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Enhanced Photosensitivity in Tin-codoped Germanosilicate Optical Fibres

L. Dong, J.L. Cruz*, L. Reekie, M.G. Xu and D.N. Payne

Optoelectronics Research Centre,
The University of Southampton,
Southampton SO17 1BJ, U.K.,
Tel: 01703 593163,
Fax: 01703 593149,
Email: LD@ORC.SOTON.AC.UK

*On leave from
Departamento Física Aplicada,
Universidad de Valencia,
Dr. Moliner 50,
Burjassot, 46100,
Valencia, Spain.

Summary: Enhanced photosensitivity is found in Tin-codoped germanosilicate optical fibres. A photo-induced refractive index change ($\sim 1.4 \times 10^{-3}$) 3 times larger than that observed in pure germanosilicate fibres has been demonstrated. Unlike the technique of using Boron-codoping to enhance the photosensitivity of germanosilicate fibres, Tin-doping does not have a significant effect on fibre loss at the important telecommunication window of 1.55 μm. High temperature stability of the gratings in Tin-codoped germanosilicate fibres is also much over Boron-codoped fibres.

Background: There has been a surge of interest in photosensitive fibre gratings in recent years chiefly due to their ease of fabrication and numerous applications in areas such as filters, narrow-band reflectors for fibre lasers, optical strain/temperature sensors, and modal couplers. Chirped fibre gratings have also been used recently for dispersion compensation in optical fibre links and for optical pulse shaping.

So far the best photosensitive optical fibres are exclusively doped with germanium. A high germanium content in the core is desirable to give a large photosensitivity. Although very large photo-induced index changes have been achieved in pure germanosilicate fibres, enhanced photosensitivity is desirable to enable gratings to be written with ease using low laser fluence. Stronger photosensitivity also opens up many new applications such as very broad band reflectors/filters, ultra-short gratings and many other photonic band gap devices. B-codoping in germanosilicate fibres has been reported to give much enhanced photosensitivity compared to that in pure germanosilicate fibres [1], but gratings in those fibres have a much poorer high temperature stability and the B-codoping can also give rise to excessive loss at the important telecommunication window of 1.55 μm. Post-fabrication techniques have also been devised to enhance the photosensitivity of germanosilicate fibres. H_2/O_2 flame-brushing of a germanium doped fibre has been demonstrated to give an enhanced photosensitivity [2]. Low-temperature hydrogen loading has also enabled very strong gratings to be written in germanosilicate fibres [3]. Apart from the time consumption with these techniques (flame brushing takes tens of minutes, low temperature hydrogen loading takes days), there are significant losses induced when a grating is written in a fibre prepared with the low-temperature hydrogen loading technique, especially at shorter wavelengths [4].

In this paper, we report on enhanced photosensitivity in Sn-codoped germanosilicate fibres. A factor of $\sim$3 larger photo-induced index changes has been demonstrated, a result comparable to B-codoping. The gratings in the Sn-doped fibres also have a much improved high temperature stability compared to B-codoped fibres. Unlike B-codoping, Sn-codoping does not introduce significant loss at the important telecommunication window of 1.55 μm. Tin can also be easily introduced in the vapour phase as $SnCl_4$ using vapour-phase deposition. Alternatively, tin can be incorporated using the solution-doping technique [5].

Experiments: Two Sn-codoped germanosilicate fibres were fabricated for this experiment by introducing $SnCl_4$ vapour using the a modified chemical vapour deposition (MCVD) process. An extra bubbler holding $SnCl_4$ was added to the system and was kept at 39 °C. The vapour pressure of $SnCl_4$ at 35 °C is 40 mmHg. Nitrogen was used as the carrier gas for $SnCl_4$. Two core layers were deposited as porous soot layers (i.e. not fused) at ~1250 °C after the deposition of the cladding layers as this was found to be necessary to incorporate tin efficiently. The layers were then fused into a clear glass at ~1600 °C with a single pass of the burner. The preform was subsequently collapsed into a solid rod in the conventional manner.

Fibre was then drawn from each of the preforms in the usual way. The first fibre (fibre I) was measured to have a numerical aperture of 0.20, first-order mode cut-off wavelength of 1.25 μm, core radius of 2.4 μm and loss of 1 dB/km at 1.55 μm. The second fibre (fibre II) has a numerical aperture of 0.29, first-order mode cut-off wavelength of 1.32 μm, core radius of 2.16 μm and loss of 25 dB/km at 1.55 μm.

