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Large Photo-Induced Index Changes in Tin-doped Phosphosilicate Fibre

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Summary: Strong photosensitive gratings of both type I and II have been demonstrated in germanium-free tin-doped phosphosilicate fibre. An index change of $\sim 1.2 \times 10^{-3}$ has been achieved in 40 seconds of exposure. This is the first time that such strong gratings were written in a phosphorous-containing silica fibre and that type II gratings were written in a germanium-free fibre.

Background: Fibre gratings have attracted much interests in recent year chiefly because of their ease of fabrication and numerous applications. So far photo-induced index change of $\sim 10^{-3}$ has only been produced in germanium-containing silica fibres. Gratings have only been written in phosphosilicate fibres with low temperature hydrogen loading [1]. For many applications such as fibre lasers, particularly single frequency fibre lasers and fibre DFB lasers, strong gratings have to be written directly into the germanium-free fibres often containing phosphorous (e.g. Er/Yb fibres). Single pulse type II gratings [2] 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 [3]. So far, Type II gratings have only be produced in fibres with very high germanium contents.

In this paper, we report the writing of strong gratings in Sn-doped phosphosilicate fibre. $\sim 10^{-3}$ index change was reached within 1 minute of exposure in this fibre, the fastest to our knowledge. Sn-doping can also be used for the production of gratings in germanium-free optical fibres and for the mass-production of strong gratings using single pulse Type II grating Technology. Tin can be easily incorporated into the conventional vapour-phase deposition techniques. 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 fibre used in these experiments was fabricated by a modified chemical vapour deposition (MCVD) system. The fibre had 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. The absorption of the core glass was measured with the technique described in [4] before and after a 5 minute exposure to a line-narrowed KrF excimer laser operating at 248 nm. 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 $\sim$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 measured in the fibre. 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.

Fibre gratings were then imprinted in sections of the fibre using the interferometer set-up described in [1]. The pulse fluence was set at $\sim$0.25 J/cm^2 for the grating writing and the grating length was $\sim$15 mm. A grating with reflectivity of 50% was written in the fibre using a writing time of 2 mins (i.e. $\sim$0.6 kJ/cm^2). An index change of 0.5×10^{-4} was estimated from this grating. The grating reflectivity decayed to 45% in the first few minutes after the writing process, but was stable thereafter. When the pulse fluence was increased to $\sim$0.4 J/cm^2, $\sim$100% gratings with $\sim$0.8 nm bandwidth were written in $\sim$40 seconds ($\sim$0.3 kJ/cm^2, see fig.3). 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 $\sim$0.5 J/cm^2, gratings with $\sim$100% reflectivity were produced using a single pulse (see fig.4). This was due to the optical damage at the core/cladding interface because of the high optical absorption in the core [2]. The measured absorption at 248 nm in the preform core was comparable to that in a fibre with 22 mol% germanium [4].

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 $\sim$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: Very strong gratings of both type I and II have been demonstrated in Sn-doped phosphosilicate fibres. This technique enables index changes of $\sim 10^{-3}$ to be written within 1 minute of exposure and gratings to be written in phosphorous-containing fibres without hydrogen loading.

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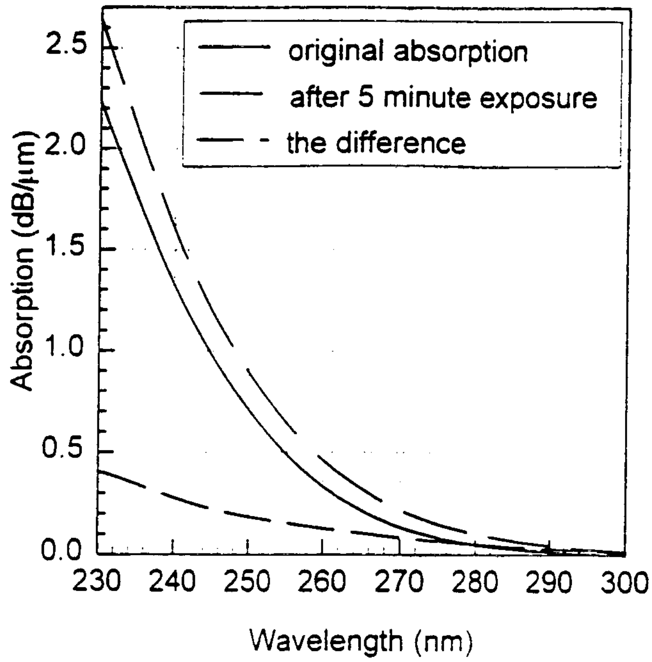

Fig.1 The UV absorption spectra measured in the Sn-doped phosphosilicate preform before and after exposure to a KrF excimer laser beam for 5 mins. The pulse fluence was set at ~50 mJ/cm^2 for this exposure.

