Ultraviolet photosensitive response in an antimony-doped optical fiber

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A silica optical fiber doped with Sb is fabricated with a refractive-index profile that is comparable with standard single-mode fiber. In D2-loaded samples, we observe UV photosensitivity with an initial refractive-index-modulation growth rate six times higher than that of the equivalent Ge-doped standard fibers. Enhanced temperature stability of the Bragg grating strength up to 200 °C is also observed. Grating growth kinetics in the Sb-doped fiber is compared with those of other Ge-doped photosensitive fibers. © 2002 Optical Society of America

Among glass-forming elements, Ge and P have been found to be photosensitive dopants in binary silica, and fiber gratings are currently fabricated in silica optical fibers whose cores contain oxides of these elements. Enhancement of photosensitivity has been reported by codoping with B (Ref. 3) or Sn. Common problems with enhanced photosensitivity fiber, however, include poor thermal stability and high splice loss with standard single-mode fiber (SSMF).

Recently, antimony oxide has drawn attention as a glass host for rare-earth-doped fiber amplifiers for which the fibers were fabricated in multicomponent silicate glasses. Binary antimony oxide–doped silica fiber was reported previously in multimode fibers fabricated by vapor axial deposition. Here we examine the use of Sb as a novel photosensitive dopant in silica, which shows three features that had not previously been reported to be achieved simultaneously: high initial refractive-index growth rate, high thermal stability, and low splice loss to SSMF.

Antimony oxides were doped in the silica core by the solgel technique. The synthesized silica preform was drawn into a fiber with a core diameter of 8.5 μm and a cladding of 125 μm. The index difference between the core and the cladding, Δn, was 0.005, which we achieved by doping 3.5 mol. % of antimony oxide. Note that the index parameters of the Sb-doped fiber (SDF) are comparable with those of SSMF.

The attenuation spectrum of the fiber is shown in the inset of Fig. 1. The optical loss at 1.55 μm was 0.7 dB/m and was attributed mainly to the OH absorption induced in wet solgel processing. A thin slice of the preform of 400-μm thickness was polished and then D2 loaded. Unlike germanosilicate glass, our Sb-doped silica has a sharp absorption edge below 250 nm, which is consistent with earlier results, as shown in Fig. 1. As the core of the preform was irradiated by a cw frequency-doubled Ar-ion laser at 257 nm with an intensity of 1.4 mW/mm², a significant increase of the UV absorption tail was observed, which contributed in part to the index change that we describe below.

The refractive-index profile of D2-loaded SDF before and after UV irradiation was measured (Fig. 2). The intensity of the cw laser at 257 nm was ~46 W/cm², and the beam was uniformly focused onto the bare fiber for 30 min, which corresponds to a UV dosage of 85 kJ/cm². A refractive-index change of more than 5 × 10⁻³ was observed.

To investigate the kinetics of grating formation, we inscribed Bragg gratings of 1-mm length, using a uniform phase mask. Two different UV light sources...
were used, a cw laser at 257 nm and a pulsed laser at 242 nm. In Fig. 3 the kinetics at 257-nm irradiation for Ge-doped SSMF and SDF is compared. SDF showed a growth of the index change, $\delta n$, that was more than a factor of 2 greater than in SSMF. The growth of the index change as a function of the total dosage of a 242-nm pulsed laser is shown in Fig. 4 for four types of fiber: 1, SSMF; 2, SDF; 3, fiber with increased Ge and O$_2$-deficient defect centers (GODC); and 4, Ge–B codoped single-mode fiber (Spectran/Lucent OFS). For the GODC fiber, $\Delta = (n_{\text{core}} - n_{\text{cladding}})/n_{\text{cladding}}$ was 0.5% and the core diameter was 4 $\mu$m. For all the other fibers, $\Delta$ was 0.35% and the core diameter was 8 $\mu$m. Fibers were $D_2$ loaded at identical standard conditions. For 242-nm irradiation, SDF showed an initial growth rate $\delta n$ approximately six times greater than that of SSMF at a low dosage range below 0.3 kJ/cm$^2$, comparable to rates for fiber types 3 and 4. Note that the amount of Ge in the two last-named fibers is substantially larger than that of conventional single-mode fibers, and it is found that Sb is a more efficient photosensitive dopant when it is normalized to the concentration. For 257-nm irradiation, Bragg gratings of greater than 1% reflectivity were successfully fabricated through a special polymer jacket. For both 242 and 257 nm, the AC index change that determines the fringe visibility of a Bragg grating was measured to be greater than 0.003 for the exposures illustrated in Figs. 3 and 4. The initial growth of the AC index change was a factor of 2 faster than for standard Ge-doped fibers.

Induced background loss in a Bragg grating would be an important factor for applications in fiber lasers, dispersion compensators, and add–drop multiplexers. A background loss of less than 0.05 dB/cm was measured in SDF near 1.5 $\mu$m for uniform 8-cm-long Bragg gratings inscribed at 242 nm. SDF was spliced to Corning SMF28 fiber by use of conventional arc parameters in a commercial fusion splicer. The splice loss was measured to be 0.026 dB on average, which is lower than for photosensitive fibers previously reported and could be reduced further by optimization of arc parameters.

The reflectivity decays as gratings are annealed at elevated temperatures as a result of the dynamics of trapping thermally activated carriers in a distribution of defect sites. The temperature stability of Bragg gratings is compared in Fig. 5. At 200 °C the Bragg grating in SDF maintained ~90% of its initial strength, whereas the strength dropped to 60% in Ge-doped fibers. We believe that the mean value of the activation energy distribution for carrier traps in SDF will be higher than that of Ge-related defects in SSMF, which will result in better stability of a grating at a higher temperature. In binary silica, Sb ions are multivalent, and in the presence of H$_2$ changes in absorption are known to be caused by reduction-oxidation processes and the formation of OH radicals. UV photosensitivity may therefore result from changes in Sb-ion valence and subsequent change in absorption in the fiber.

A novel photosensitive silica single-mode fiber has been developed by doping antimony oxides. For irradiation by a 242-nm pulsed laser, Sb-doped fiber showed a growth in index modulation that was as rapid as for highly photosensitive fibers such as B–Ge-doped and O$_2$-deficient fibers, with photoinduced index changes greater than $5 \times 10^{-3}$.
Fig. 5. Comparison of temperature stability of Bragg gratings. Vertical axis, reflectivity relative to that of a Bragg grating inscribed at room temperature. All fibers were $D_2$ loaded under the same conditions, and the 242-nm dosage was retained. Duration of annealing at each temperature, ~10 h. Fiber types are described in text.

A UV-induced background loss of 0.05 dB/cm was measured during grating inscription. Matching the index profile to the standard fibers resulted in a splice loss of 0.026 dB. Bragg gratings in Sb-doped fiber showed an enhanced thermal sensitivity of more than 200 °C with 90% of their initial strength retained.

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References