The absorption of the core glass in the first preform (preform I) was measured with the technique described in [6] before and after a 5 minute exposure to a line-narrowed pulsed KrF excimer laser operating at 248 nm. The pulse fluence was set at ~50 mJ/cm^2 for this exposure. The pulse duration was 20 ns and pulse repetition rate was 20 Hz. The original absorption of the preform core shows the tail of an absorption band centred below 190 nm with a peak at 250 nm. (see fig.1). The 250 nm band is related to the oxygen-deficient centres, located near 240 nm in pure germanosilicate fibres. The 248 nm exposure caused a general increase of the absorption, in contrast to that in pure germanosilicate fibres where a reduction of the 240 nm band is observed.

The excimer laser induced loss in the infrared region was also measured in fibre I by probing the fibre transmission with a white light source while exposing a 15 mm long section of the fibre to the excimer laser for 5 mins. There was a significant induced loss in the visible (~0.44 dB/mm at 600 nm), but virtually no induced loss above 0.9 μm. A slightly stronger temporary induced loss was also noted during exposure, but only a smaller permanent induced loss remained after the exposure.

Fibre gratings were then written in sections of the fibres using the interferometric set-up described in [7]. The pulse fluence was set at ~0.25 J/cm^2 for the grating writing and the grating was ~15 mm in length. The grating in fibre I reached ~100% reflectivity within ~1 min (i.e. ~0.3 kJ/cm^2) (see fig.2). After 30 minutes, the FWHM bandwidth attained a saturation level of ~0.75 nm. An index change of ~1.4×10^{-3} can be deduced from this grating. Fig.3 gives a comparison between the saturated photo-induced index changes deduced from gratings written by the interferometric set-up in fibres of the following core compositions, A) SiO_2/GeO_2, B) $SiO_2/GeO_2/B_2O_3$, C) $SiO_2/GeO_2/SnO_2$. The saturated photo-induced index changes in the Sn-codoped germanosilicate fibre are comparable with those in B-codoped germanosilicate fibres and are several times larger than those in pure germanosilicate fibres. Although an index change of ~1.2×10^{-3} has been reported in a pure germanosilicate fibre (depressed cladding PCVD fibre) [8], similar results have not been repeated by other groups in similar fibres. It should be pointed out that the B-codoped fibres in which ~2×10^{-3} index change was achieved had a loss of ~100 dB/km at 1.55 μm.

The stability of the gratings is very important, especially for applications at elevated temperatures. As the lifetime of the gratings is very long at room temperature (several years to tens of years), the gratings are normally tested at elevated temperature to produce accelerated decay. The results of high-temperature stability tests for gratings in fibres with the three core compositions A) SiO_2/GeO_2,

B) $SiO_2/GeO_2/B_2O_3$, C) $SiO_2/GeO_2/SnO_2$ are shown in fig.4. The grating in a Sn-codoped germanosilicate fibre (fibre I) is much more stable than that in a B-codoped germanosilicate fibre, but is comparable in stability to that in a pure germanosilicate fibre.

Conclusions: We have demonstrated a factor of ~3 enhancement in the photo-induced index change with Sn-codoped germanosilicate fibres over pure germanosilicate fibres. The grating stability at elevated temperatures in the Sn-codoped germanosilicate fibres is much improved comparing to that in B-codoped germanosilicate fibres. Unlike B-codoping, Sn-codoping does not introduce a significant loss at the important telecommunication window of 1.55 μm. Tin can also be easily incorporated into optical fibres using the vapour-phase-deposition technique.

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Figure captions:

Fig.1 The UV absorption spectra measured in the Sn-codoped germanosilicate preform before and after exposure to a KrF excimer laser beam for 5 mins.

Fig.2 Growth of a grating in fibre I when written using a KrF excimer laser at 20 Hz with a pulse fluence of 0.25 J/cm^2.

Fig.3 248 nm-induced refractive index changes in three types of fibres A) SiO_2/GeO_2, B) $SiO_2/GeO_2/B_2O_3$ and C) $SiO_2/GeO_2/SnO_2$.

