Strong Photosensitive Gratings in Tin-doped Phosphosilicate Optical Fibres

L. Dong, J.L. Cruz*, J.A. Tucknott, L. Reekie 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: Strong photosensitive gratings of both type I and II have been demonstrated in germanium-free tin-doped phosphosilicate fibres. An index change of $\sim 1.2 \times 10^{-3}$ has been achieved in 40 seconds of exposure. The fibres have strong absorption (~ 0.8 dB/μm) at the writing wavelength of ~ 248 nm from tin-doping. This is the first time that such strong gratings were written in a phosphorous-containing silica fibre without low temperature hydrogenation and that type II gratings were written in a germanium-free fibre. The tin-doping technique can be used to write gratings in rare-earth doped phosphosilicate fibres and to produce low NA fibres for mass production of strong single pulse Type II gratings during fibre pulling.

Background: Fibre gratings have attracted much interests in recent year chiefly because of 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 for dispersion compensation in optical fibre links, and for optical pulse shaping.

So far strong gratings have only been written in germanium-containing silica fibres if low temperature hydrogen loading is not used. Although it is possible to write strong gratings in some germanium-free silica fibres after they have been hydrogenated at room temperature in a high pressure hydrogen cell for a few days [1,2], long writing time (sometimes several hours) was needed. In phosphosilicate fibres, strong gratings can only be written after low temperature hydrogenation even when germanium is co-doped. Phosphorous is known to suppress the photo-induced index change in a germanium-doped fibre because it reduces the intensity of the 240 nm absorption band in these fibres [3], a band which is closely related to the photosensitivity of germanium-doped waveguides. In pure phosphosilicate fibres, a 193 nm ArF excimer laser with very poor coherence has been used to write gratings [2]. Gratings can only be written using a phase mask with this excimer laser and this is very inflexible when gratings have to be written at many different Bragg wavelengths. For some applications such as fibre lasers, particularly single frequency fibre lasers and fibre DFB lasers, strong gratings have to be written directly into the doped fibres often containing phosphorous (e.g. Er/Yb fibres) due to the short laser cavity length (few centimetres) and the nature of the lasers [4]. Currently, hydrogenation is always required for such applications which, apart from the large time-consumption and inconsistency, produces significant loss, particularly at short wavelengths for the pump laser [5].

Single pulse type II gratings [6] are very promising for mass-production of strong fibre gratings when combined with the technology of writing the gratings during the fibre drawing process before the fibre is coated [7]. So far, Type II gratings have only be produced in fibres with very high germanium contents. Such fibres

have a high NA (~ 0.3) and lower NA fibres are therefore desirable for compatibility with standard telecommunication fibre.

In this paper, we report the writing of strong gratings in Sn-doped phosphosilicate fibres. Strong Type I and II gratings have been demonstrated. An index change of $\sim 1.2 \times 10^{-3}$ has been achieved in 40 seconds of exposure. This method can be used for the production of gratings in germanium-free optical fibres, particularly phosphorous-containing fibres and for the mass-production of strong gratings using single pulse Type II grating technology. The Sn-doping is particularly suitable for optical fibres made by the conventional vapour-phase deposition techniques, since $SnCl_4$ is a volatile liquid with a vapour pressure of 40 mmHg at 35.2 °C and can be easily incorporated into the process. Alternatively, SnO_2 can be incorporated using the solution-doping technique [8]. Doping silica fibres with SnO_2 does not substantially affect the loss of the fibre around the telecommunication windows of 1.3 μm and 1.55 μm.

Experiments: The Sn-doped phosphosilicate fibres used in these experiments were fabricated by a modified chemical vapour deposition (MCVD) system. An extra bubbler which held $SnCl_4$ was added to the system. Nitrogen was used as the carrier gas for $SnCl_4$. All the bubblers were kept at 25.0 °C, apart from the $SnCl_4$ bubbler, which was kept at 39 °C to have an increased the vapour pressure. Two core layers were deposited as porous soot layers (i.e. not fused) at ~ 1250 °C after the deposition of cladding layers and this was found to be necessary to incorporate SnO_2 efficiently. The layers were then fused into a clear glass at ~ 1600 °C in a single pass of the burner. The preform was subsequently collapsed into a solid rod in the conventional way.

A fibre was then drawn from the preform in the usual way. The resulting fibre was measured to have a numerical aperture of 0.23, first-order mode cut-off wavelength of 1.32 μm, core radius of 2.16 μm and loss of 40 dB/km at 1.55 μm.

