Highly photosensitive nitrogen-doped germanosilicate fibre for index grating writing

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Indexing terms: Gratings in fibres, Optical fibres

A germanosilicate fibre (7 mol.% GeO_2) codoped with nitrogen has been fabricated by the surface plasma CVD process. The fibre has demonstrated a photoinduced refractive index change of 2×10^{-3} at an irradiation dose of 75 kJ/cm^2 and a wavelength of 244 nm without hydrogen loading, and an index change of 1×10^{-2} after hydrogen loading.

Introduction: In-fibre grating writing based on the photorefractive effect is now attracting considerable interest [1]. However, the photosensitivity of standard germanosilicate fibres with a moderate concentration of germanium in the core (5–7 mol.% GeO_2) is not large and does not allow efficient writing of refractive index gratings. To increase the writing efficiency, we need to increase the germanium concentration and/or load the fibre with hydrogen [2]. Increasing the germanium concentration results in a reduction of the mode spot size and in additional losses when the fibre is spliced with a standard telecommunication fibre. Hydrogen loading complicates the grating technology and raises losses in the IR region owing to the OH-group absorption. Therefore, optimisation of the grating writing technology and development of novel types of photosensitive fibres are now a priority.

It was shown in [3], on films synthesised on silica substrates by plasmachemical deposition (PECVD), that doping germanosilicate glass with nitrogen increases its photosensitivity. Clearly, fabrication of such a glass by using a fibre preform technology and investigation of the final fibres would be of great practical interest.

With the help of a hydrogen-free plasmachemical technology, we have fabricated, for the first time, a preform and a fibre with a silica core codoped with nitrogen and germanium. This Letter deals with both the UV absorption spectra of the core glass and the photosensetivity of the fibre.

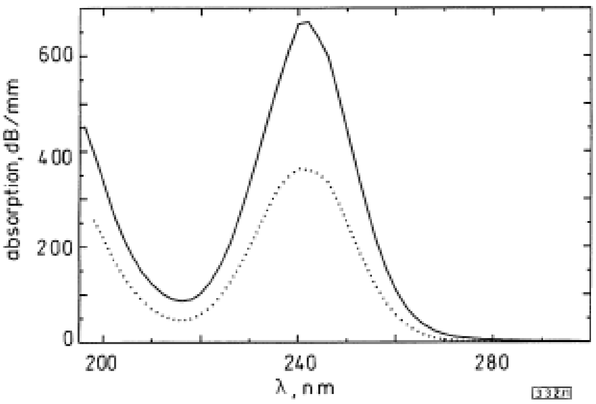

Fig. 1 *Absorption spectra of silica glass*

——— doped with 7 mol.% GeO_2 and 0.1 at.% N (SPCVD-technology)
·········· doped with 20 mol.% GeO_2 (MCVD-technology)

Sample preparation and experiments: The fibre preform was fabricated by the SPCVD process [4]. Doping silica with nitrogen was performed under the conditions described in [5]. The preform core contained ~7 mol.% GeO_2 and ~0.1 at.% N, and the core/cladding index difference was $\Delta n \simeq 0.01$. For comparison, we used nitrogen-free germanosilicate fibres prepared by a standard MCVD process.

The UV absorption spectra were measured on transverse preform slices (~100 μm in thickness). The measuring setup incorporated two monochromators in order to rule out the effect of photoluminescence.

The dynamics of refractive index change under the action of CW radiation of a frequency doubled Ar^+-laser (λ = 244 nm) was measured by the interferometric technique [6]. For this purpose, two long-period 3 dB gratings were written in the fibre under test to form a Mach-Zehnder interferometer. Half of the fundamental mode power was transferred to a cladding mode by the first grating, and these two modes then interfered in the second grating again. The transmission spectrum of the interferometer depended on the phase difference between these two modes $\Delta\varphi$. By measuring the evolution of the transmission spectrum of the interferometer in the process of side irradiation of the fibre section between the gratings, it was possible to determine the induced refractive index of the fibre core: $\Delta n_{IND} \simeq \lambda\Delta\varphi/(2\pi L\eta)$, where λ is the probe light wavelength, L is the length of the fibre section being irradiated, η is the share of the fundamental mode power propagating in the core. The irradiation light intensity was ~13 kW/cm^2. The transmission spectrum of the interferometer was measured using a tungsten halogen lamp as the probe light source and an optical spectrum analyser with a resolution of 2 nm.

