Simultaneous effects of photo-and radio-darkening in ytterbium-doped aluminosilicate fibres

Jean-Bernard Duchez, Franck Mady, Yasmine Mebrouk, Mourad Benabdesselam

Simultaneous effects of photo- and radio- darkening in ytterbium-doped aluminosilicate fibres

Jean-Bernard DUCHEZ, Franck MADY, Yasmine MEBROUK, Mourad BENABDESSELAM

University of Nice Sophia Antipolis, Laboratoire de Physique de la Matière Condensée
CNRS UMR 7336, Parc Valrose, 06108 NICE cedex 2, France

Preference: oral / **Radiation effects**

ABSTRACT

We present original characterizations of photo-radio-darkening in ytterbium-doped silica optical fibres submitted to the simultaneous action of the pump and of an ionizing radiation. We present the interplay between both radiations, showing e.g. that the pump is able to darken or bleach the fibre depending on the ionizing dose. The photo-resistance of the fibre is shown to play a crucial role on its radio-resistance, and that photo-resistant fibres should be also radio-resistant in low dose rate conditions. All the results are thoroughly explained by a physical model presented in a separate submission by Mady *et al*. (this conference).

PACS Keywords: Fiber optics, Radiation effects on optical elements, devices and systems.

INTRODUCTION

Ytterbium-doped silica optical fibres (YDF) may suffer from twofold degradation when operated in amplifying conditions and harsh environments. Excess optical losses are induced by external ionizing radiations (radio-darkening or RD), but also, possibly, due to the pump itself (photo-darkening, PD). PD and RD of YDF have been well characterized already [1], but by distinct communities. Possible interplay between PD and RD has neither been characterized nor modelled, though pumping and ionizing radiations should be at play simultaneously in some operation conditions, as in space-based applications. We present an experimental study of simultaneous photo-radio-darkening (PRD). The results show that the PD level is of first importance in the RD resistance. A complementary work by Mady's *et al.*, also submitted in this conference, presents a model that explains all of the present results.

EXPERIMENTAL METHODS

The measurement bench is based on a pump-probe scheme [2] with contra-propagating pump (977 nm, ~230 mW) and visible probe (633 nm, a few mW). Customized wavelength division multiplexers (OZ-optics) are used for coupling pump and probe lights into the fibre under test (FUT). Two YDF FUT were compared: K10 (0.9% Al_2O_3, 0.3% Yb_2O_3, NA = 0.11), fabricated and drawn in our lab, which is not optimized to resist against PD nor RD, and a commercial one (nLight Yb1200-4/125, NA=0.2), that offers low PD levels. The FUTs consisted in ~2 cm long uncoated samples. They were irradiated in-line, under pumping or not, by an X-ray generator (Cu anode, 45 kV).

RESULTS

The effects of PD and PRD in the K10 sample are shown in Fig. 1. When the FUT is in-core pumped, the pump output power decays due to PD, but the PD level tends to a stable value. Such a PD equilibrium was already observed, carefully examined by Jetschke *et al.* [3], and shown to be determined by the pump power. Hence the pump is not only responsible for PD, but also for a photobleaching (PB) effect, which balances PD at long pumping time.

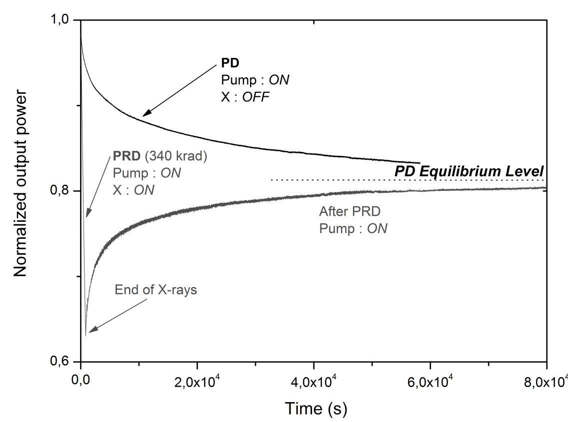

Fig. 1. Decay of the normalized output power at 977 nm for the K10 fibre, for pure PD and PRD.

The same K10 fibre (fresh sample) was submitted to a PRD run: it was irradiated by X-rays (22,7 krad(SiO_2). min^{-1}, 340 krad(SiO_2)) during pumping and then, after the end of the X-ray irradiation, left to the action of the pump. In the PRD stage, the FUT output power decays very rapidly. Then the YDF is obviously photo-bleached by the pump: the output power moves back up, tending to the same equilibrium level than pure PD. The pump is therefore capable of bleaching *also* the PRD, which is essentially due to RD. This demonstrates a basic interplay between PD and RD and highlights the crucial role of the PD equilibrium level (PDEL). It is not surprising that the pump bleaches both PD and RD, because our team showed that trapped-states responsible for PD and RD in YDF are identical [4].

Similar experiments were done at various doses (K10, fresh samples). Results are displayed in Fig. 2 for pump and probe wavelengths. Log-log scales are used to enlarge the PRD region. For the 2 highest doses, the result is the same as in Fig. 1: PRD followed by pump-induced PB. When X-rays are stopped at 45 krad, the output power level is still above the PDEL and the pump is responsible for further degradation, i.e. PD. All plots tend to the PDEL. Therefore *the primary action of the pump (PD or PB) depends on the ionizing dose*. Similar behaviours are always found for the pump and the probe, even if degradation is more important in the visible range.