Rare earth-ions can be conveniently doped into the fibre core at the appropriate levels to form an active medium by solution-doping the porous core layers before fusing them into a clear glass [8]. B_2O_3 can also be introduced into the fibre core by simply introducing BBr_3 in the vapour phase or through solution doping of the porous core layers. Fibres with lower NAs can be achieved through boron-doping.

The absorption of the core glass was measured with the technique described in [3] 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 loss of ~ 0.8 dB/μm at the KrF excimer laser of 248 nm (see fig.1). The absorption after exposure shows a general increase of the absorption tail.

The excimer laser induced loss at infrared wavelength was also measured in the Sn-doped phosphosilicate fibre by probing the fibre transmission with a white light source while exposing a section (~ 15 mm long) of the fibre to the excimer laser for 5 mins, as it is very important to know the insertion loss after a fibre grating is written. Fig.2 gives the spectrum of the induced loss. There was a strong induced loss in the visible, but virtually no induced loss above 1.1 μm. The inset of fig.2 shows the dynamics of the induced absorption when monitored at 633 nm. There was a stronger transient induced loss during exposure, but a relatively smaller permanent induced loss.

Fibre gratings were then imprinted in sections of the fibre using the interferometer set-up described in [6]. The pulse fluence was set at ~ 0.25 J/cm^2 for the grating writing and the grating length was ~ 15 mm. A grating with reflectivity of 50% was written in the fibre using a writing time of 2 mins (i.e. ~ 0.6 kJ/cm^2). This reflectivity and a 15 mm length implies an index change of 0.5×10^{-4}. The grating reflectivity decayed to 45% in the first few minutes after the writing process, but was stable thereafter. A typical growth of such gratings is shown in fig.3. The

saturation was normally reached in ~2 minutes. When the pulse fluence was increased to ~0.4 J/cm^2, ~100% gratings with ~0.8 nm bandwidth were written in ~40 seconds (~0.3 kJ/cm^2, see fig.4). An index change of $\sim 1.2 \times 10^{-3}$ is deduced from the gratings. When the pulse fluence of the UV writing beam exceeded ~0.5 J/cm^2, gratings with ~100% reflectivity were produced using a single pulse (see fig.5). This was due to the optical damage at the core/cladding interface because of the high optical absorption in the core [6]. The absorption in the preform core was measured to be ~0.8 dB/ mm at the writing wavelength of 248 nm, comparable to that in a fibre with 22 mol% germanium [3]. Such type II gratings can be conveniently produced on-line during fibre drawing before the usual polymer coating is applied and have an improved high temperature stability compared to Type I gratings [7]. Type II gratings have only previously been reported in high germanium-containing fibres.

Although a writing wavelength of 248 nm was used here, any radiation with a wavelength below 280 nm should be able to write gratings in this fibre due to the strong absorption measured in the preform core below this wavelength (Fig.1). The absorption spectrum contrasts with that in germanosilicate fibre where a narrow absorption band is centred at ~240 nm. A larger photo-induced effect is expected when a shorter writing wavelength is used due to the much stronger absorption at shorter wavelengths (see fig.1).

Conclusions: We have demonstrated for the first time gratings of both type I and II in germanium-free Sn-doped phosphosilicate fibres without using low temperature hydrogen loading. The Sn-doping technique enables strong gratings to be written in phosphorous-containing fibres easily and consistently. Phosphorous-containing fibres are very important for the construction of rare-earth-doped waveguide lasers and amplifiers. The Sn-doping technique also allows fibres with low NAs to be made for strong single pulse Type II gratings, a very important technique for mass production of strong gratings during fibre pulling. The wavelength at which the

gratings can be written is thought to be less restricted in the Sn-doped phosphosilicate fibres than for germanosilicate glass or B_2O_3-doped germanosilicate glass. Tin can also be easily incorporated into optical fibres using the conventional vapour-phase-deposition technique and Sn-doping does not affect the loss of the fibre significantly around the telecommunication windows.

Acknowledgement: J.L. Cruz is financially supported by DGICYT of Spain and the Institució Valenciana d'Estudis i Investigació.

