Enhanced photosensitivity in CO_2 laser treated optical fibres

Gilberto Brambilla, Valerio Pruneri, Laurence Reekie and David N. Payne

Optoelectronics Research Centre, University of Southampton, Highfield, Southampton, SO17-1BJ, U.K.

Fax.++44-1703-593149, Tel.++44-1703-593954

e-mail: gb2@orc.soton.ac.uk

Enhanced UV photosensitivity and increase in defects' concentration have been observed in GeO_2-doped optical fibres thermally treated using CO_2 laser.

Enhanced photosensitivity in CO_2 laser treated optical fibres

Gilberto Brambilla, Valerio Pruneri, Laurence Reekie and David N. Payne
Optoelectronics Research Centre, University of Southampton, Highfield, Southampton, SO17-1BJ, U.K.
Tel.++44-1703-593954, Fax.++44-1703-593149
e-mail: gb2@orc.soton.ac.uk

Since the discovery of photosensitivity in optical fibres by Hill and co-workers in 1978, many techniques have been developed to enhance the UV response of germanosilicate fibres [1]: among post-fabrication processes on Ge-doped fibres hydrogen loading and flame brushing are the most common. These processes are based on the reaction of molecular hydrogen with a common Ge-O-Si site to produce OH groups and germanium-oxygen deficient centres (GODC), believed to be responsible for photosensitivity in Ge-doped fibres. As consequence, the absorption in the third telecom window at 1.55 μm is increased because of the formation of nearby OH absorption bands at 1.40μm. Here we propose and investigate a novel post-fabrication technique to increase the photosensitivity of germanosilicate fibres. The fibres (not hydrogenated) have been exposed to intense CO_2 laser radiation before the gratings were written using high intensity UV laser. The fibre used in the experiment was produced via modified chemical vapour deposition (MCVD) and had an external diameter of 120 μm, numerical aperture (NA) of ~0.27 and cut-off wavelength (λ_c) of ~1.36 μm. The fibre was side-exposed to ~13.5 W continuous wave CO_2 laser for 15 seconds and subsequently rapidly cooled down with liquid nitrogen. The photosensitivity was tested via grating writing.

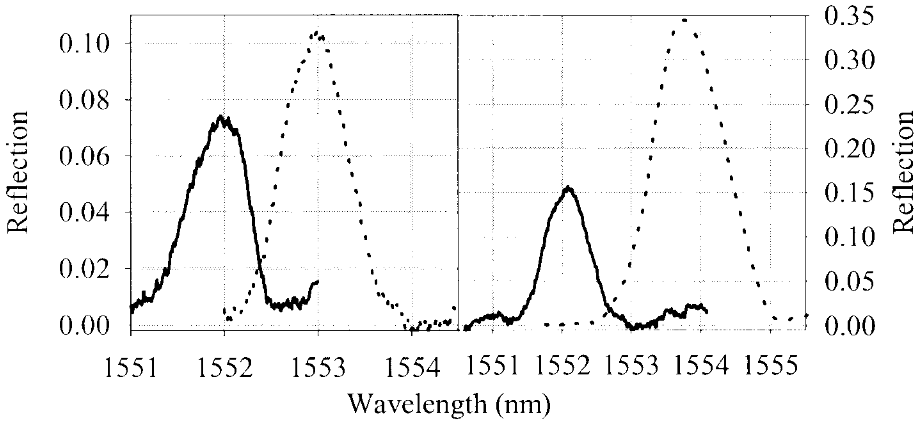

Fig. 1 Comparison of reflection spectra of gratings written using pulsed excimer laser in fibres treated with CO_2 laser (dashed lines) and in untreated fibres (continuous lines); UV laser intensity was ~100mJ/cm^2 in a), ~200mJ/cm^2 in b). The fibre (NA~.27 and λ_c~1360nm) has been exposed to 13.5W CO_2 laser radiation for 40s.

Gratings were written with a phase-mask exposing the fibres for 100 s to 248 nm Kr-F excimer pulsed at 20 Hz; two different UV intensities were used: ~100 and ~200 mJ/cm^2 per pulse. The reflection spectra of gratings written in the fibre exposed to the CO_2 laser and in the untreated fibre are shown in fig. 1. Compared to the untreated fibre gratings, the treated fibre gratings provide higher reflectivity and a longer Bragg-wavelength when exposed to high UV laser intensities, just a Bragg-wavelength shift when exposed to low UV intensities. No measurable induced loss was detected in the treated fibre. It was suggested that both in silica [2] and germanosilicate fibres [3-4] two types of defects contribute to the 242 ÷ 248 nm absorption peak. Since the difference between gratings written in treated and untreated fibres increases with increasing UV intensity, our results seem to be consistent with a model implying two types of GODC defects with different bleaching dependence on UV intensity; one of these defects, whose concentration increases after CO_2 treatment, can be bleached only at high UV intensities, probably through multi-photon absorption.