Fig.4 Decay of the UV-induced index changes at elevated temperatures in fibres containing A) SiO_2/GeO_2, B) $SiO_2/GeO_2/B_2O_3$ and C) $SiO_2/GeO_2/SnO_2$.

Fig. 1. Dong "Enhanced Photosensitivity in Tin-doped ..."

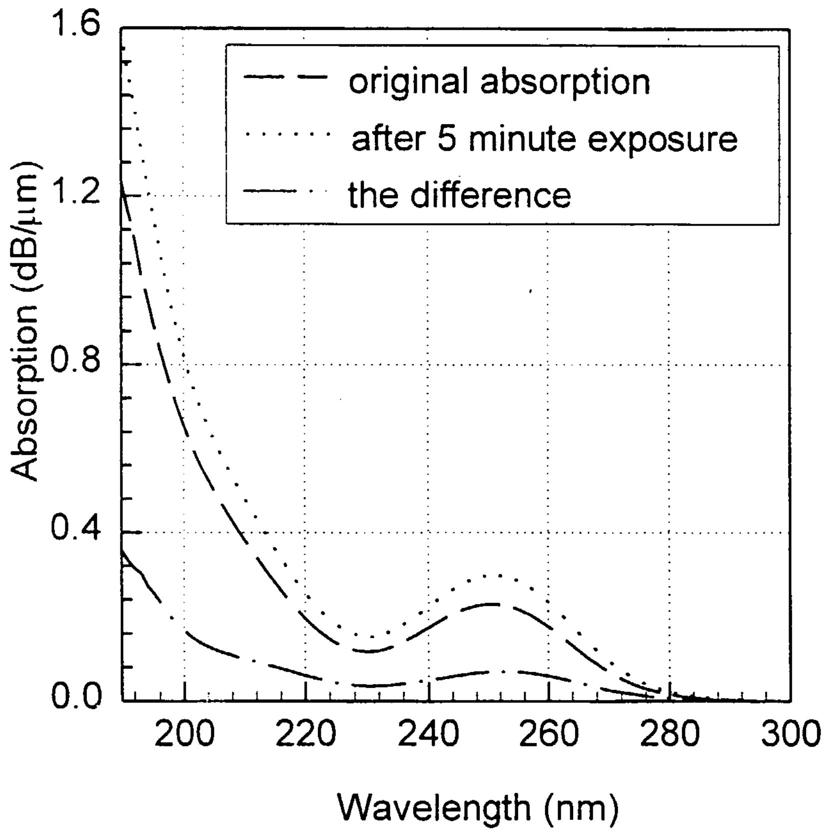

Fig.2 Dong "Enhanced photosensitivity in Tin-doped..