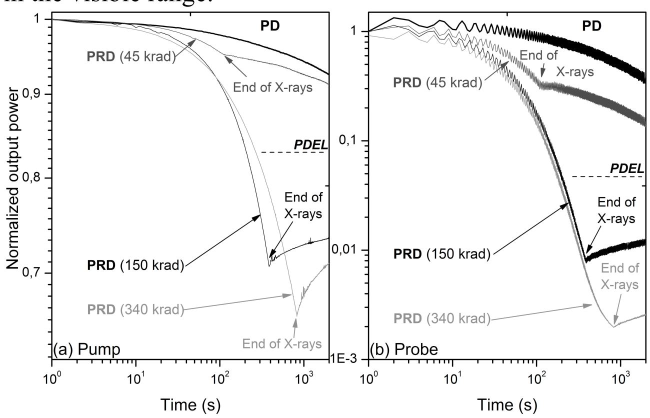

Fig. 2. PD and PRD of K10 at various doses at 977 nm (a) and 633 nm (b).

To highlight the pump effect *during PRD*, same doses were given with and without pumping during X-ray irradiation (RD and PRD conditions) for the K10 and Yb1200 fibres. Results are shown in Fig. 3, now in terms of the excess absorption coefficient. Two doses have been imparted: one is small (30 krad) to keep the radio-induced degradation below the PDEL, the other is high (450 krad) to exceed this level. At the same pump input power the Yb1200 fibre has a much lower PDEL than our K10 fibre. It is also found to present a better X-ray resistance (the 2 fibres show RD or PRD levels in similar proportion with respect to their PDEL). At low dose, below the PDEL, both fibres are less darkened in RD than in PRD conditions. Then, the pump accelerates degradation. For the dose above the PDEL, RD yields more degradation than PRD so the pump slows-down the degradation. The pump has hence the same PD or PB effect during as after PRD, according to the dose. Because of its PB action, the pump will mitigate RD at high doses. Indeed the PRD will also reach a stationary state above the PDEL at long irradiation time, thus freezing the PRD level despite the continuous irradiation. Decreasing the dose rate will drop this PRD equilibrium closer to the PDEL. In very low dose rate conditions *the PRD level will be minimal and equal to the PDEL.* RD will then develop very slowly so the pump will bleach the fibre "adiabatically" as soon as the PRD level will exceed the PDEL (PRD saturation at the PDEL). To confirm this point, we gave a same high dose (900 krad) to the K10 and Yb1200 fibres, at decreasing *mean* dose rates. To illustrate PB by the pump, we did not use lower constant dose rates, but impart the dose in 1, 3 and 6 fractions by observing a 75 min PB time between each fraction. Results are displayed in Fig. 4. For both fibres, the *mean* PRD well tend towards an equilibrium value that decreases with the mean dose rate. We could not reach very low dose rate as those typically encountered in space (too long experiments), but the validated model presented in the submission by Mady *et al.*, which reproduce our experiments, enabled us to extrapolate the observed behaviour to such low dose rates where the PRD is well found to saturate at the PDEL. These outcomes have major consequences on the understanding and assessment of the YDF resistance for applications concerned with PRD.

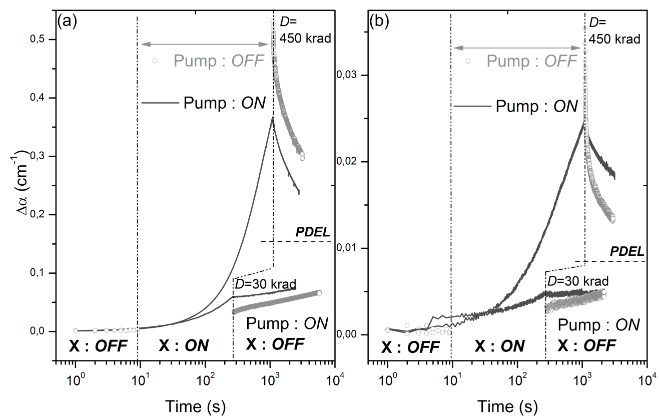

Fig. 3. Excess loss $\Delta\alpha$ at 977nm, 30 and 450 krad doses, for K10 (a) and Yb1200 (b). Pump effect during PRD.

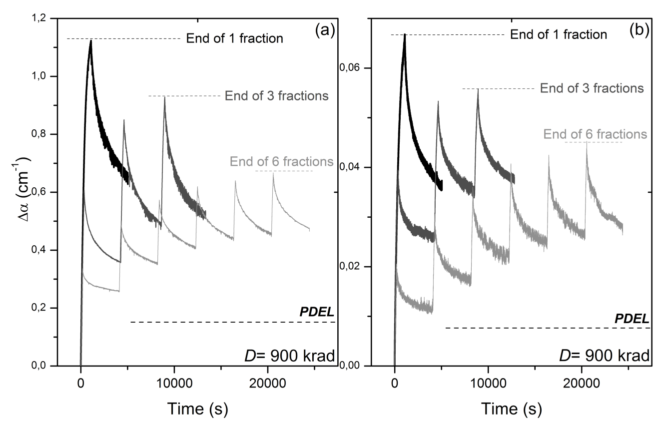

Fig. 4. Excess loss $\Delta\alpha$ in K10 (a) and Yb1200 (b) after a 900 krad X-ray dose given in 1, 3 and 6 fractions.

REFERENCES

[1] A. Schwuchow *et al.*, Applied Optics, 53, 1466-1473, 2014.

[2] L. Nanxi *et al.*, Photonics Techno. letters, 26, 115-118, 2014.

[3] S. Jetschke *et al.*, Opt. Express 15, 14838-14843, 2007.

[4] F. Mady *et al.*, Opt. Lett. 35, 3542–3543, 2010.