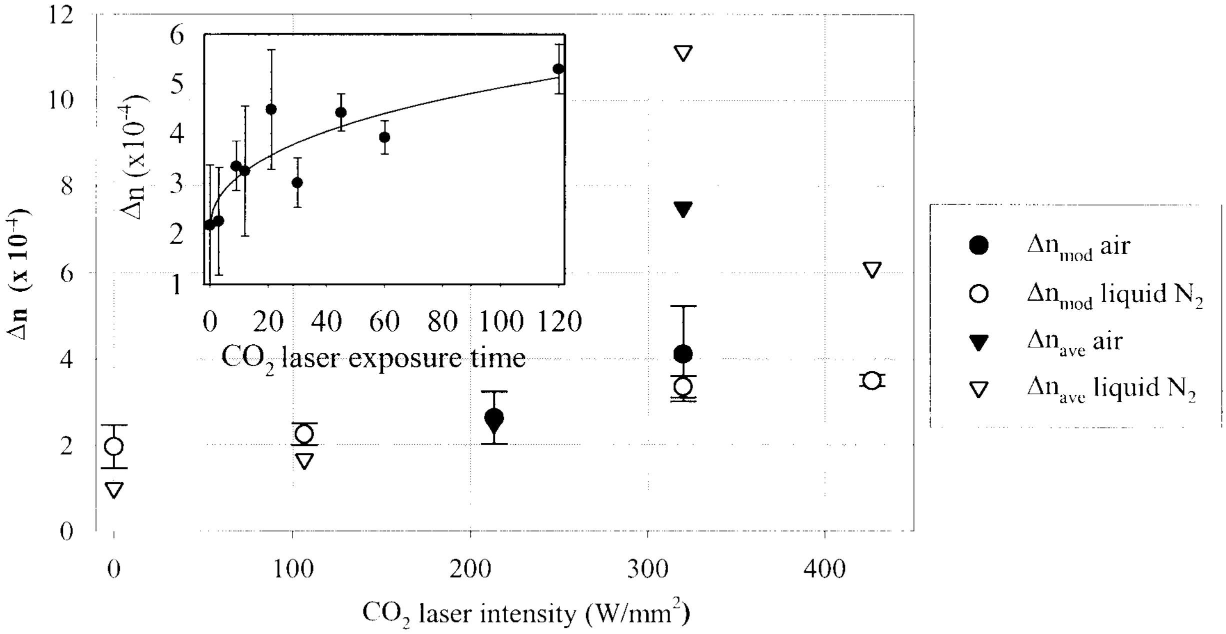

Fig. 2 Dependence of the induced Δn on CO_2 laser intensity. Open symbols represent fibres heated up by CO_2 laser and cooled by liquid N_2, filled symbols represent fibres only treated with CO_2 laser. In the inset: dependence of Δn_{mod} on the cumulative CO_2 laser exposure time (laser intensity 250 W/mm^2, single exposure time 3 s, cooling in air). Gratings were written by exposing fibres to pulsed excimer laser (average pulse energy 250 mJ/cm^2, frequency 20 Hz, pulse duration 20 ns). The fitting curve is a stretched exponential.

Other samples from the same fibre were exposed for 3 s at different levels of CO_2 laser intensity; the cooling of these samples was either in liquid N_2 or in air. The values of the induced refractive index modulations (Δn_{mod}) and average refractive indexes (Δn_{ave}) were estimated from the reflection spectrum and are presented in fig. 2. They show significant increase in the photorefractive response for increasing CO_2 intensity, with no difference due to cooling process. Moreover, the large Bragg-wavelengths shifts detected at high CO_2 intensity levels gave a deviation of Δn_{ave} from $\Delta n_{mod}/2$ more significant than at low intensities. Other fibres with similar properties (NA~0.3 and λ_c~1.26 μm) were exposed several times to ~8 W CO_2 laser for 3s, in order to understand if there is a cumulative effect. The dependence of Δn_{mod} on the cumulative exposure time is presented in the inset of fig. 2 and clearly shows a larger photosensitivity increase for a greater number of exposures. Photorefractive changes are always positive and seem to saturate after several treatments. It has to remarked that the Δn_{mod} reached after 40 exposures (~$5.2*10^{-4}$) is remarkably larger than the value (~$2.2*10^{-4}$) obtained in the untreated fibre.

