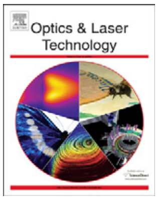
Optics & Laser Technology 44 (2012) 821–824

Contents lists available at SciVerse ScienceDirect

Optics & Laser Technology

journal homepage: www.elsevier.com/locate/optlastec



Regenerated fibre Bragg grating fabricated on high germanium concentration photosensitive fibre for sensing at high temperature

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ARTICLE INFO

Article history:
Received 4 October 2011
Received in revised form
10 November 2011
Accepted 15 November 2011
Available online 1 December 2011

Keywords:
Regenerated fibre Bragg gratings
High temperature
Grating-based sensor.

ABSTRACT

A Regenerated Fibre Bragg Grating (RFBG), with repeatable high temperature response between 400 °C–1200 °C, has been demonstrated using a hydrogen-loaded, highly germanium-doped, photosensitive fibre. A wavelength shifts of as much as 20 nm is attained during temperature calibration up to 1300 °C. A large temperature response of 17 pm/°C is obtained from the RFBG, with very good repeatability.

1. Introduction

For high temperature sensing utilising Fibre Bragg Grating (FBG) based sensors, chemical composition gratings [1], enhanced type IIA gratings [2], water-molecule-induced gratings [3] and Regenerated Fibre Bragg Grating (RFBG) [4] are among the more promising candidates. In particular, the RFGB has been brought into the spotlight for high temperature sensing over the last three years [5]. The RFBG can be created through a thermal regeneration process, under isothermal annealing condition within the temperature range 600–950 °C , depending on the composition of the fibre used [6]. To date, the highest temperature of operation of a RFBG sensor was reported as 1295 °C [7]. Meanwhile, the temperature responses of RFBG-based sensors were found to have an almost linear relation in the high temperature region (600–1000 °C) [7–8]. On the other hand, the highest temperature cycling of RFBG using hydrogen-loaded, high-germanium, photosensitive fibre was demonstrated at 1100 °C [9]. The maximum sensing temperature of RFBG relies mainly on the pre-annealing treatment at high temperatures (~1000 °C). **There has been an earlier report by Lindner et al. on RFBG using highly germanium-doped fibre of 18 mol% without hydrogen loading achieving stable temperature response up to 550 °C [10]. There is a need to increase the temperature response higher than this value, and in this work, a highly germanium-doped fibre with the addition of hydrogen loading have achieved a temperature response up to 1300 °C.** It has good repeatability of high temperature response until 1200 °C.

2. Thermal regeneration and pre-annealed treatment of regenerated grating

The high germanium photosensitive fibre (FIBERCORE-SM1500) used in this experiment has a germanium concentration about 15 times higher than the conventional SMF-28 fibre. The photosensitive fibre has cladding- and coating-diameters of 125.5 μm and 243 μm respectively. The modal-field diameter is 4.4 μm, with a numerical aperture of 0.29. The fibre is hydrogen-loaded at a pressure of 150 atm at room temperature, for 5 days. The inscription of the seed grating is performed using ultra-violet (UV) exposure with a 244 nm frequency-doubled argon ion laser at a power level of 20 mW through a phase mask. **The grating length is approximately 20 mm.**

The thermal annealing processes are carried out in an Elite BRF1600 box furnace with a maximum rated continuous temperature of 1600 °C . For thermal regeneration of the grating, the seed grating is isothermally annealed in the furnace at a temperature of 900 °C. After erasure of the seed grating, the regenerated grating appears with a growing strength (reflectivity) over time and eventually stabilizes after 44 min. After the thermal regeneration process, the regenerated grating is pre-annealed at 1100 °C for a period of seven minutes, in order to stabilise the refractive index change of the grating. The reflection spectrum of the seed grating, regenerated grating after thermal regeneration and pre-annealing treatment, is shown in Fig. 1. **Fig. 1(a) shows**

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doi:10.1016/j.optlastec.2011.11.024

