Photosensitivity in germanium-free antimony doped alumino-silicate optical fibre prepared by MCVD

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Abstract: *Bragg gratings with index modulations of ~3x10^{-4} is reported in antimony (Sb) codoped fibres. Gratings in germanium-free fibres of different Sb concentration are analysed and those in higher concentration fibres are found the more temperature-resistant.*

Introduction

Photosensitive fibre for use in for example Bragg grating devices has been widely exploited in the area of fibre optic based communications, lasers and sensor systems. Most of the photosensitivity studies so far have concentrated on germano-silicate (Ge/Si) core optical fibres. However, co-doping with for-example boron (B), as well as post-fabrication processes have been proposed to increase the photosensitivity in Ge/Si fibres [1,2]. Looking for other dopants to make photosensitive fibres has been the aim of much research [3,4] not least because incorporation of large concentrations of rare-earths can impose a problem such as clustering in Ge/Si glasses. For example, recently antimony (Sb) -doped fibre made by the sol-gel technique was found to be highly photosensitive [5]. However, a large residual OH content in sol-gel glasses may limit this route from making these fibres commercially viable. Additionally, the incorporation of antimony using standard MCVD techniques can be difficult, because of its enormous volatilisation at the collapse temperature. However, our modified MCVD technique which is fully compatible with the conventional MCVD method of making optical fibre, have proven a reliable technique to incorporate reasonable concentrations of antimony. Recently there have been reports of codoping Ge/Si fibres with large concentrations of Sb with the aim of achieving highly temperature resistant index-changes formed using high-intensity pulsed (KrF) UV-light at 248nm [6].

In this work we report photosensitivity in ***germanium-free*** antimony (Sb) -doped alumino-silicate (Al/Si) fibre, prepared by the MCVD method. We characterise the induced index-modulations against fluence for 244nm CW UV exposure and investigate their temperature stability. We find hydrogen loading of the fibres is necessary to achieve sufficient index changes and that gratings written into hydrogenated samples of the fibres exhibit the highest temperature resistance and furthermore that the achievable index changes are highly dependant on the concentration of Sb as is the temperature stability of these.

Experiments, results and discussion

Both Al and Sb is incorporated into the fibre-perform through the solution doping technique during the perform preparation. In the two fibres reported here the concentration of Al is the same. After drawing the fibres have outer diameters of ~120 µm, NA values of ~0.2 (high conc. Sb) and ~0.16 respectively and cut-off wavelengths of ~1.5 µm. From the NA we estimate the concentration of Sb in the fibres to be 2500ppm and 800ppm respectively. The low concentration fibre additionally are co-doped with ~1000ppm of Thulium (Th) which is believed not to contribute to the level of the NA or the photosensitivity.

To test the level of photosensitivity in the fibres, uniform Bragg gratings were written using a frequency doubled Ar$^+$-ion laser operating at 244nm operated with a beam-intensity of ~300W/cm^2 to operate strictly in a type I regime only. The coupling-coefficient (index-modulations) was extracted from the reflectivity of the gratings using coupled-mode theory. To fully characterise the photosensitivity in the both un-loaded and H_2-loaded versions of the fibres these were tested with the loading conditions for the H_2-loaded fibre being 200atm for 2 weeks @ 70°C. After the inscription of the gratings, these were annealed at 100°C for 24 hrs to outgas any residual hydrogen in the loaded sample and to stabilise the index-modulations at room temperature. Fig.1 summarises the index-growth against fluence for gratings written in both the loaded and unloaded samples although the photosensitivity of the unloaded low conc. Sb fibre was too low to get reliable data.

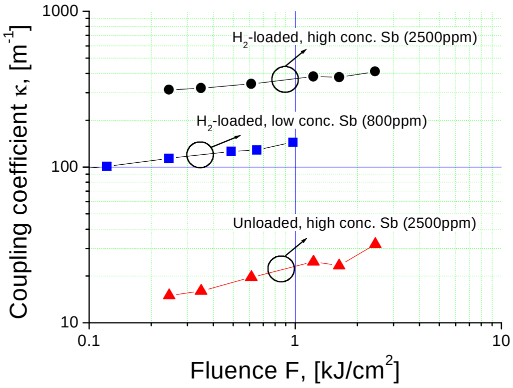

Fig. 1. Measured coupling coefficient against 244nm CW-fluence for fibres of different Sb-concentration.

