Photonex 2001

0370

Material optimisation for high-temperature grating devices written by KrF excimer lasers

G. Brambilla, T. P. Newson and H. Rutt
Optoelectronics Research Centre, University of Southampton, Southampton, SO17 1BJ, UK
Tel: ++44-(0)23-8059-3954, Fax: ++44-(0)23-8059-3149, GB2@ORC.SOTON.AC.UK

Abstract: We have studied the thermal stability of gratings written in fibres of different composition using a 248 nm KrF excimer laser. Measurements up to ~800 °C confirm the long-term thermal stability of Bragg-gratings written in tin-doped silica fibres and demonstrate a significant advantage over gratings written in conventional photosensitive fibres.

1. Introduction

Optical fibre devices have minimal intrusion and considerable advantages in hostile environments, such as in the presence of high electric, magnetic or strong RF fields [1]. Bragg-gratings can be used as a possible transducer for temperature measurements [2], as an alternative to the use of fluorescence emission from rare earth-doped and transition metal-doped fibres [3-4]. Bragg-gratings can also be used to measure many other physical parameters including strain [5,6] and pressure [7,8]. Moreover, grating sensors can be multiplexed in arrays along a single fibre, thus sampling the spatial distribution of a parameter or simultaneously measuring several different parameters [9]. However, fibre gratings written in conventional fibres exhibit poor stability at high temperatures, especially if produced using the hydrogen-loading technique. In this paper, we compare the thermal stability of Bragg-gratings written in the tin-doped fibres recently developed at the University of Southampton [10] with three conventional fibres up to a temperature of approximately 800 °C.

2. Experimental results

The stability of Bragg gratings can be studied either with isothermal or isochronal experiments [11,12]. Although isothermal measurements are more suitable for predicting the grating lifetime and its decay at a certain temperature [11], isochronal experiments are extremely useful to compare different materials because they provide a semi-quantitative indication of the relative stability over a wide range of temperatures. In this type of experiment, the grating reflectivity R(T,t) at the Bragg wavelength λ_B is measured at a temperature T as a function of time t and the normalised integrated coupling constant ($\eta = \frac{\tanh^{-1}\sqrt{R(T,t)}}{\tanh^{-1}\sqrt{R(0,0)}}$ [11]) is plotted for different materials. η gives the fraction of the initial grating photosensitivity that has not been erased by the thermal treatment. Four fibre compositions have been studied: tin-doped silica (SS), germanosilicate (GS), boro-germanosilicate (BGS) and hydrogen loaded telecom (HLT) fibres. The SS, GS and BGS fibres were produced by MCVD in Southampton.

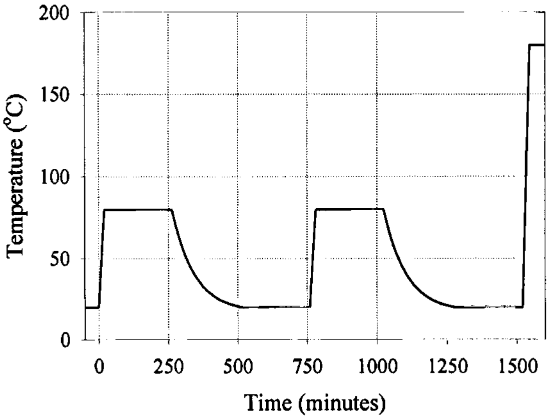

Fig. 1. Portion of the thermal cycle experienced by the Bragg gratings in the furnace. After ~1500 minutes the maximum temperature is raised to 180 °C and the fibres experience a thermal cycle analogous to the one undergone in the initial 1500 minutes.

Hydrogen loading was carried out on a standard telecom fibre by leaving the fibre in a cell containing pure hydrogen at 25 °C and 165 bar for 14 days. Gratings were written using a phase mask and a KrF excimer laser delivering 20 ns pulses at 20 Hz. Pulse fluence was estimated to be ~0.1 J/cm^2. The gratings were spliced together and placed in a furnace. Grating reflectivity was measured by launching light from a white light source and monitoring the reflected light with an optical spectrum analyser via a coupler. Part of the thermal cycle experienced by the gratings is shown in figure 1: the temperature was raised at a rate of ~25 °C/min, stabilized at the measurement temperature for 4 hours and then was decreased to room temperature. Reflection spectra were recorded before, during and after each thermal step. Every cycle was repeated before increasing the maximum temperature in steps of 100 °C.

