Ultra-High Temperature Gratings

John Canning, Somnath Bandyopadhyay, Michael Stevenson, and Kevin Cook

Abstract—Regenerated gratings seeded by type-I gratings are shown to withstand temperatures beyond 1000 °C. The method of regeneration offers a new approach to increasing temperature resistance of stable fibre Bragg and other gratings. These ultra-high temperature (UHT) gratings extend the applicability of silicate based components to high temperature applications such as monitoring of smelters and vehicle and aircraft engines to high power fibre lasers.

Index Terms—Annealing, Bragg gratings, regenerated gratings, temperature sensing, ultra-high temperature.

1. Introduction

The development of fibre Bragg gratings (FBGs) which are suitable for high temperature applications is an increasingly important researcher driver in sensing. Previous studies have already established that operable temperature of FBGs can be increased by several means: e.g., through tailoring the glass composition\cite{1,2}, or by inscribing gratings using femtosecond IR lasers\cite{3,4}. There is another different variant with superior high temperature stability referred to as chemical composition grating (CCG)\cite{5,6}. It was shown that a periodic index modulation can be regenerated after erasure of the UV induced type-I grating written in H-loaded germanosilicate fibre that contains fluorine if it is annealed at temperature as high as ~1000 °C. The prediction was a gradual erasure of the original grating and the exact temperature of the hot zone was ascertained from the calibration data supplied by the manufacturer as well as calibration with a Bragg grating. A C-band EDFA and spectrum analyzer (res=50 pm) were used to record the spectral characteristics of the FBGs. Identical FBGs with transmission loss about 25 dB at Bragg wavelength were used throughout. The FBGs were kept at room temperature for 72 hours before performing any annealing experiment. Through isochronal annealing it was observed that the grating vanishes completely at temperature ~900 °C. Further increases in the temperature did not show any regeneration in the index modulation; therefore, no new grating was formed.

In the next experiment, a progressive isothermal annealing is carried out at the temperature of erasure of the type-I grating. This led to the observation of the phenomenon of regeneration of a new peak. The evolution of the new grating during isothermal annealing is shown in Fig. 1 (a) to (d) recorded during the process. We observed a gradual erasure of the original grating (marked 1) and generation of the new one (marked 2) with a wavelength...
shift.

![Graph showing the evolution of new grating at ~900 °C](image)

Fig. 1. Evolution of the new grating at temperature ~900 °C.

Fig. 2 shows the excursion of wavelength as well as the strength of the grating. The first 10 minutes in the figure shows these variations during isothermal annealing at 900 °C. During 10 minutes to 20 minutes, the temperature was increased from 900 °C to 1000 °C and during the last 10 minutes isothermal annealing was done at 1000 °C. During the growth of the grating, the wavelength was found to be almost steady. It drifted throughout the duration while the temperature was increased and continued to shift during initial part of the isothermal annealing at 1000 °C but became steady during the last 5 minutes. The most interesting aspect is the steadiness of the peak value of the grating after it is regenerated. It continued to survive throughout the rest of the experiment at ~1000 °C.

![Graph showing strength and wavelength excursion of regenerated grating during annealing](image)

Fig. 2. The strength and wavelength excursion of the regenerated grating during the process of annealing.

The Bragg wavelength was shifted from the original grating by ~2nm once the grating is taken back to room temperature. We tested the stability of the grating by keeping it at different elevated temperatures for 20 minutes each. The experimental result from 600 °C to 1000 °C is shown in Fig. 3. The grating reached the same wavelength at 1000 °C as it was at the end of annealing. To explain the observed phenomena fully and to explain some unanswered questions like the shift of wavelength during regeneration (as shown in Fig. 1) more experiments need to be carried out. Unlike in [10], we were able to cycle the regenerated grating and no appreciable change in the grating strength has been found during the temperature rise from 900 °C to 1000 °C. These results indicate we can fabricate gratings which perform reliably as ultra high temperature components and sensors in excess of 1000 °C.

![Graph showing stability of regenerated grating at different elevated temperatures](image)

Fig. 3. Stability of the regenerated grating at different elevated temperature.

To date, we have obtained results that show survival approaching 1300 °C, although the grating strength diminished significantly in strength, there was full recovery when cooled back to room temperature. We think the
grating strength decrease reflects the changes in core cladding index contrast as the core has a larger expansions coefficient than the cladding. The fibre itself became brittle at this temperature and broke readily. This is a surprising result as it indicates the grating itself outperforms the fibre host. The nature of the mechanism is therefore most unlikely to be simply chemical diffusion. Instead, we propose a mechanism based on crystallization from vitreous silica to crystal silica, something similar to cristabolite which is slightly more stable than vitreous silica with a higher index.

3. Conclusions

Regenerated gratings operating at temperatures as high as 1300 °C have been fabricated. Temperature cycling was also successfully demonstrated with no decay observed. A model based on glass crystallisation is proposed to account for such extreme performances, which in fact appear to outlast the fibre host itself.

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References


John Canning is currently a professor and heads the Interdisciplinary Photonics Laboratories, School of Chemistry at the University of Sydney. His research interests include waveguides, devices, photonics, lasers, gratings, applications and glassy materials.

Somnath Bandyopadhyay was born in 1965. He received M.S. Tech. degree in applied physics from Calcutta University, Calcutta, India, in 1990 and was awarded the Ph.D. degree in 1998. He is currently with CGCRI, Kolkata, India. His research interests include fiber Bragg grating based sensors, gain flattening filters (GFF) for EDFA, development of swept wavelength fiber laser source for use in FBG sensor system, and sensor demodulation techniques using FBG based linear edge filters.

Michael Stevenson was born in Melbourne, Australia in 1983. He received the B.S. degree in photonics from The University of Newcastle in 2005. He is currently working with the Interdisciplinary Photonics Laboratories at the University of Sydney. His research focuses on Bragg gratings for sensing applications.

Kevin Cook was born in Broxburn, Scotland, in 1980. He received his M.S. degree in optoelectronics and Laser Engineering from Heriot-Watt University, Edinburgh, in 2001. He was awarded the Ph.D. degree in physics in 2005, also from Heriot-Watt University. He is currently working with the Interdisciplinary Photonics Laboratories of the University of Sydney. His research interests include Bragg gratings in novel microstructured fibres for use in fibre sensing, fibre lasers, and nonlinear optics applications.