Investigation into the Photosensitivity of germanium-free antimony co-doped alumino-silicate optical fibres

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Abstract: Photosensitivity of different concentrations of antimony (Sb) codoped alumino-silicate optical fibres are analysed. Bragg gratings with index modulations of ~3x10^{-4} are reported. The temperature stability of the gratings is tested and those in higher concentration fibres are found to be more temperature-resistant.

1. Introduction

UV written fibre Bragg gratings (FBGs) devices have many applications in the area of fibre optic based communications, lasers and sensor systems. Most of the photosensitivity studies of the fibre for photoinduced refractive index changes 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 large concentrations of rare-earths can impose a problem such as clustering in Ge/Si glasses. Recently, antimony (Sb) –doped fibres made by the sol-gel technique was found to be highly photosensitive [5]. A larger residual OH content in sol-gel glasses may limit this route from making these fibres commercially viable. Though 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 sufficient concentrations of antimony. 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 the photosensitivity in *germanium-free* antimony (Sb) codoped alumino-silica (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 that gratings written into hydrogenated samples of the fibres exhibit the higher photosensitivity and temperature stability and furthermore that the achievable index changes are highly dependant on the concentration of Sb as is the temperature stability of these.

2. Experiments, results and discussion

Both Al and Sb is incorporated into the fibre-preform 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 these have outer diameters of ~ 120µm, NA values of ~ 0.2 (high conc. Sb) and ~0.16 respectively and cut-off wavelengths of ~ 1.5µm. From the NA we estimate the concentration of Sb in the fibres to be 2500ppm and 800ppm respectively although it is difficult to predict exactly. The low concentration fibre additionally is co-doped with ~1000pppm of Thulium (Tm) which is believed not to contribute to the level of the NA or the photosensitivity.

To test the level of the photosensitivity in the fibre, 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 grating 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. Fig.1 summarises the index-growth against fluence for gratings written in both the loaded and unloaded samples. The photosensitivity of the unloaded low conc. Sb fibre was too low to get reliable data and hence these are not plotted. As indicated, the coupling-coefficient (index-modulation) in the high concentration of Sb reaches ~400m^{-1} (~$2.8\cdot10^{-4}$) and 150m^{-1} (~$1.0\cdot10^{-4}$) for the low concentration at a moderate fluence of ~1 kJ/cm^2, which is ~15 times higher than that induced in the unloaded sample (high conc. Sb) for a similar fluence. Also noted how these appear to be close to saturation as they are as high as ~300m^{-1} (~$2\cdot10^{-4}$) (high conc. Sb) and ~100m^{-1} (~$2\cdot10^{-4}$) (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.

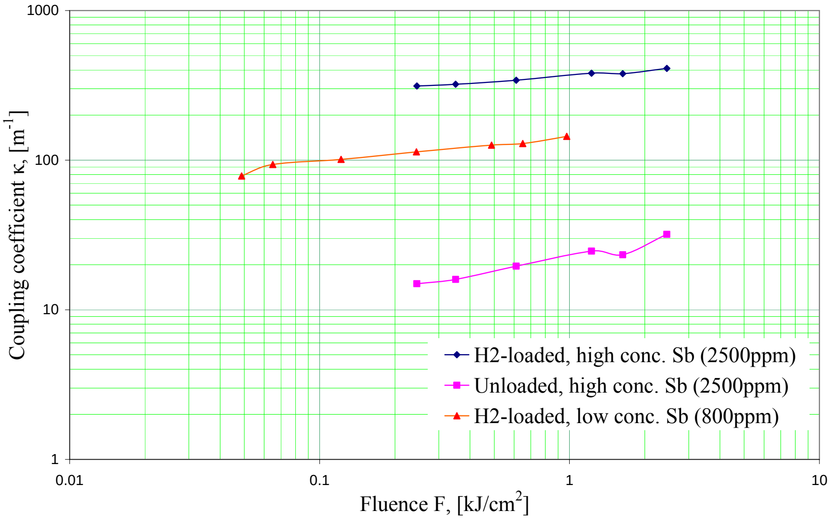

Fig.1. Measured coupling coefficient against 244 nm CW-fluence for fibres of different Sb-concentration.

To investigate the temperature-stability of the index modulations the gratings were annealed in temperature-increments of 100°C starting at 200°C 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 characteristics 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 unloaded 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].

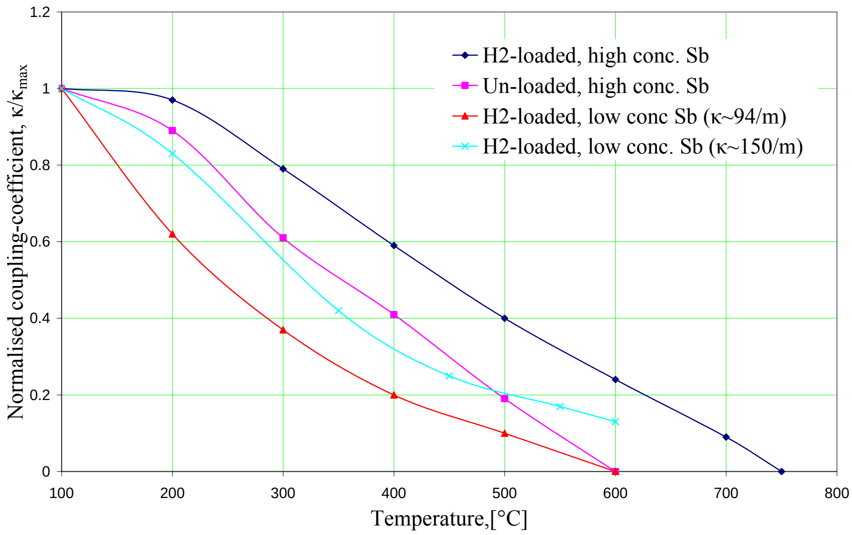

Fig.2.Thermal decay of the refractive index modulation of FBGs written into the Sb codoped fibres.