References:

1. J.L. Archambault, L. Reekie, L. Dong and P.St.J. Russell: "High reflectivity photorefractive Bragg gratings in germanium-free optical fibres", CLEO, Paper CWK3, May 1994, Anaheim.
2. T. Kitagawa, K.O. Hill, D.C. Johnson, B. Malo, J. Albert, S. Theriault and F. Bilodeau: "Photosensitivity in P_2O_5-SiO_2 waveguides and its application to Bragg reflectors in single-frequency Er^{3+}-doped planar waveguide laser", OFC, Technical Digist Series, **4**, paper PD-17, 1994.
3. L. Dong, J. Pinkstone, P.St.J. Russell and D.N. Payne: "Ultraviolet absorption in modified chemical vapour deposition preforms", J. Opt. Soc. Am. B, **11**, 1994, pp.2106-2111.
4. J.T. Kringlebotn, P.R. Morkel, L. Reekie, J.L. Archambault and D.N. Payne: "High power single frequency erbium:ytterbium fibre laser", ECOC'93 Proc., **2**, 1993, p.65.
5. P.J. Lemaire, R.M. Atkins, V. Mizrahi and W.A. Reed: "High pressure H_2 loading as a technique for achieving ultrahigh UV photosensitivity in GeO_2 doped optical fibres", Elect. Lett., **29**, 1993, pp.1191-1193.
6. L. Reekie, J.L. Archambault and P.St.J. Russell: "100% reflectivity fibre gratings produced by a single excimer laser pulse",

OFC/IOOC'93, Paper PD14, 1993, San Jose.

7. L. Dong, J.L. Archambault, L. Reekie, P.St.J. Russell and D.N. Payne: "Single pulse Bragg gratings written during fibre drawing", Elect. Lett., **29**, 1993, pp.1577-1578.

8. J.E. Townsend, S.B. Poole, and D.N. Payne :"Solution-doping technique for fabrication of rare-earth doped optical fibres", Elect. Lett., **23**, 1987, pp.329-331.

Figure captions:

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

Fig.2 Induced absorption in the Sn-doped phosphosilicate fibre after exposure to a KrF excimer laser for 5 mins. The inset shows the dynamics of the induced absorption at 633 nm.

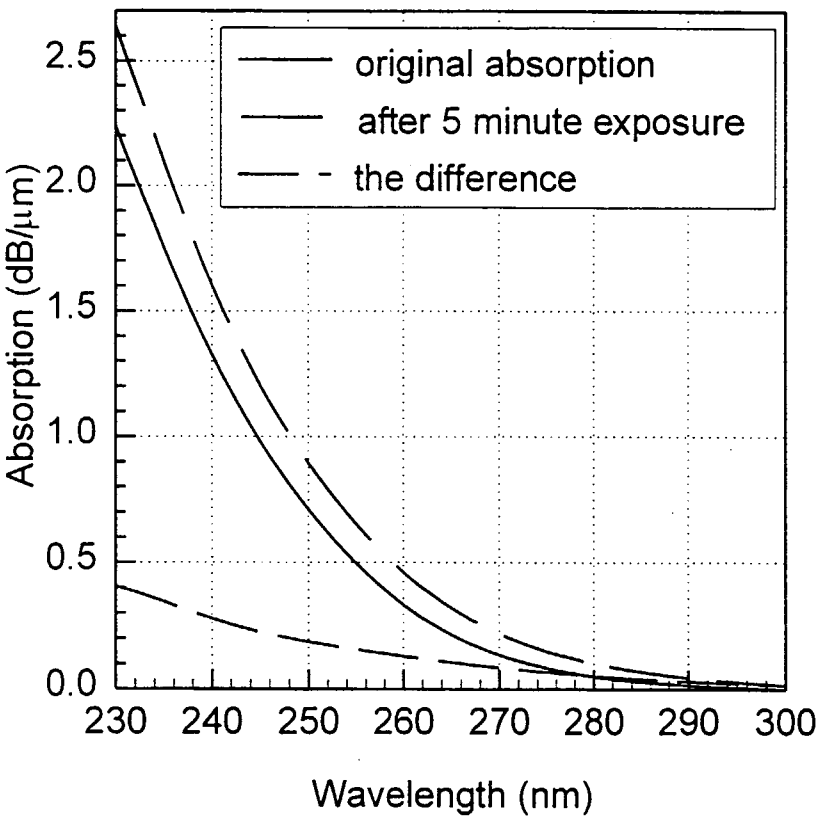
Fig.3 Growth of a grating in the Sn-doped phosphosilicate fibre when writing with a KrF excimer laser at 20 Hz with a pulse fluence of 0.25 J/cm^2.

Fig.4 Growth of a grating in the Sn-doped phosphosilicate fibre when writing with a KrF excimer laser at 20 Hz with a pulse fluence of 0.4 J/cm^2. The inset shows the reflection spectrum of the grating.

Fig.5 The transmission and reflection spectra of a Type II grating written in the Sn-doped phosphosilicate fibre.