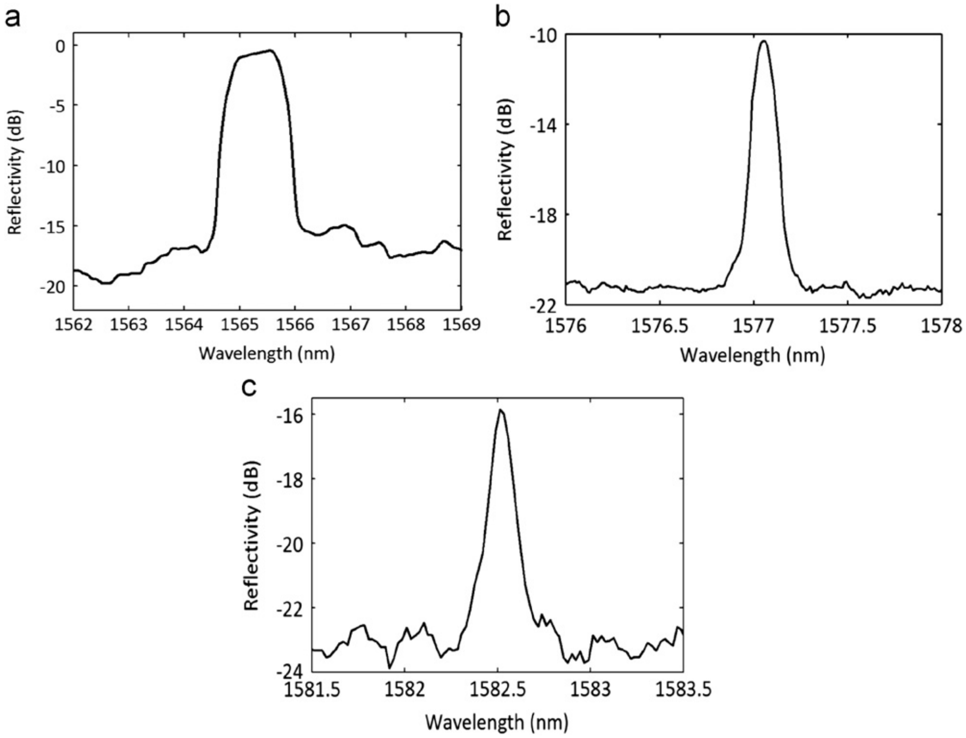

Fig. 1. Reflection spectrum of regenerated grating after: (a) Seed grating (b) thermal regeneration at 900 °C and (c) pre-annealing treatment at 1100 °C.

the reflection spectrum of the seed grating having a centre wavelength of 1565.306 nm with a 3-dB bandwidth of 1.008 nm and reflectivity of -0.45 dB. The regenerated grating was brought back to room temperature and left for one day before the calibration process was begun. The spectral response of the grating is monitored using amplified spontaneous emission (ASE) from an erbium doped fibre amplifier (EDFA) and an optical spectrum analyser (OSA), with the highest spectral resolution of 50 pm.

3. Calibration of the RFBG as a high temperature sensor

In the first calibration, the regenerated grating is placed in an isochronal thermal environment and the resulting wavelength shift is recorded for temperatures between 400 and 1300 °C. Fig. 2 depicts the wavelength shift of the grating against temperature for both heating and cooling processes. A wavelength shift of 20 nm is attained at the maximum calibration temperature of 1300 °C . Hysteresis is observed between the heating and cooling processes, which is believed to originate from the different rate of heating/cooling between the RFBG and thermocouple as they are not located at the same position in the furnace. It should be noted that a 10 dB degradation in reflectivity is observed when the RFBG is subjected to 1300 °C, which is inevitable since 1300 °C is beyond the softening point of the silica glass. In the meantime, the 3 dB reflection bandwidth of the RFBG shows no significant degradation for either heating or cooling processes. In Fig. 2, the magnitude of the grating sensitivities toward temperature for both heating and cooling processes, were found to be 17.7 pm/°C and 17.0 pm/°C, respectively, within temperature range of 400 °C–1200 °C. Besides, coefficient of determination (R^2) of 0.9989 and 0.9995 were obtained for both processes, which indicate an almost linear relationship between the temperature and the amount of wavelength shift.

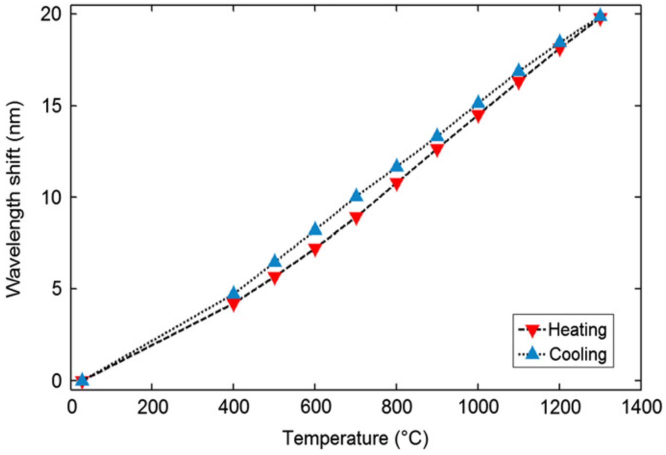

Fig. 2. First calibration of regenerated grating up to 1300 °C for both heating and cooling processes.

4. High temperature sensing

After calibration, two cycles of high temperature sensing from 400–1200 °C, in steps of 100 °C, were carried out. In essence, the wavelength shift of the grating is the crucial parameter in determining the temperature variations and is the priority for all grating based sensor. The wavelength shift against temperature for two heating/cooling cycles along with the first calibration process is illustrated in Fig. 3. Clearly, the wavelength shift for both temperatures cycles (cycle1 and 2) fits well with the calibrated value, for both the heating and cooling processes. In this experiment, the temperature elevation per unit time for calibration, for cycle 1 and cycle 2 are (30.7 ± 0.05) °C min^{-1}, (32.5 ± 0.05) °C min^{-1} and (36.9 ± 0.05) °C min^{-1} , respectively, over the temperature range of