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 temperature stability of gratings with coupling coefficient of both ~150m^{-1} and ~94 m^{-1} as tested. As demonstrated the grating of higher the coupling coefficient exhibits more temperature stabile index changes against temperature. The temperature stability of the grating with coupling coefficient of ~150m^{-1} for the low conc. Sb fibre is actually higher than the unloaded fibre at above 500°C.

The absorption spectra of a ~100µm perform-slice of the Sb/Al/Si glass from which the 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 (right) shows these spectra and demonstrates similar results to what has been observed in Sb/Si fibre made using the sol-gel technique [5]. The show that the loss-peak centret ~255nm grow dramatically with increasing fluence. This increase is also evident in the un-loaded sample despite this being much smaller (Fig. 3 (left)). 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, although these are only really evident on the H_2-loaded sample. 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 [7]. It is also noted that during the UV-exposures a strong white-luminescence that only gradually diminishes during prolonged exposure is generated. Note that the amount of loss increase in the un-loaded and H_2-loaded perform sample correspond to the amount of induced index-changes in the fibres (~15 times).

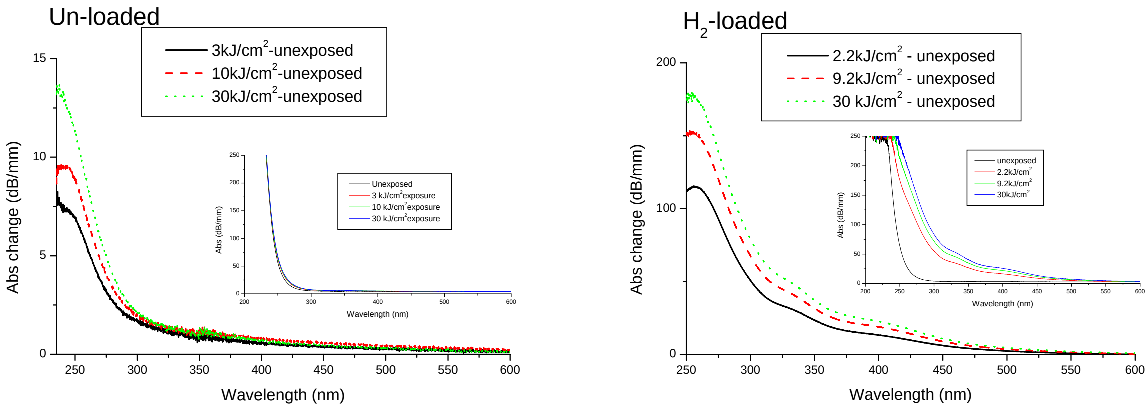

Fig.3.Absorption spectra of un-loaded and hydrogen-loaded perform-slice of the high conc. Sb glass.

3. Conclusions

We have analysed the photosensitivity @244nm CW UV-light in 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 fibre and that the index changes and temperature stability is strongly dependent on the concentration of Sb. We also show the higher the coupling coefficient the higher the temperature resistant. 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.

4. References

[1] D.L.Williams, B.J.Ainslie, J.R.Armitage, R.Kashyap, and R.Campbell., "Enhanced UV photosensitivity in Boron codoped germanosilicate fibres," *Electronics Letters*, vol. 29, pp. 45-47, 1993.

[2] P.J.Lemaire, R.M.Atkins, V.Mizrahi, and W.A.Reed, "High pressure H_2 loaading as a technique for achieving ultrahigh UV photosensitivity and thermal sensitivity in GeO_2 doped optical fibres," *Electronics Letters*, vol. 29, pp. 1191-1193, 1993.

[3] G.Brambilla and V.Pruneri, "Enhanced photorefractivity in Tin-doped silica optical fibres (Review)," *IEEE Journal on selected topics in Quantum Electronics*, vol. 7, pp. 403-408, 2001.

[4] A.Othonos and K.Kalli, *Fibre Bragg grating:Fundamentals and applications in telecommunications and sensing*: Artech House Inc., 1999.

[5] K.Oh, P.S.Westbrook, R.M.Atkins, P.Reyes, R.S.Windeler, W.A.Reed, T.E.Stockert, D.Brownlow, and D.DiGiovanni, "Ultraviolet photosensitive response in an antimony-doped optical fiber," *Optics Letters*, vol. 27, pp. 488-490, 2002.

[6] Y.Shen, J.He, T.Sun, and K.T.V.Grattan, "High-temperature sustainability of strong fibre Bragg gratings written into Sb-Ge-codoped photosensitive fiber: decay mechanisms involved during annealing," *Optics Letters*, vol. 29, pp. 554-556, 2004.

[7] M. Shimizu and Y. Ohmori, "Antimony oxide-doped silica fibers fabricated by the VAD method", *J. of Lightwave Technol.*, vol. LT-5, (6), pp. 763-68, (1987).