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STRONG UV ABSORPTION IN GERMANOSILICATE FIBRE PREFORMS INDUCED BY EXPOSURE TO 248 NM RADIATION

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Abstract: A new technique has enabled us to resolve the strong UV absorption spectrum in the UV-exposed germanosilicate preforms. Our results show that the strong UV-induced band at 195 nm is responsible for as much as 1×10^{-4} of index change at 1.5 μm after only moderate UV exposure in a 0.18 NA preform. The thermal annealing properties of this band also resemble those of fibre gratings, supporting a colour-centre model of photosensitivity.

Introduction: In-core Bragg gratings based on the UV photosensitivity of germanosilicate fibres have attracted much attention since their first demonstration. They are useful in a wide range of applications where wavelength selectivity is required. The precise origins of the refractive index change are not yet fully understood, although two classes of mechanism have been suggested. The first is based on colour-centre related changes in UV absorption which through the Kramers-Kronig relation give rise to refractive index changes in the visible and the infra-red; and the second is based on major structural changes in the glass matrix, induced by the absorption of UV light. Very-high UV absorption (as high as several dB/μm) in UV-exposed fibres and preforms make measurements very difficult and has hampered the resolution of the argument. In this paper, we report a study of the UV-induced absorption change, made possible by a new technique [1], which allows us to measure samples as thin as several μm. We have found, through the Kramers-Kronig relation, that a strong band at 195 nm (6.35 eV) is the chief cause of the index change in the infra-red. The bleaching of the band at 242 nm contributes negatively to the index change, but initialises the process by releasing electrons to be trapped to form the 195 nm band. Our results also show that the

absorption change starts to decay at temperatures as low as 200°C, totally disappearing at 800°C. This behaviour resembles that of fibre gratings. The germanosilicate glass under investigation was prepared using modified chemical-vapour-deposition and is in the form of a thin film ranging from several μm to tens of μm on the inside of a high-purity silica substrate tube, which was subsequently cut into curved samples.

Theory: If a Gaussian distribution, $A_i(1/m) \times \exp(-(\omega-\omega_i)^2/B_i^2)$, is assumed for each induced absorption band, the induced index change in the IR can be simply derived from Kramers-Kronig relation:

$$\Delta n(\omega) = \frac{c}{2\sqrt{\pi}} \sum_i \frac{A_i B_i}{\omega_i^2 - \omega^2}$$

where c is the speed of light in vacuum. The results of Atkins et al [2], who measured down to 165 nm, have indicated that the main absorption changes in germanium-doped silica are due to bands at 195 nm (6.35 eV) and 242 nm (5.1 eV). There are also weak bands at 256 nm (4.85 eV), 224 nm (5.64 eV), 183 nm (6.82 eV) and 175 nm (7.1 eV). These weak bands are an order of magnitude weaker than the main band at 195 nm and they contribute only a small fraction of the total index change. The change in the strength of the 242 nm band is typically less than half that of the 195 nm band and contributes a negative index change some ~20% of the positive index change caused by the 195 nm band. We used the bands at 242 nm, 195 nm and 256 nm in our analysis. A fit with the three bands to the measured differential absorption spectrum is shown in Fig.1. The B parameters are 0.23 eV, 0.77 eV and 0.5 eV respectively.

Experiments: We used a pulsed KrF excimer laser at 248 nm set at 20 Hz and a Perkin Elmer Lambda 9 spectrophotometer to measure the induced absorption change. Fig.2 gives the evolution of the two main absorption bands in a sample containing 8.3 mol% germania for different exposure times at 0.9 mJ/mm^2/pulse. At the end of the 1 hour exposure, no saturation was observed, whilst the calculated index change at 1.5 μm attained 1×10^{-4}. Note that the 195 nm band has increased by 0.4 dB/μm - a very significant change. Thermal annealing was conducted on another sample with 10.2 mol% germania (0.2 NA) after an

exposure of 20 mins at 0.5 mJ/mm^2/pulse. It was brought to 100°C at 10°C/min in air, kept at 100°C for 10 mins. After cooling, the absorption spectrum was measured and the process was repeated at increasing temperatures. Fig.3 shows the decay of the two main bands together with the calculated index change at 1.5μm. A very similar curve was reported by Meltz et al for fibre gratings [3]. We have also shown that, for the same exposure (20 mins at 0.5 mJ/mm^2), the two main bands increase linearly with germania concentration, with a preform of numerical aperture 0.25 attaining a calculated index change of 7×10^{-5} at 1.5 μm.