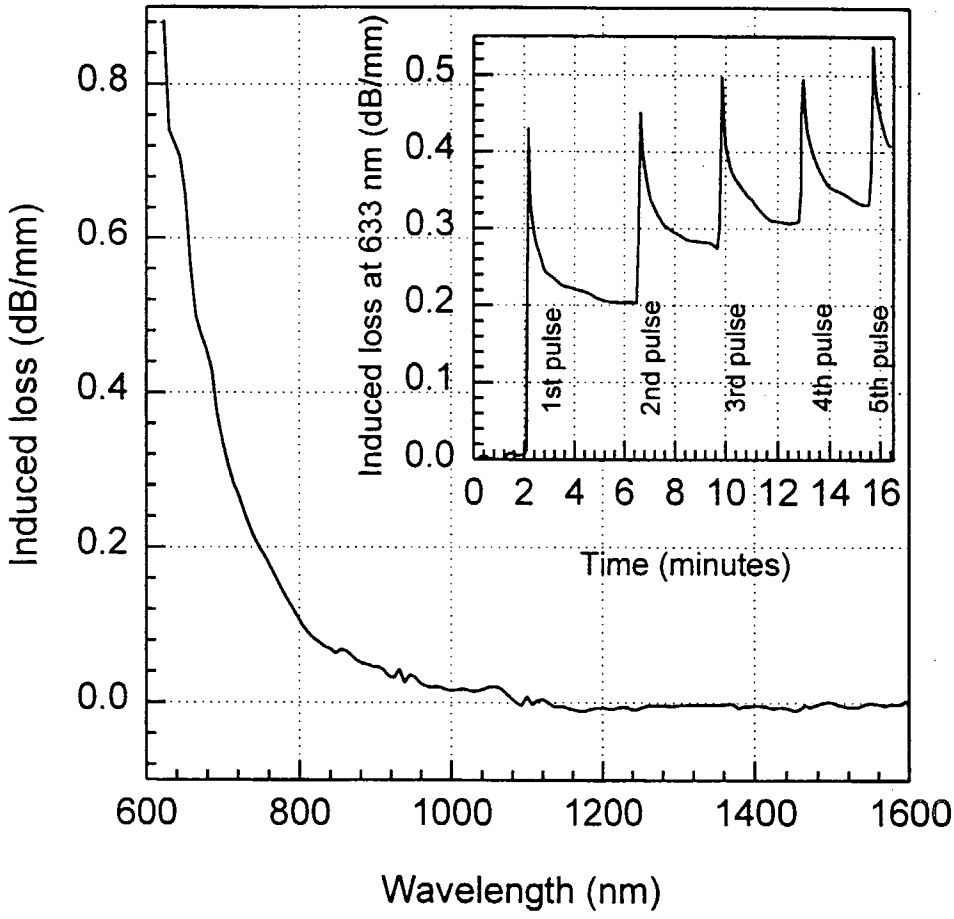
Dong et al: Strong Photosensitivity Gratings in [illegible]

Fig. 1



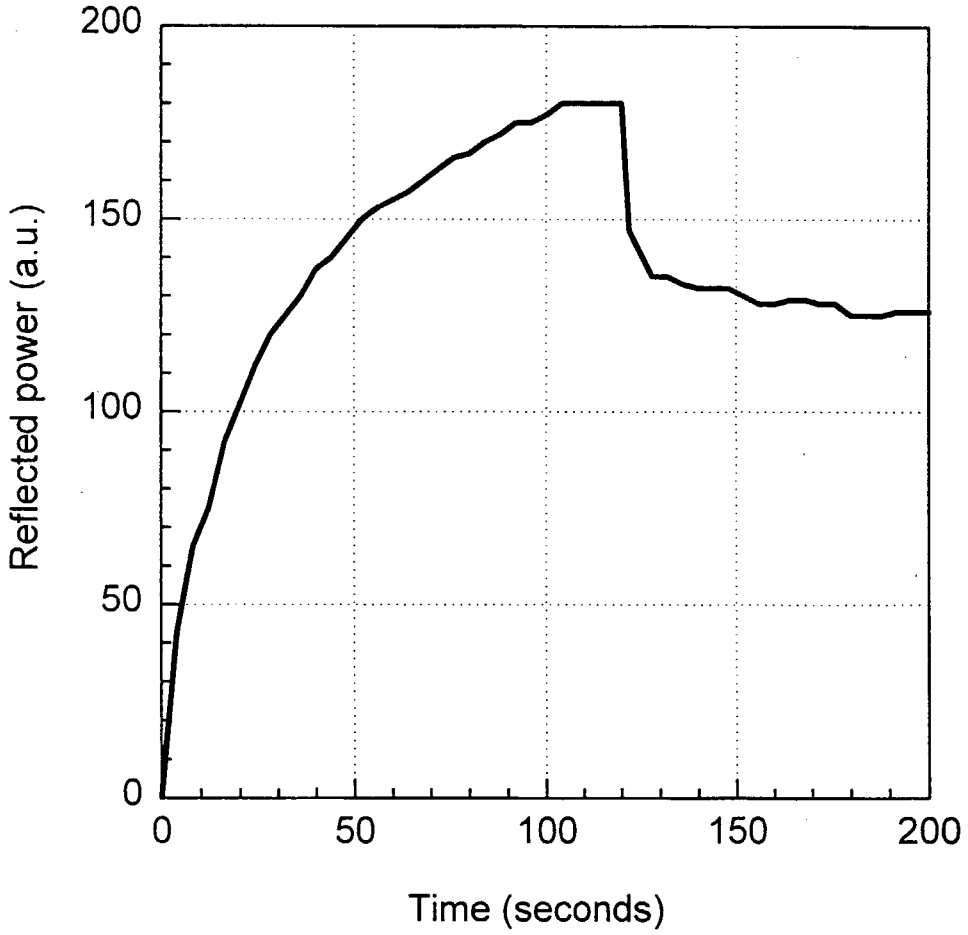
Dong et al "Strong photosensitive gratings in ..."

