High temperature stable Type I IR ultrafast induced FBGs

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Abstract

Fibre Bragg gratings formed with Type I exposure conditions in SMF-28 fibre are presented that retain more than 60% of their initial index change after annealing up to 1000 °C.

Introduction

Typically UV induced fibre Bragg gratings are formed by combining the multiple diffracted orders of an UV beam through a phase mask to produce an interference pattern which is then inscribed in the core of Ge-doped optical fibre. The modification of the Ge-doped core happens through a process known as Type I index change [1]. Recently, there has been growing interest in the use of fibre based devices, including fibre gratings, for sensing applications. For high temperature sensing a fibre Bragg grating that survives at temperatures up to 1000 °C is particularly attractive. Unfortunately the Type I index induced with UV lasers is completely erased at 800 °C. Several other UV induced devices, such as Type IIA, II and chemical composition gratings [2-4], have been investigated that show some improved temperature stability. However, these gratings do suffer from a relatively small induced index change compared to Type I UV induced gratings.

With the advent of ultrafast phase mask induced gratings it became possible to produce high index change Type II gratings [5,6]. While this was a significant improvement, Type II gratings are formed using intense ultrafast pulses that damage the fibre reducing its tensile strength and renders it difficult to properly tailor the grating spectrum.

We demonstrate here, for the first time to our, knowledge, a grating formed with Type I ultrafast induced grating exposure conditions that retains as much as 60 % of its initial index change after isochronal annealing up to 1000 °C followed by isothermal annealing at this temperature for 96 Hrs. This grating is then cycled showing no further degradation in the induced index, a nearly linear dependence of the Bragg wavelength on temperature and no hysteresis in the room temperature wavelength.

Experiment

Ge-doped *Corning* SMF-28 fibre was loaded with molecular hydrogen at a pressure of 2600 psi and a temperature of 23 ºC for 14 days and kept at –40 ºC until it was exposed.

Fibre Bragg gratings were inscribed by focusing the output of an amplified 800 nm Ti:sapphire ultrafast laser with a 30 mm cylindrical lens through a 4.28 μm phase mask onto the core of the fibre sample. The fibre was placed 3 mm beyond the phase mask to ensure the production of a pure two-beam interference grating [7]. The incident laser beam had a 1/e intensity spot radius of 3.2 mm. The spot size at the core was smaller than the ~8 μm core diameter. A piezo-actuated stage was used to scan the beam vertically to cover the entire core region. The repetition rate of the laser was 100 Hz.

The energy used to fabricate all the gratings in this study was set at 450 μJ, corresponding to an intensity of $1.5\times10^{13}\ W/cm^2$, below that required to induce an index change in unloaded SMF-28 fibre, and significantly below the type II threshold [6]. The loss at the Bragg resonance was continuously monitored with an erbium source and an optical spectrum analyzer.

The resulting gratings were isochronally annealed in a tube furnace in increments of ~150 °C per hour up to a maximum temperature of 1000 °C. A thermocouple was used to measure the temperature at the grating.

Observations

The grating spectra for a low and a high peak index change grating are shown in Fig. 1. The time to produce a low and high index change grating was typically 1 min and 20 min, respectively. If a first order grating resonance is assumed the corresponding peak induced index change for the 5 dB and 30 dB loss gratings is 3×10^{-4} and 1.5×10^{-3}, respectively. A cladding mode has developed for the higher index change sample. The actual induced index change in the material is likely much higher than that estimated with a first order resonance as gratings produced with a 4.28 μm mask have their fourth order resonance at 1550 nm [8]. A fourth order grating in hydrogen loaded fibre has a much smaller resonance at 1550 nm than a

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first order grating. It is possible that the actual induced index change could be as high as $5-7\times10^{-3}$.

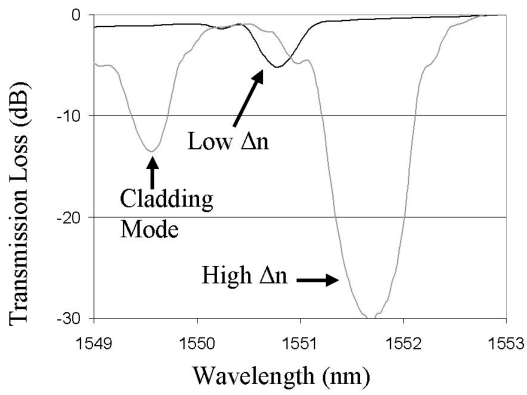

Figure 1: A low and a high peak index change grating.

The isochronal annealing curves of 3 low and 3 high peak index change gratings are shown in Fig. 2. The error bars represent the standard deviation for the set of 3 gratings

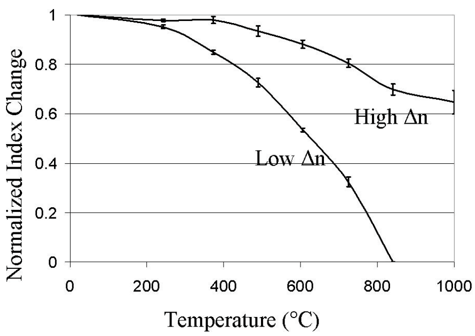

Figure 2: Isochronal annealing curves of Low and High index gratings.

It is clear that the temperature stability is vastly improved for the gratings formed with larger index changes. The high Δn gratings retain in excess of 60 % of the initial index change.

One high Δn grating was then pre-annealed and cycled to determine the post-anneal temperature stability and the presence of any hysteresis in the initial wavelength of the grating. As is shown in Fig. 3 the pre-annealed grating is stable up too 1000 °C with a nearly linear wavelength shift slope of ~15 pm/°C. The index change was normalized to the room temperature value and the estimated error was ±2 %. It is likely then that any trend in the normalized index change does not possess any statistical significance. No hysteresis was observed in the wavelength after the grating cooled to room temperature.

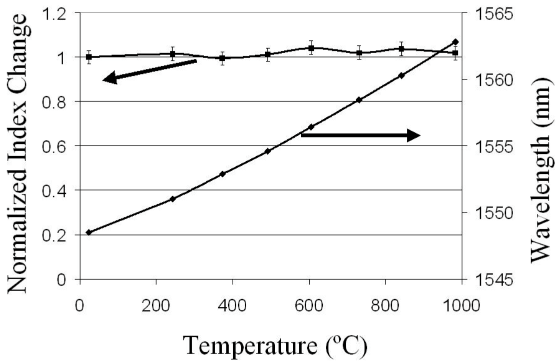

Figure 3: Temperature stability and wavelength shift of pre-annealed grating.

With UV induced Type I gratings it is believed that the temperature stability is improved with increased exposure [9]. It is likely that the heightened temperature stability of these ultrafast induced Type I gratings is also a consequence of longer exposure and, consequently, larger induced index change.

The use of higher order phase mask pitches is advantageous as very large index changes can be induced, which will exhibit high temperature stability, while the magnitude of the observed grating resonance will remain relatively small.

Conclusion

We have demonstrated a fibre Bragg grating formed with Type I ultrafast induced grating conditions that exhibits high temperature stability. The use of higher order Bragg resonances is advantageous with these gratings as the loss at 1550 nm will remain relatively small even for large, highly stable, induced index change. The resulting gratings possess both the temperature stability of Type II gratings but can be easily spectrally tailored.

References

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