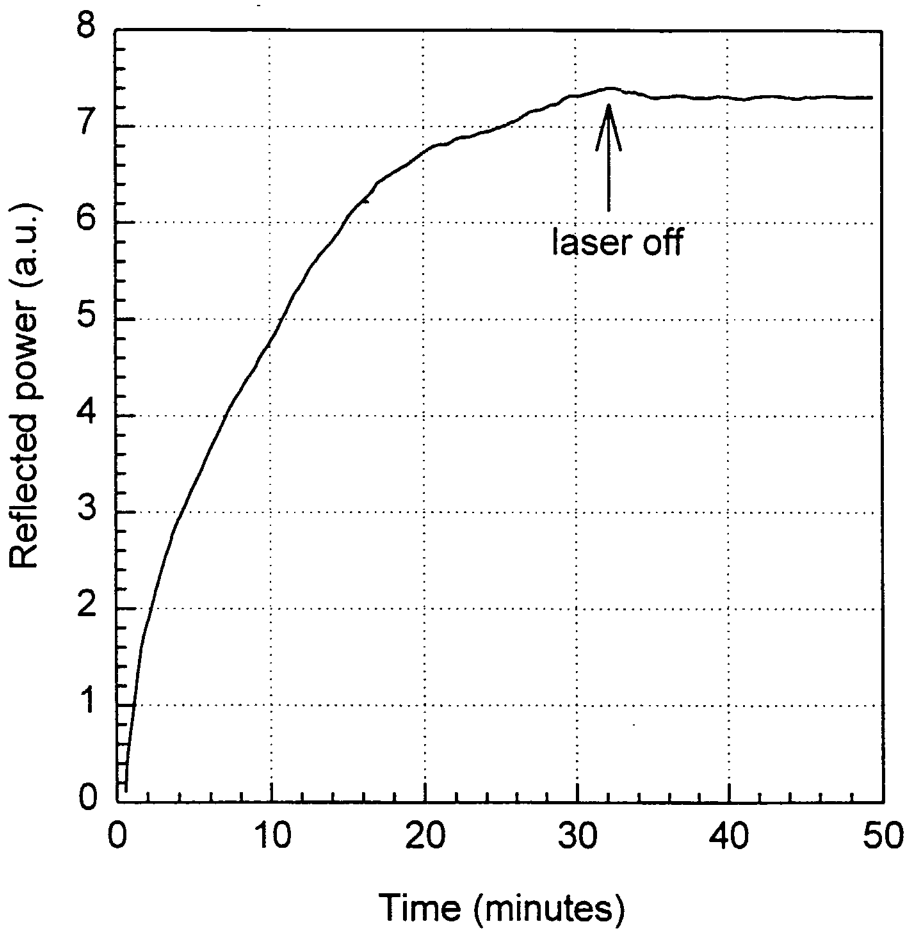

Fig. 3. Dong "Enhanced Photosensitivity in Tin-doped ... "

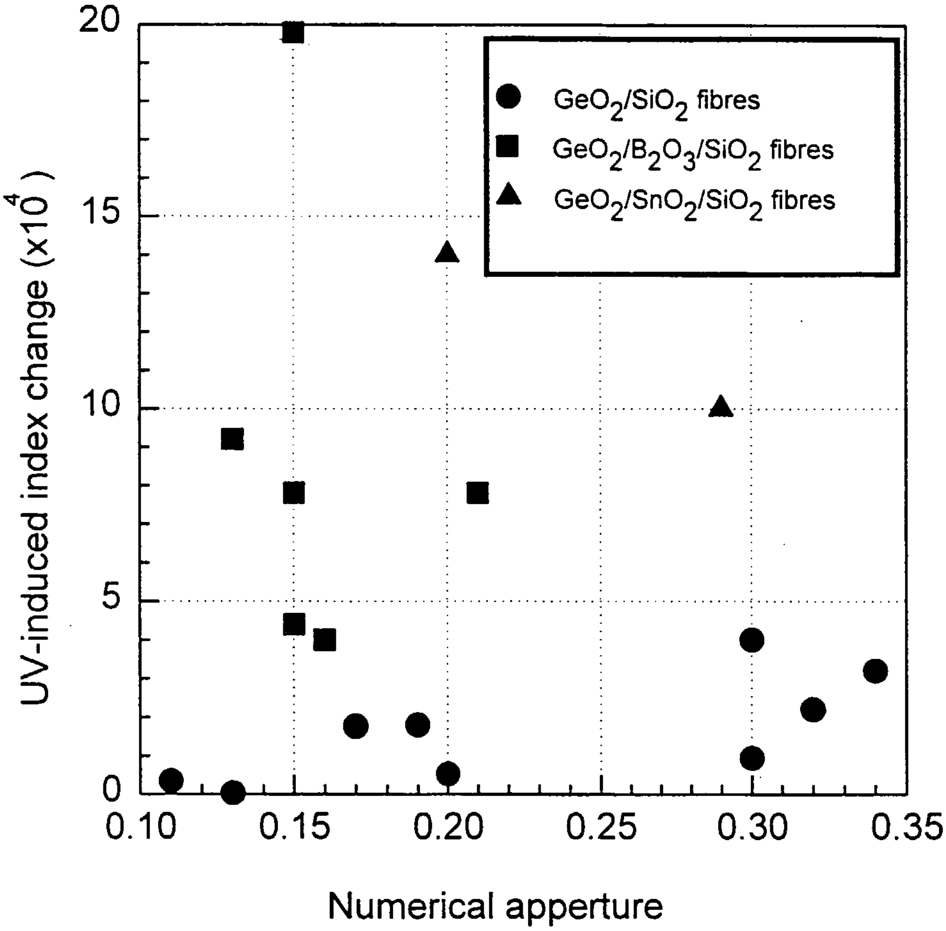

Fig 6 Dong et al "Enhanced Photosensitivity in Tin-doped...