Ultraviolet-induced absorption during very short continuous exposure in Ge-doped optical fiber

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Abstract: We report ultraviolet (UV)-induced absorption measurements, in the 360-440 nm spectral region, in germanium (Ge) doped fiber, H_2-loaded or not. This technique allows gives evidence of the photoinduced mechanisms occurring during very short continuous (cw) UV exposure, contrary to the usual absorption technique. Our results show that the 4.5 eV absorption band, extending in the visible region, is responsible for the measured absorption. We demonstrate that two different defects absorbing at around 4.5 eV are involved in the two successive reactions, leading to the creation and the partial of the absorption respectively.

1. Introduction

Despite various studies and numerous commercial optical systems achievements, the photosensitivity of Ge-doped optical fibers remains still unclear from the fundamental point of view. Photoinduced processes, involving different Ge-related defects, have been proposed to explain the evolution of the UV absorption spectrum during UV exposure [1, 2]. However, there is still no clear picture of the optically active defects responsible for all the variety of absorption transitions observed in the UV region spectral region. As a matter of fact, the assignments of the UV-induced 5.8 and 4.5 eV absorption bands to definitive defects have generated inconsistent results [1, 2, 3]. When the experiments are performed by use of low power density cw UV irradiation, long time exposure (up to several hours) are needed to propose some photoinduced reactions. Much shorter irradiation times are required in case of pulsed UV laser irradiation but two-photon absorption becomes likely, giving other chemical pathways processes. In this paper, we demonstrate an original technique to measure the UV-photoinduced absorption between 360 and 440 nm in Ge-doped fibers, which allows the measurement of the absorption after very short (few ms) cw exposure at 244 nm, contrary to usual absorption techniques. We have applied this technique to Ge-doped fibers and our results show that two different mechanisms with very different kinetics occur during the short exposure, leading to the creation of absorbing defects on one hand, and to the partial bleaching of these defects on the other hand. Applying the same measurement to H_2-loaded fibers indicates that hydrogen quenches completely the second process.

2. Experimental set-up

The UV-induced blue emission at around 400 nm, ascribed to the Oxygen Deficient Centres (ODC) defects [4], is used as the light source propagating in the fiber core, instead of a classical white light source whose coupling efficiency into a fiber remains low, rendering uncertain the absorption measurements below 400 nm. During the transversal UV irradiation, the fiber is moved with a constant speed towards a detection system, so that the blue photoluminescence propagates within the irradiated part of the fiber where it is partially absorbed. The corresponding decay of the blue luminescence is measured by the detection system during the fiber displacement, whose speed varies from 0.2 to 1 cm/s. Typically, the blue luminescence is totally absorbed within an irradiated length of few centimetres. The spectral region covered by this technique is given by the spectral width of the blue spectrum, which extends from 360 to 440 nm. Most of the experiments have been performed in a Corning SMF-28 fiber containing 4.3% mol. of germanium in the core but a pure silica fiber has also been used. Experiments have also been carried out in an H_2-loaded SMF28 fiber. Hydrogenation was done at 180 atm at room temperature for three weeks, resulting in about 0.5% of H_2 in the fiber core. Isochronal experiments have been performed to elucidate the structure of the absorbing species. The irradiated fiber length is annealed during 15 minutes at each temperature and the heating is then stopped to allow the fiber to cool down to room temperature for measuring the transmitted the blue intensity across this irradiated length. A cw laser at 244 nm, focused on the side of the fiber by use of a cylindrical lens is used to transversally irradiate the fibers. The beam size on the fiber is 60 µm longitudinally and 800 µm transversally to the fiber axis, giving a UV power density ranging from 17 to 1700 W/cm^2 by varying the laser power from 10 to 100 mW. Dividing the longitudinal beam size by the fiber displacement speed gives the exposure time, during which each part of the irradiated length receives the UV radiation, which varies from 6 to 30 ms. The UV fluence is obtained by multiplying this exposure time by the UV power density.