Conclusions: We have demonstrated that the UV-induced absorption band at 195 nm in germanium-doped silica is chiefly responsible for the index change of the order of 10^{-4} observed in fibre gratings. The similar thermal annealing property of the UV-induced absorption and fibre gratings supports the conclusion.

References

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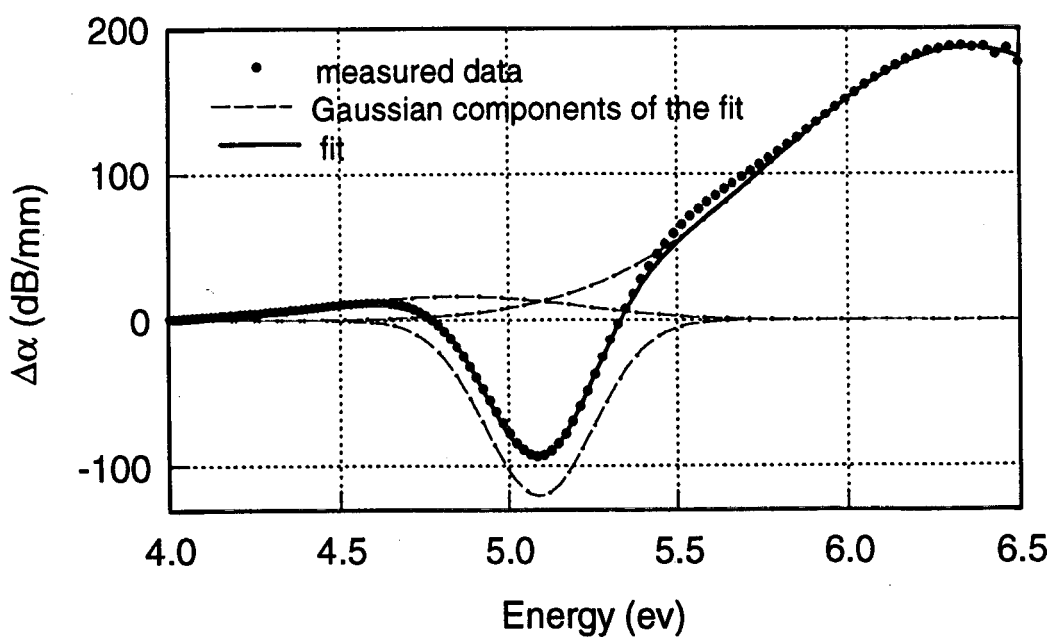

Figure 1. Measured $\Delta\alpha$ in a 0.2 NA preform after an exposure of 20 mins at 0.5 mJ/mm^2/pulse fitted with three Gaussian functions.