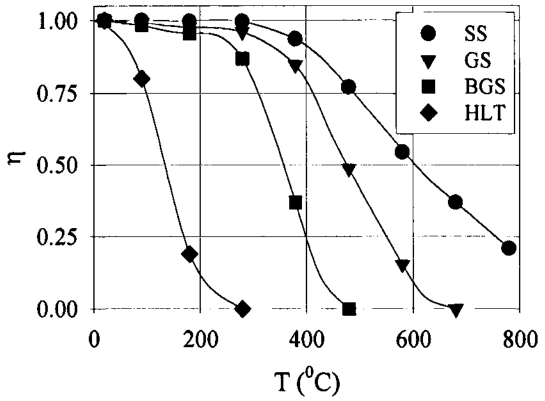

Fig. 2. Temperature stability of gratings written in tin-silicate (SS), germanosilicate (GS), boro-germanosilicate (BGS) and hydrogen-loaded telecom (HLT) fibres. η represents the normalised integrated coupling constant.

Fig. 2 shows the temperature dependence of η for the four gratings and clearly demonstrates the enhanced thermal stability of gratings written in SS with respect to the others. In fact, although HLT and BGS fibres are highly photosensitive and are commonly used to write gratings, gratings written in these fibres may be completely erased at temperatures below 500 °C in ~8 hours. GS shows better stability than HLT and BGS but poorer than SS and may be completely erased in less than 10 hours at a temperature below 680 °C. In contrast SS still has >35% of its initial photosensitivity after the same treatment at 680 °C.

In conclusion, the comparison between tin-doped and traditional photosensitive fibres has shown the enhanced thermal stability of gratings written in the tin-doped fibre. Moreover, SS fibres show a telecom-matched numerical aperture and low propagation and splice losses. This facilitates large scale multiplexing of Bragg gratings with remote interrogation.

4. References

[1] K.A.Wickersheim and W.D.Hyatt, "Commercial applications of fiber optic temperature measurement", Fiber Optic Sensors IV, SPIE 1267, p. 84, (1990).

[2] A.D. Kersey and T.A. Berkoff, "Fiber-optic Bragg-grating differential-temperature sensor", IEEE Photon. Technol. Lett. **4**, 1183-1185, (1992).

[3] V.Fernicola and L.Crovini, "A high-temperature digital fiber-optic thermometer", Proceedings of the 10th International Conference on Optical Fibre Sensors, Glasgow, pp. 211-214, (1994).

[4] Z.Zhang, K.T.V.Grattan, A.W.Palmer and B.T. Meggitt, "Thulium-doped intrinsic fiber optic sensor for high temperature measurements (>1100 °C)", Rev. Scient. Instr. **69**, 3210-3214, (1998).

[5] A.D. Kersey, T.A. Berkoff and W.W. Morey, "High resolution fibre-grating based strain sensor, with interferometric wavelength-shift detection", Electron. Lett. **28**, 236-238, (1992).

[6] M.A. Davies and A.D. Kersey, "All-fibre Bragg-grating strain sensor, demodulation technique using a wavelength division coupler", Electron. Lett. **30**, 75-77, (1994).

[7] W.W. Morey, G. Meltz and J.M. Weiss, "Evaluation of a fiber Bragg grating hydrostatic pressure sensor", Proceedings of the 8th International Conference on Optical Fibre Sensors, Monterrey, USA, PD 4.4, (1992).

[8] M.G. Xu, L. Reekie, Y.T. Chow and P.J. Dakin, "Optical in-fibre-grating high pressure sensor", Electron. Lett. **29**, 398-399 (1993).

[9] J.P. Dakin and M. Volanthen, "Distributed and multiplexed fibre grating sensors, including discussion of problem areas", IEICE Trans. Electron. **E83-C**, 391-399, (2000)

[10] G. Brambilla, V. Pruneri and L. Reekie, "Photorefractive index gratings in SnO$_2$:SiO$_2$ optical fibers", Appl. Phys. Lett. **76**, 807-809 (2000).

[11] T. Erdogan, V. Mizrahi, P. Lemaire and D. Monroe, "Decay of ultraviolet-induced fiber Bragg gratings", J. Appl. Phys. **76**, 73-80, (1994).

[12] D. Razafimahatratra, P. Niay, M. Douay, B. Poumellec and I. Riant," Comparison of isochronal and isothermal decays of Bragg gratings written through continuous-wave exposure of an unloaded germanosilicate fiber", Appl. Opt. **39**, 1924-1933 (2000).