As indicated, the coupling-coefficient (index-modulation) in the hydrogenated samples reach ~400m^{-1} (~2.8·10^{-4}) and 150m^{-1} (~1.0·10^{-4}) at a moderate fluence of ~1kJ/cm^2, which is ~15 times higher than that induced in the unloaded sample (high conc. Sb) for a similar fluence. It also demonstrates how these appear to be close to saturation as they are as high as ~300m^{-1} (~2·10^{-4}) (high conc. Sb) and ~110m^{-1} (~0.7·10^{-4}) (low conc. Sb) for a very moderate fluence of just 240J/cm^2. It is clear that the concentration of Sb clearly have an effect of the achievable relative index modulations, in fact it appear to follow the relative concentrations although this is believed to be a coincident. To investigate the temperature-stability of the index modulations the gratings were annealed in temperature-increments of 100ºC starting at 200ºC until these were completely erased. At each temperature the gratings were annealed for ~24h to be able to analyse the stabilised-level of the induced index-modulations and not so much the rapid decay which are seen just after the temperature is increased. Fig 2 summarises these results through a plot of the coupling-coefficient normalised against the coupling-coefficient observed after the initial annealing at 100°C. These show that the gratings written in the H_2-loaded sample of the high conc. Sb fibre were completely erased at around 750°C where as the gratings in the un-loaded sample of the same fibre showed a much faster decay with an erasure temperature closer to 575°C and hence suggests that the gratings in the loaded sample are more temperature-stabile index-modulations than the unloaded sample. This is in strong contrast to what has been observed previously in Ge/Si or B/Ge/Si fibres [4].

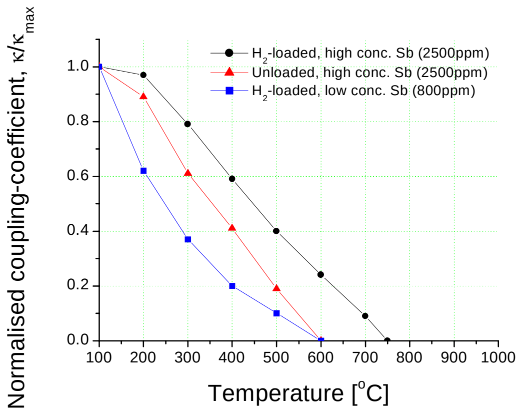

Fig. 2. Temperature resistance of the refractive index-changes in the germanium-free Sb co-doped fibres.

In the 800ppm conc. Sb-fibre the gratings clearly are erased much faster and follow a much different pattern of the erasure compared to the high concentration fibre. It is evident though that the concentration of Sb plays an important role in the temperature stability of the index modulations and we speculate that even higher concentrations will lead to highly temperature stabile index changes.
The absorption spectra of a ~100µm perform-slice of the Sb/Al/Si glass from which the 2500ppm conc. Sb-fibre is made are also investigated against different UV-fluence levels. The perform-slice was polished on both sides and H_2-loaded under similar conditions as the fibre, before UV irradiation. Fig. 3 shows these spectra and demonstrates similar results to what has been observed in Sb/Si fibre made using the sol-gel technique [5]. They show that the loss-peak centret at ~255nm grow dramatically with increasing fluence. The UV-induced losses are seen to extend all the way to ~600nm with possible evidence of peaks of slightly increased losses at ~330nm and ~410nm. The increase in losses with UV-exposure could be due to new colour-centres being generated related to Sb^{4+}-centres in antimony oxide-doped silica glass [6]. It is also noted that during the UV-exposures a strong white-luminescence that only gradually diminishes during prolonged exposure is generated.

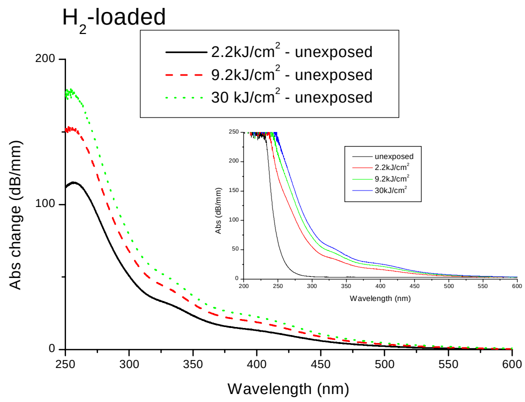

Fig. 3. Absorption spectra on hydrogen-loaded perform-slice of the high conc. Sb glass.

Conclusions

We have analysed the photosensitivity @ 244nm CW UV-light in ***germanium-free*** Sb/Al/Si glass performs and fibres of different Sb concentration under pristine and hydrogen-loaded conditions. We find that induced index-changes are more temperature resistant when formed in the loaded fibres and that the index changes and temperature stability is strongly dependent on the concentration of Sb. We believe that these results will facilitate the manufacture of higher concentration photosensitive rare-earth doped fibres, which previously have been difficult to achieve because of the need for germanium to make them photosensitive enough to for example grating writing.

References

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