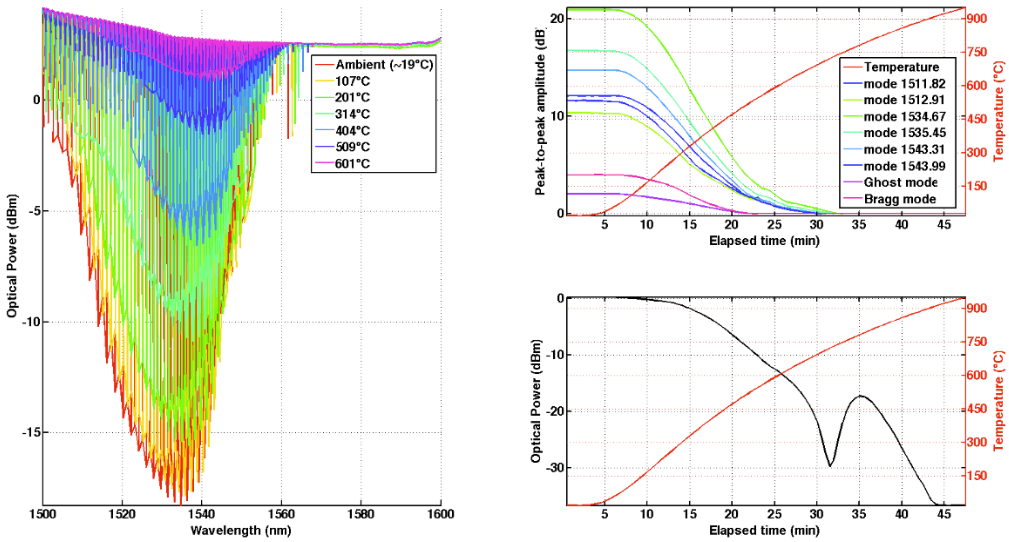

Fig. 1.a Transmission spectrum of the TFBG for different temperatures (left), 1.b Evolution of the peak-to-peak amplitude of some resonances measured in transmission (upper right) and 1.c Evolution of the Bragg mode reflected optical power (lower right).

Discussion

As seen in these early results and as expected, TFBGs are not thermally stable in high temperature environments, since the amplitude of their resonances starts to decrease as soon as a temperature of just 100 °C is reached. However, the fact that these resonances are present in the grating spectrum even at temperatures of 600 °C suggests that it might be possible to develop some kind of thermal annealing process to increase the thermal stability range and contribute to resonance conservation.

Another way of improving their thermal working range could be to go beyond: erase the grating from the fiber core and try to regenerate it, as already investigated [3]. In the TFBGs used in these experiments a weak regeneration of the Bragg mode is observed. In addition, it has been demonstrated with uniform FBGs that a regeneration process contributes to their thermal stability [4], so the challenge might be to translate this process to TFBGs and regenerate both Bragg and cladding mode resonances in order to be able to take advantage of the properties offered by this kind of gratings, also in high temperature environments.

References

[1] J. Albert, L. Shao and C. Caucheteur, “Tilted fiber Bragg grating sensors”, Laser & Photonics Reviews, vol. 7, pp. 83-108, 2013.

[2] V. Voisin, J. Pilate, P. Damman, P. Mégret and C. Caucheteur, “Highly sensitive detection of molecular interactions with plasmonic optical fiber grating sensors”, Biosensors and Bioelectronics, vol. 51, pp. 249-254, 2014.

[3] R. Cotillard, G. Laffont and P. Ferdinand, “Regeneration of Tilted Fiber Bragg Gratings”, Proc. SPIE 9157 of the 23rd International Conference on Optical Fibre Sensors, 2014, 91572S

[4] T. Wang, L. Shao, J. Canning and K. Cook, “Temperature and strain characterization of regenerated gratings”, Optics Letters, vol. 38, pp. 247-249, 2013.