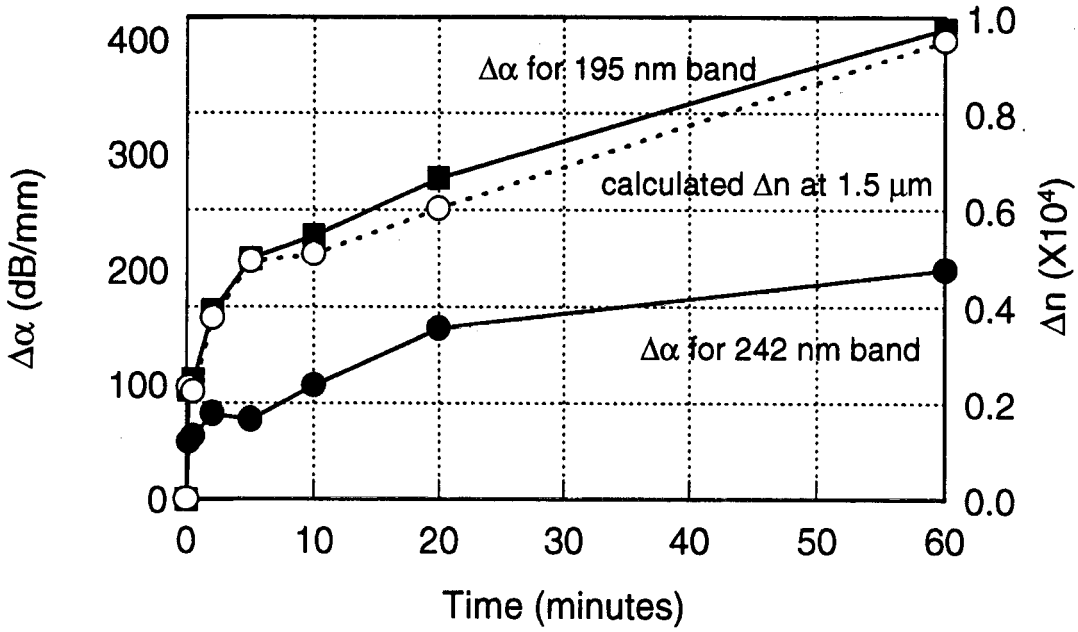

Figure 2. Growth of Δα in a 0.18 NA preform at 0.9 mJ/mm^2/pulse and calculated Δn at 1.5 μm.

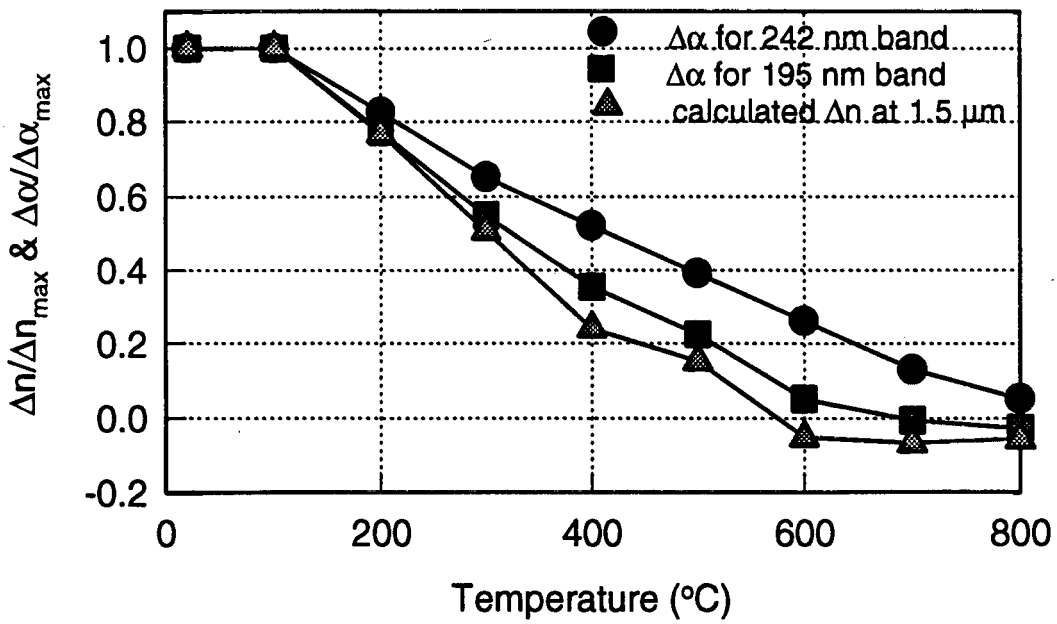

Figure 3. Thermal annealing of UV-induced changes in a 0.2 NA preform. The heating rate was 10 °C/min and the sample stayed for 10 mins at each point.