3. Results

The figure 1 shows the absorption spectra of the virgin and hydrogenated fibers, which have been calculated for each wavelength between 360 and 460 nm using the Beer-Lambert relation: $I(\lambda) = I_0(\lambda) \exp(-\alpha l)$, where λ stands for the emission wavelength, $I(\lambda)$ is the measured blue intensity having crossed the irradiated fiber length l, $I_0(\lambda)$ is the non-absorbed initial blue intensity and α is the photoinduced absorption coefficient. The two absorption spectra are characteristic of the tail of one or several absorption bands centered in the UV part of the spectrum. Figure 2 describes the evolution of the absorption coefficient with the cumulative UV fluence in the virgin and H_2-loaded fibers. It is important to point out that a virgin fiber sample has been used for each fluence. The photoinduced absorption increases for fluences lower than 0.6 J/cm^2 in the two fibers and then remains constant in the hydrogenated fiber but decreases by about 50% to reach a constant value in the virgin fiber. Moreover, the absorption increase is slightly slower in the H_2-loaded fiber.

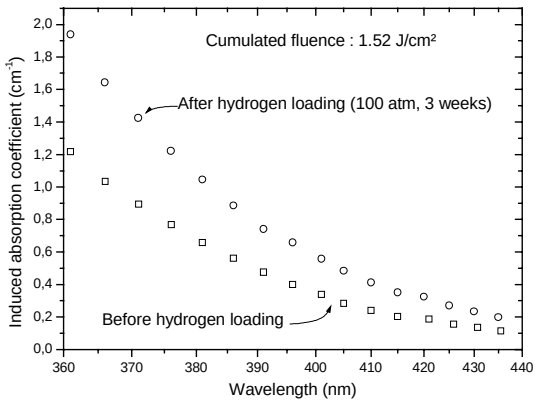

Figure1: UV-induced absorption spectrum in the virgin (circles) and H_2-loaded (squares) fibers recorded for a fluence of 0.6 J/cm^2. Note the almost similar absorption coefficient in the two fibers, showing that H_2-loading does not modify the efficiency of the underlying mechanism.

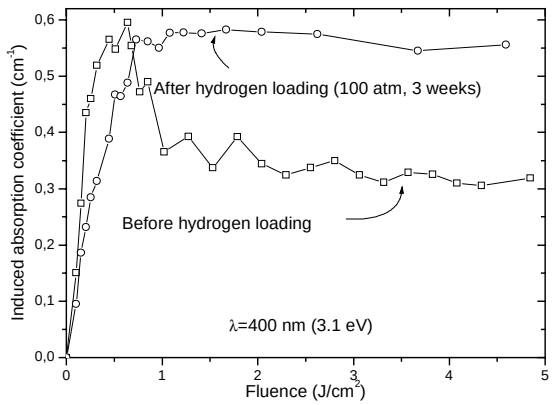

Figure 2: evolution of the absorption coefficient (at 400 nm) with the UV fluence. All the fluences have been obtained by varying the moving speed and the UV power density. Note that a new fiber sample has been used for each fluence.

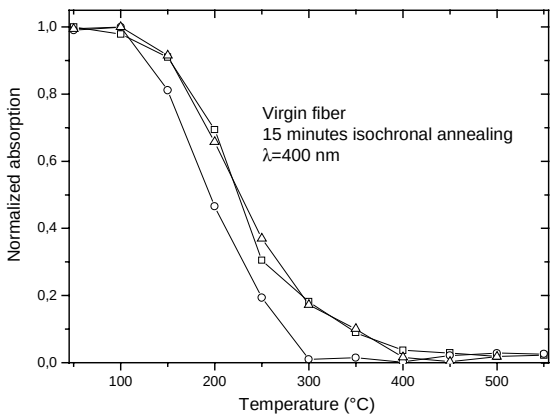

Figure 3: annealing curves of the UV-induced absorption in the virgin fiber, for three different fluences

The figure 3 shows the evolution of the photoinduced absorptions, obtained with three different UV fluences, during isochronal annealing between 50 and 600 °C, for different UV fluences. This absorption decreases monotically from 150 °C and becomes completely bleached at around 400 °C. Moreover, the absorption created at high fluence (4.3 J/cm^2) bleaches at lower temperature than the absorption generated under lower fluence.