To understand what was the reason of photosensitive enhancement, we have recorded the absorption spectrum modifications of thin preform samples, treated in a similar way to the fibres that showed high induced Δn_{mod}. The absorption in germanosilicate is quite high for high germanium concentrations and it is not possible to reduce the sample thickness below 100 μm because it becomes brittle and reaches the melting temperature during CO_2 exposure; for these reasons we used slides cut from a preform with NA (~0.2) lower than the NA of the fibre used in the previous experiments and subsequently polished to optical quality.

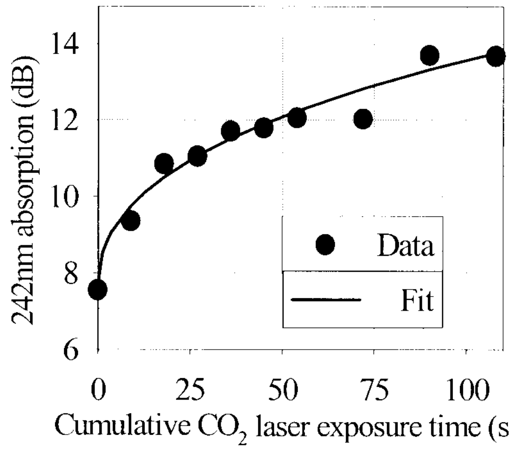

Fig. 3 Relation between the 242 nm absorption peak of the germanosilicate preform slide and the cumulative CO_2 laser exposure time; the preform slide thickness was 120 μm, CO_2 laser intensity and pulse duration were 210 W/cm^2 and 3 s respectively. The fitted curve is a stretched exponential: $A=7.56+12\cdot(1-\exp(-0.0282\cdot t^{0.72}))$.

The absorption spectra of samples exposed to the CO_2 laser beam (intensity: 210 W/cm^2, exposure time: 9s) showed a marked increase in the GODC peak at 242 nm, without any significant modification in other ranges of frequency. Fig. 3 shows the dependence of GODC absorption peak on the cumulative laser exposure time. It is evident that the absorption increases continuously and reaches a saturation level after long exposures. The trend shown for GODC absorption in the preform is equal to the behaviour observed for Δn_{mod} in the fibre (fig. 2); it is reasonable then to assume that the large increase in the photorefractivity of the fibre can be correlated to the increment of the number of oxygen-related defects observed in the UV spectrum.

In order to clarify whether the enhanced photosensitivity associated with CO_2 laser exposure is just a thermally driven effect, we treated two different fibres with the same thermal cycle by using the CO_2 laser and the furnace used during fibre drawing. Gratings, written as previously, showed that the increase in photosensitivity due to CO_2 exposure is closely related to temperature effects - the reflection increase is almost the same in the two fibres differently treated, as is the induced Δn_{mod}. However, one clear difference is that the grating written in the fibre thermally treated in the furnace shows a small Bragg wavelength shift ($\Delta n_{ave} \sim \Delta n_{mod}/2$), while, as previously pointed out, for gratings written in the fibre exposed to CO_2 laser radiation $\Delta n_{ave} >> \Delta n_{mod}/2$. The reason why such average refractive index variation occurs in the fibre treated with the CO_2 laser and not in the thermally treated fibre is still under investigation.

References

1. M. Douay, W.X. Xie, B. Leconte, T. Taunay, P. Bernage, P. Niay, P. Cordier, J. Bayon, H. Poignant and E. Delevaque, *Ann. Telecommun.* **52**, 543 (1997); A. Othonos, *Rev. Sci. Instrum.* **68**, 4309 (1997).
2. J. Lee, G.H. Sigel Jr. and J. Li, *J. Non-Cryst. Sol.* **239**, 57 (1998).
3. H. Hosono, Y. Abe, D.L. Kinser, R.A. Weeks, K. Muta and H. Kawazoe, *Phys. Rev. B* **46**, 11445 (1992).
4. M. Takahashi, T. Fujiwara, T. Kawachi and A. J. Ikushima, *Appl. Phys. Lett.* 72, 1287 (1998).