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Photodarkening in Yb/Al/Ce Optical Fibers: Study of Photoinduced Defects by Electron Paramagnetic Resonance

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Abstract: Yb/Ce/Al silica fiber preforms were studied by means of Electron Paramagnetic Resonance before and after exposure to high energy photons. Clustering of Yb^{3+} ions and creation of Al-OHC and Si-E' defects were observed.
OCIS codes: 160.2290 Fiber materials; 160.5690 Rare-earth-doped materials.

1. Introduction

Yb-doped silica optical fibers recently demonstrated their outstanding performance in the field of high power lasers [1]. Outstanding performances up to 3 kW for a single emitter were obtained with a high quality beam and high wall plug efficiency [2]. However a gradual increase of background absorption, taking place during laser operation, was seen to cause a decrease of the laser system output power. This phenomenon, called photodarkening, is particularly evident when high levels of inversion are created by pump photons, e.g. in pulsed sources [3].

Several methods were explored to reduce photodarkening (PD) in optical fibers among which co-doping with Ce^{3+} ions in parallel with a significant Al^{3+} content [4].

The aim of this paper is to study a series of Yb/Al/Ce preform core glasses after irradiation with high energy photons (gamma rays and UV laser photons) by means of Electron Paramagnetic Resonance (EPR). Comparison among the types of sources employed and the effect of glass composition on the type and amount of defects was assessed.

2. Experimental

Five silica optical fiber preforms were fabricated by MCVD and solution doping technique, having a core made of Yb/Al/Ce silica. The reason behind the choice of the preform configuration was to allow for a sufficient amount of active material to be measured, which could result in a higher density of induced defects. In order to avoid the possible interference of the cladding glass material in terms of overlapping of defect signals and/or masking the occurrence of low intensity signals caused in the active material, the cladding layer was mechanically removed. The final samples were then in the form of cylinders with a radius of approximately 2 mm and a length of around 50 mm. Each sample was further cut in three parts, two for parallel irradiations in the UV and gamma ray region and one as reference. Table 1 reports the glass names, the Yb^{3+} ion concentration and the Yb/Al and Ce/Al ratios respectively.

Table 1 – Activator ion (Yb^{3+}) concentration and ratio of co-dopants in the prepared glass samples.

	Sample name	**Yb^{3+} ion content (cm^{-3})**	**Al/Yb ratio**	**Yb/Ce ratio**
A1271	518	8.3 E+19	5	1
A1297	1053	3 E+19	10	5
A1305	1023	3 E+19	10	2.5
A1311	1013	3 E+19	10	1
E0352	10110	10E+19	10	1

The two irradiation sources employed were selected at higher energies than the near infrared pump photons: the effect of the pump photons can be accelerated by using UV photons [ref] and gamma rays are another important source used for photodarkening studies [ref]. A KrF excimer laser was used for UV photon irradiation at a

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wavelength of 248 nm with a repetition rate of 200 Hz and with 200000 pulses for each sample along the length. The source of gamma rays was had a dose rate of 500 rad/h for a total of 1000 Krad.

Pulse EPR and CW EPR measurements were performed on an ELEXYS 580 Bruker spectrometer (at the microwave frequency of 9.76 GHz) equipped with a liquid-helium cryostat from Oxford Inc. All experiments were performed at 10 K. The magnetic field was measured by means of a Bruker ER035M NMR gauss meter. Electron-spin-echo (ESE) detected EPR experiments were carried out with the pulse sequence: $\pi/2- \tau- \pi- \tau$–echo, with microwave pulse lengths $t_{\pi/2}$ = 16 ns and t_{π} = 32 ns and a τ value of 180 ns. Hyperfine Sublevel Correlation (HYSCORE) experiments were carried out with the pulse sequence $\pi/2- \tau - \pi/2 - t_1 - \pi- t_2 - \pi/2 - \tau -$ echo with the microwave pulse length $t_{\pi/2}$ = 16 ns and t_{π} = 16 ns.

3. Results and discussion

Pulsed EPR measurements carried out on as made samples allowed observing and monitoring the Yb3+ ion signature for the different glass compositions. A clear evidence of Yb^{3+} ion clustering was measured, which was recorded at zero magnetic field values, for the samples containing higher amounts of the activator ion (i.e. 518 and 10110). HYSCORE spectra could detect the interaction of Yb3+ ions with the neighboring showed that neighboring ions of Yb were mainly Si^{4+} ions and not Al^{3+} ions.

After irradiation, the occurrence of induced defects was recorded for all samples the same type of defects were obtained with both employed sources and in particular the occurrence of E'(Si) and Aluminum Oxygen Hole Centers (AlOHC) were detected (Fig. 1).

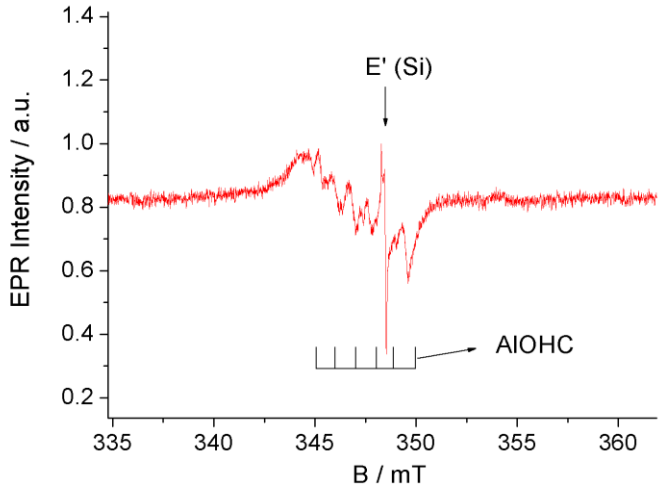

Fig. 1. CW EPR spectrum of sample 518 after UV irradiation. The main paramagnetic defects detected are showed in the plot.

The study also concerned a comparison among the samples and the relationship between the composition of the glass preforms and the defect types and concentrations. The research work was supported by FP7 LIFT (Leadership in Fiber Laser Technologies), Project Grant #228587.

5. References

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