Fig 2



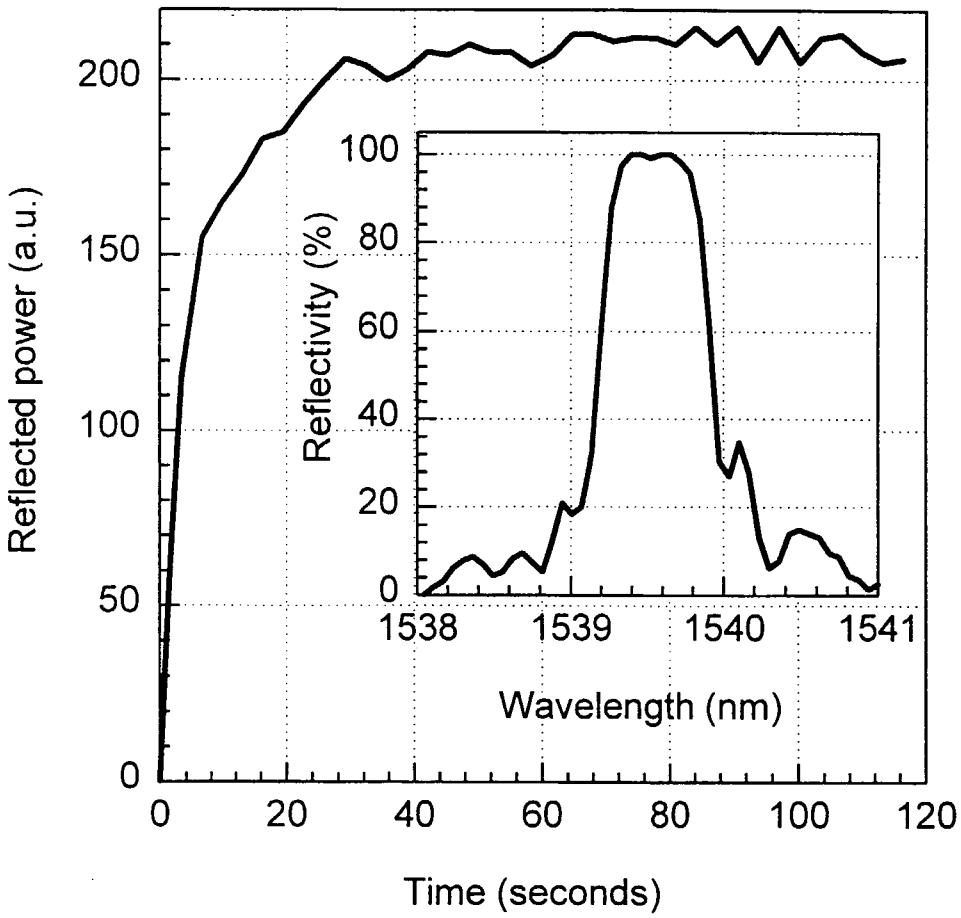
Doiy et al Strong Photosensitivity

Fig. 2



Dong et al "Strong photosensitivity

Fig. 4



Dong et al strong photosensitive Gratings in Ti...

Fig 5