Results and discussion: The UV absorption spectrum in the Ge- and N-codoped silica is similar to that in N-free germanosilicate glass (Fig. 1): we see the 242 nm singlet-to-singlet absorption band of the germanium oxygen-deficient centre (Ge-ODC) and a short wavelength absorption edge (λ < 210 nm). Note that the bands observed earlier in Ge-free N-doped silica [7] are absent. The amplitude of the Ge-ODC absorption band in the Ge- and N-codoped silica amounted to 670 dB/mm, which far exceeds the values commonly observed in germanosilicate glass with 7 mol.% GeO_2 fabricated by the MCVD process. In the latter case, the ratio of the absorption at 242 nm to the concentration of germanium dioxide $k = \alpha_{242}/C_{GEO_2}$ lies in the range 10–40 dB/(mm× mol.% GeO_2) [8], whereas for the Ge- and N-codoped silica, this ratio turned out to be 100 dB/(mm× mol.% GeO_2). Thus, the addition of nitrogen strongly increases the Ge-ODC concentration. The luminescence spectrum of the Ge- and N-codoped silica excited at 242 nm exhibited only the two well-known bands of Ge-ODC (290 and 395 nm).

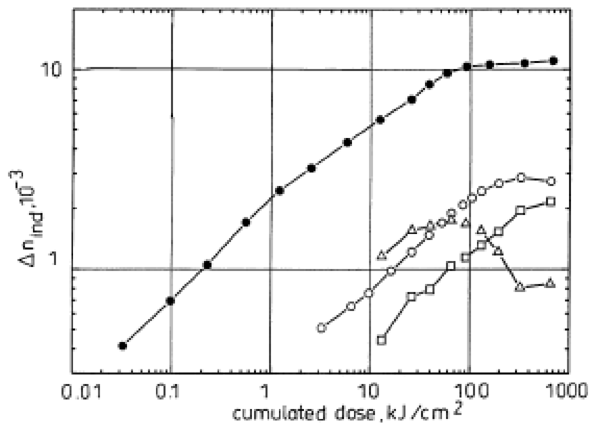

Fig. 2 *Dose dependencies of induced index change in different germanosilicate fibres and in Ge- and N-codoped fibre*

Irradiation intensity ~13 kW/cm^2
□ 12 mol.% GeO_2
△ 20 mol.% GeO_2
○ 7 mol.% GeO_2/0.1 at% N
● 7 mol.% GeO_2/0.1 at% N (H_2-loaded)

The dose dependencies of photoinduced refractive indexes in different fibres are shown in Fig. 2. The Ge- and N-codoped fibre showed a greater photosensitivity than an N-free fibre with 12 mol.% GeO_2. The induced refractive index in the N-and Ge codoped fibre amounted to 2.8×10^{-3} without hydrogen loading and 1×10^{-2} in a fibre piece treated in hydrogen at a pressure of 200 atm over two weeks. It is noteworthy that the induced refractive index in the N-codoped fibre rose up to doses of ~ 300 kJ/cm^2 (type I photosensitivity), whereas an N-free germanosilicate fibre with 20 mol.% GeO_2 demonstrated the type IIa photosensitivity [9] at a dose of ~50 kJ/cm^2.

We also compared the photosensitivity of the unloaded pieces of different fibres on the basis of the time necessary to imprint Bragg gratings with the second harmonic of the Ar^+-laser. At a UV intensity of ~100 W/cm^2 and a grating length of ~3 mm, the reflectivity at λ = 1550 nm in the N-codoped fibre reached 80% after 15 mm of exposure. In the N-free fibre with 12 mol.% GeO_2, the same exposure yielded a reflectivity of only 20%. To obtain a type IIa grating with a reflectivity of 80% in the N-free fibre with 20 mol.% GeO_2, it was necessary to irradiate the fibre for 40 min.

Conclusion: The novel nitrogen-doped germanosilicate fibre prepared by SPCVD has been found to be much more photosensitive than similar N-free fibres. The increase in photosensitivity is due to an increase in the concentration of the germanium oxygen-deficient centres in this glass. Hydrogen loading magnifies the photosensitivity of N-doped germanosilicate fibres. Since the waveguide parameters of such fibres can be made very close to those of standard telecommunication fibres, gratings written in N-doped germanosilicate fibres may find wide applications in fibre-optic communication.

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