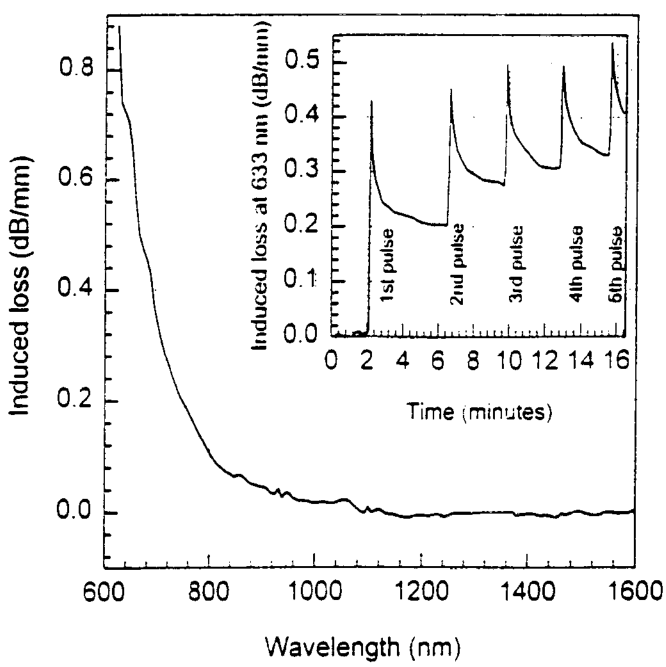

Fig.2 Induced absorption in the Sn-doped phosphosilicate fibre after exposure to a KrF excimer laser for 5 mins. The inset shows the dynamics of the induced absorption at 633 nm.

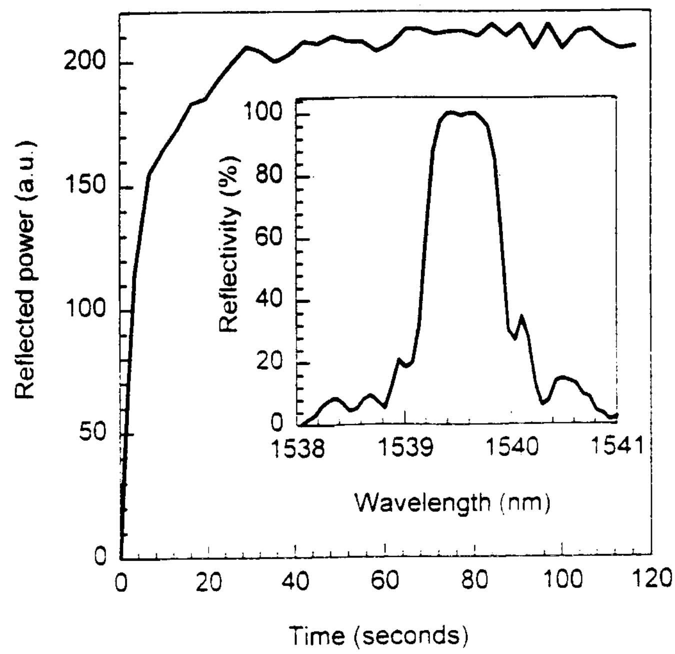

Fig.3 Growth of a grating in the Sn-doped phosphosilicate fibre when writing with a KrF excimer laser at 20 Hz with a pulse fluence of 0.4 J/cm^2. The inset shows the reflection spectrum of the grating.

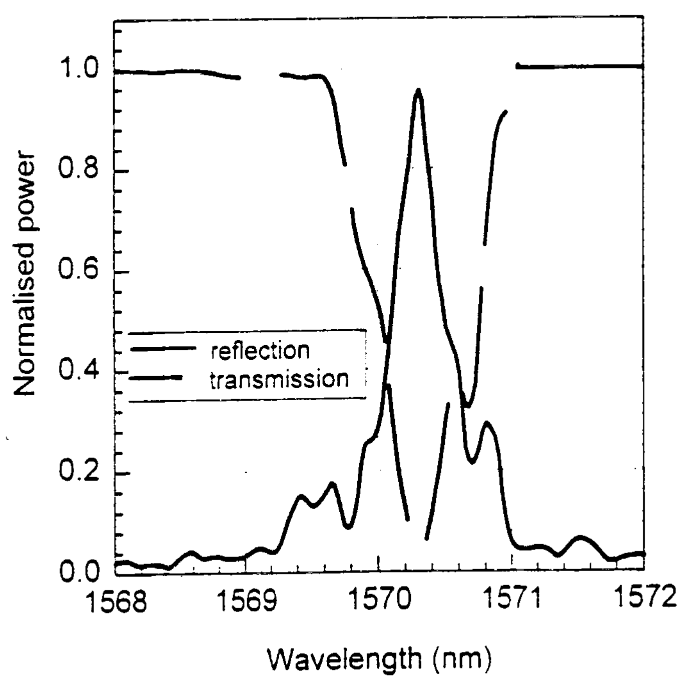

Fig.4 The transmission and reflection spectra of a Type II grating written in the Sn-doped phosphosilicate fibre.