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PHOTOSENSITIVITY IN TIN CO-DOPED SILICA OPTICAL FIBRES

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Abstract: Bragg gratings have been written in SiO_2:SnO_2:Na_2O optical fibres, where the presence of Na_2O allows for higher concentrations of SnO_2. Significant refractive index modulations (up to $6.2\cdot10^{-4}$) have been achieved with enhanced temperature stability (no erasure up to temperatures >600 °C).

Introduction

UV photosensitivity of glass materials (e.g. change in refractive index induced by exposure to optical radiation) is a fundamental property for the realization of many optical devices. For example Bragg gratings in optical fibres/waveguides have attracted much attention since their first demonstration because of their many applications, such as sensors, dispersion compensators and laser mirrors [1]. Telecom optical SiO_2 fibres which have low content of GeO_2 (~3 mol %) show small refractive index changes when exposed to UV radiation. It is thus necessary to increase the photosensitivity of optical fibres/waveguides through post-fabrication methods (such as hydrogen/deuterium loading and flame brushing) and co-doping (B_2O_3, SnO_2 and rare earths) [2]. SnO_2 has been used mainly as a codopant to increase the photosensitivity of germanosilicate and phosphosilicate [3], and more recently SiO_2:SnO_2 optical fibres have also been investigated [4]. Ref.4 has shown that small concentrations (~0.15 mol %) of SnO_2 in the silica network, without the need of adding any other co-dopant (e.g. GeO_2, P_2O_5), give permanent refractive index changes with a high degree of photorefractivity. Compared to other techniques, the use of SnO_2 keeps the absorption in the third telecom window at 1.5 μm low, provides better temperature stability of the grating: simpler and potentially cheaper process. Unfortunately the incorporation of SnO_2 in silica presents several problems. A limit for the binary glasses based on SiO_2:SnO_2 is given by the crystallization process which takes place for SnO_2 concentrations of ~1% mol. Any crystallization would increase the optical loss in the waveguide devices. Another problem with the production of SnO_2 doped or co-doped silica fibre via MCVD (or solution doping) techniques is related to the high volatility of SnO_2 at the temperature required for preform collapse which would prevent the retention of high SnO_2 concentration in the fibre. From previous works [3] co-dopants such as GeO_2 and P_2O_5 can allow incorporation of SnO_2 up to ~1 mol %. Following the reports that alkaline elements can increase the solubility of SnO_2 in bulk silica glass (up to 20 mol % without crystallization) [5], here it is proposed to use Na_2O to increase the concentration of SnO_2 in silica fibres. Bragg gratings have been written in optical fibres with SiO_2:SnO_2:Na_2O core and SiO_2 cladding. In these preliminary experiments refractive index modulations up to $6.2\cdot10^{-4}$ have been achieved using a 248 nm excimer laser and a phase mask. Compared to gratings written in germanosilicate and boro-germanosilicate optical fibres, the gratings written in SiO_2:SnO_2:Na_2O show much greater temperature stability (up to ~600 °C there is no sign of any erasure).

Experiments

The fibre used in these experiments was produced using RIT [6]. The core glass was produced by melting powders of Na_2O, SiO_2 and SnO_2 in a Pt crucible at 1500 °C for 60 mins, consolidating at 1750 °C for 60 mins and casting on a Cu mold at room temperature. The molar composition of the batch powders was: $[SiO_2]$=75%, $[SnO_2]$=5%, $[Na_2O]$=20%. The glass was drilled with an ultrasonic drill. The cylinder (1.5 mm diameter and 50 mm height) was cleaned in an ultrasonic bath and etched in Hydrofluoric acid to reduce the surface roughness. The cladding (a Suprasil tube with outer diameter (OD) of 34 mm and internal diameter (ID) of ~1.6 mm) was collapsed onto the core at 2000 °C whilst pulling the fibre (the final fibre had OD=74 μm).

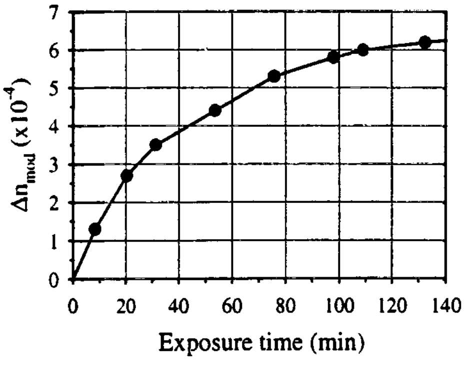

Figure 1: Growth of refractive index modulation (Δn_{mod}) resulting from exposure to 248 nm KrF laser at 30 pulses/s with 140 mJ/pulse·cm².

