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# Photo-darkening In Thulium-Doped Alumino-Silicate Fibres Pumped At 1.07 $\mu\text{m}$ : Effect of Co-Doping with Lanthanum or Cerium

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Rare-earth (RE) doped fibre lasers and amplifiers based on silica offer the best performances in terms of combined efficiency, power and beam quality. Silica glass had indeed chemical, mechanical and economic advantages over alternative hosts such as fluoride glasses (ZBLAN). Nevertheless, some characteristics of silica limit the implementation of otherwise extremely interesting applications, such as short wavelength optical transitions, in selected RE ions, reachable by pump up-conversion. For instance, when thulium (Tm) is excited at 1.07  $\mu\text{m}$ , up to eight laser emissions (spanning from 450 nm to 1.9  $\mu\text{m}$ ) are observed in ZBLAN [1], while only one (1.9  $\mu\text{m}$ ) is exploited in silica. In this glass, RE emissions from high energy levels undergo strong non-radiative decays (NRD) due to high phonon-energy (as compared with fluorides), whereas the up-conversion pumping schemes cause strong photo-induced absorption (photo-darkening, PD) accentuated by RE aggregation due to silica low solubility. The NRD may be mitigated by co-doping with aluminum ions [2,3]. However the mechanisms responsible for PD are still under debate [4]. It is therefore crucial to study alternative modifications of Tm-doped silica-based fibres.

For the first time we study the reduction of PD in Tm-doped fibres by co-doping with lanthanum (La) and cerium (Ce) to reduce PD, as observed with other RE elements [5,6]. Three samples series were prepared by MCVD and solution doping. Series-1 contains Tm varying from 70 to 6500 mol.ppm, codoped by Al and/or Ge only. Series-2 contains  $\sim 2$  mol%  $\text{Al}_2\text{O}_3$ , 550 mol.ppm of Tm and varying Ce contents from 0 to 700 mol.ppm. Series-3 contains  $\sim 2$  mol% of  $\text{Al}_2\text{O}_3$ , 700 mol.ppm of Tm and varying La contents from 600 to 3000 mol.ppm.

The Photo-Induced Attenuation (PIA) coefficient is the ratio of a 550-nm probe signal recorded at room temperature before and after exposure at 1.07  $\mu\text{m}$  (750 mW) up to steady state. The PIA for Series-1 (varying Tm-concentration, Fig. 1a.) increases with thulium concentration, as in ZBLAN [7]. The threshold ( $\sim 100$  ppm) is close to the solubility limit of RE in pure silica. The PIA for Series 2 and 3 (varying Ce and La concentrations, respectively) are shown Fig. 1b. Both Ce and La reduce PD even at low co-doping concentrations. These results are promising and are used as input in a new model to be proposed during the conference: it explains the role of Ce and La on the PD mechanism in Tm-doped alumino-silicate fibres.

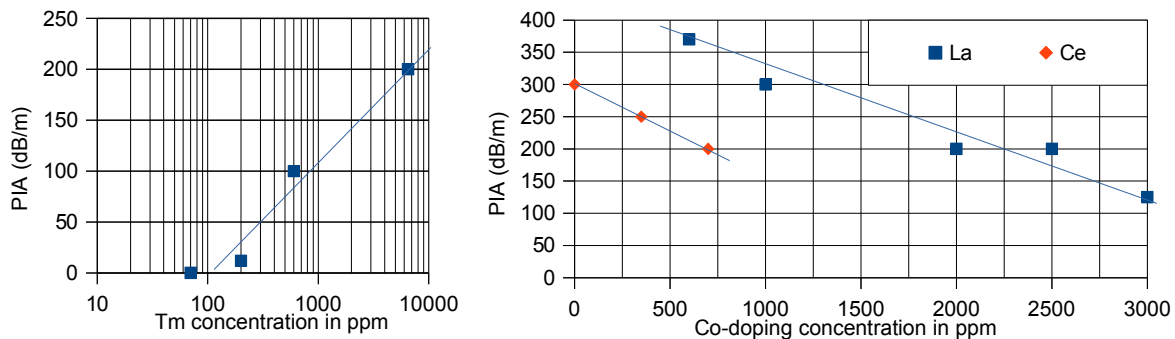


Fig. 1a (left) PIA vs. Tm concentration. Fig. 1b (right) PIA vs. La or Ce concentration. Solids lines are guides for the eye.

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