4. Discussion

The similar shapes of the absorption bands in the virgin and hydrogenated fibers (fig.1) indicate that the same species are responsible for the absorption in the two kinds of fibers. The absorption reaches the same maximum

levels in the virgin and H_2-loaded fibers , but the absorption increases is slower in the hydrogenated fiber (fig.2), showing the influence of hydrogen to passivate in the underlying photoinduced process. Several photoinduced defects, either linked to Si or Ge atoms and having optical absorption band in the UV region, can be candidate to explain the absorption spectrum. However, similar experiments have been conducted in a pure silica fiber but no photoinduced absorption has been measured, showing that the absorption is due to Ge-related defects. Among all the UV-induced absorption bands reported in the literature, only the 4.5 eV (275 nm) band extends in the visible region and could explain our results. However, the assignment of this band to a Ge-related defect has generated inconsistent results: Fujimaki et al. [1] assigned this band to the Ge(1) defect, formed from the conversion of the twofold coordinated germanium through a two-photon absorption process, while Crivelli et al. [2] observed the same band under low power density UV exposure without any Ge(1) defect. The annealing behaviour of the absorption is close to the decrease of the Ge(1) concentration measured by Anoikin et al. [5]. The evolution of the absorption with the UV fluence is in good agreement with the increase of the Ge(1) concentration in Ge-doped fibers for the fluences up to 1J/cm^2 measured by Tsai et al. [3] with a KrF pulsed laser. However, the same authors have observed a slight decrease in the Ge(1) concentration for fluences higher than 1J/cm^2, whereas we observe a 50% decrease of the absorption. Moreover, Ge(1) defects are known to be UV-created by two-photon absorption process [1] but this mechanism is unexpected for UV fluence lower than 100W/cm^2 [6] so that such a process is unlikely in case of an irradiation performed at 1.7 W/cm^2.

The 50% bleaching of the absorption in the virgin fiber for high UV fluence reveals that some of the absorbing defects are converted into non-absorbing species. Consequently, two successive reactions are clearly required to explain this evolution, the first one leading to the creation of the absorbing species and the second one bleaching partially these species, whereas no UV-induced bleaching occurs in the hydrogenated fiber. It is noteworthy to notice that for a given UV power density, the absorption increases when increasing the fiber moving speed, thus decreasing the irradiation time. This shows that the second step needs rather long exposure to efficiently occur and that the creation kinetic is much faster than the bleaching one. It is possible to propose that two different defects give rise to the absorption but we should observe a distortion of the absorption spectrum when one of these species is thermally annealed, but this is not observed. The annealing behaviour of the absorption (fig.3) reveals that the absorbing species created at high fluence bleach more rapidly than those generated at lower fluence, while the absorption shape remains constant.

Finally, despite some good correlations of the absorption with the Ge(1) defect, our results show that short cw UV exposure induces different mechanisms from those proposed in case of pulsed irradiations. It is possible that the diamagnetic ODC(III,A) defect proposed by Poumellec et al. [6] as responsible for the 4.5 eV absorption band, is also involved in the process leading to the observed absorption.

5. Conclusion

We present an original experimental technique, which allows the measurement of the UV-induced absorption in Ge-doped fiber in the 360-440 nm spectral region, under very short cw irradiation. This absorption is attributed to the tail of an absorption band centered at 4.5 eV, usually attributed to the paramagnetic Ge(1) defect. However, our results demonstrate that two different centers absorbing at around 4.5 eV are involved during the very short cw irradiation.

7. References

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