Gratings for reflectivity at ~1.55 μm were written in the fibre using a pulsed KrF excimer laser (wavelength 248 nm) working at 30 Hz and a phase mask. Pulse duration and fluence were estimated to be 20 ns and 140 mJ/pulse·cm^2. The growth of the refractive index modulation is presented in fig. 1 and seems to saturate at levels larger that $6.2\cdot10^{-4}$ after 120 minutes of exposure. Measurements at different intensities (pulse energy) have been carried out in order to understand whether the photosensitivity of this sample is driven by a one or two-photon absorption process. Fig. 2 shows that the slope of the initial growth of the refractive index modulation as a function of pulse energy in a log-log scale is ~1.1, indicating that the photorefractive response of this glass is based on a one photon process [4].

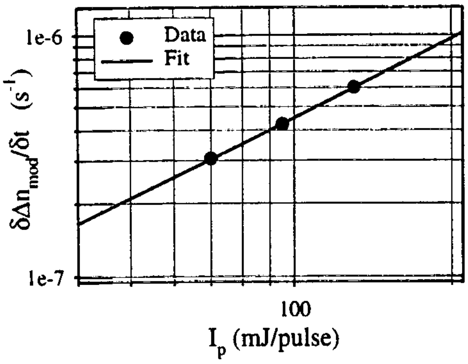

Figure 2: Initial modulation growth ($\delta\Delta n_{mod}/\delta\Delta t$) rate as a function of KrF laser energy per pulse. The continuous line is the best linear fit. The resulting slope is ~1.1, indicating that the process is one photon driven.

Temperature stability studies were carried out on gratings written into the SiO_2:SnO_2:Na_2O fibre. The reflectivity (hence refractive index modulation) of the grating was measured during step heating: the sample was heated up of ~45 °C (starting from 205 °C) in 2 minutes and kept at that temperature for the subsequent 28 minutes, before increasing the temperature again with another step. Fig. 3 shows a comparison for four different fibre compositions, making evident the enhanced stability of gratings written in SiO_2:SnO_2 and SiO_2:SnO_2:Na_2O (SSN) compared to those written in germanosilicate (SiO_2:GeO_2) and boro-germanosilicate (SiO_2:GeO_2:B_2O_3). In fact for SSN there is no sign of any erasure up to ~600 °C.

Conclusions

In conclusion, we have reported the fabrication of optical fibres based on the ternary glass composition SiO_2:SnO_2:Na_2O which can allow for SnO_2 concentrations in SiO_2 well above the crystallization limit of ~1 mol %. Compared to other dopants (e.g. GeO_2, P_2O_5) the introduction of sodium oxide increases the solubility of SnO_2 as well as not causing any significant background refractive index change in the silica matrix. This last feature may be important for the realization of photosensitive optical fibres and waveguides that are compatible with current telecom fibres.

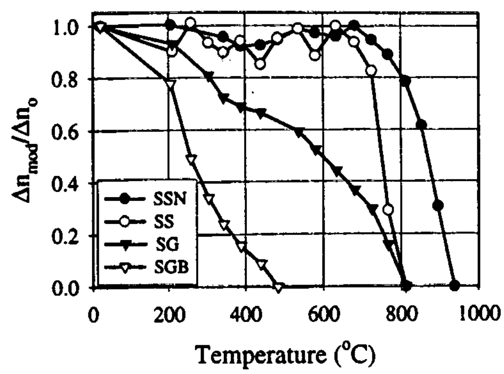

Figure 3: Comparison of temperature stability of gratings written in different core glass compositions: SiO_2:SnO_2: Na_2O (SSN), SiO_2:SnO_2 (SS), SiO_2:GeO_2 (SG), SiO_2: GeO_2 :B_2O_3 (SGB).

The remarkable temperature stability shown by the photoinduced refractive index modulations in SiO_2:SnO_2:Na_2O optical fibres may be very important for the realization of gratings and other devices which require or are subjected to high operating temperatures, e.g. sensors or high power lasers/amplifiers. The high temperature stability may also indicate traps with high activation energy for the photoinduced defects and this could be relevant for applications where intrinsic absorption effects (one or more photon for high light intensities) could erase the induced refractive index modulation. Further improvements will be necessary to fabricate routinely fibres with levels of refractive index modulation approching 10^{-3}.

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