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Abstract: We investigate the impact of 405 nm radiation on photodarkening evolution in Yb-doped fiber. Simultaneous photodarkening and photobleaching effects induced by 976 nm and 405 nm radiations respectively were investigated in a 1070 nm laser.

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1. Introduction

The efficiency, reliability and stability of high power fiber lasers may be compromised and limited by photodarkening (PD) phenomenon which leads to a fast power degradation [1,2]. This effect is not yet completely understood and different theories have been proposed in the last years including the presence of Oxygen Deficiency Center (ODC) defects in pristine fibers [3]. The PD induced loss appears as a broad absorption band decreasing from UV-VIS up to IR region which impacts 1 μm laser performances. For this reason, in the last two decades, many research groups tried to investigate and mitigate this phenomenon and partial [4,5] or complete [6] bleaching of the doped fiber was obtained by using UV-VIS light. The possibility to efficiently remove a significant percentage of PD induced loss [5] by using UV-VIS radiation is called photobleaching (PB) and represents an important goal in higly-doped Al-silicate fibers. In a previous work we used 633 nm radiation to reduce PD degradation in laser systems [7] and in this work we investigated the possibility of PD mitigation using higher-energy photons at 405 nm. Laser maximum output power at 1070 nm, threshold and slope efficiency were monitored for about 33 hours under different irradiation conditions. Finally, in order to understand the influence of each wavelength on the observed laser behaviour, we also investigated PD and PB effects in pristine fiber samples.

2. Experimental

In order to investigate the effect of 405 nm together with 976 nm pump radiation on the temporal evolution of the output power in a CW Yb-doped fiber laser, the set-up shown in Fig.1 was used. Two customized fiber bragg gratings (FBGs) centered at 1070 nm were spliced at both ends of the active fiber. A single mode (core pumped) active fiber 4.8 cm long, 6.6 μm core diameter, 1.35 wt.% ($1.12 \cdot 10^{26}$ ions/m^3) dopant concentration and 3.2 wt% Al^{3+} content was used. The small signal absorption coefficient at 1070 nm lasing wavelength is small and we can assume gain and PD depending only on the number of inverted Yb^{3+} ions. Further, to provide a uniform longitudinal inversion along the cavity [2] we used short lengths (4-5 cm) of the Yb-doped fiber and FBGs with reflectivity peaks 0.99 and 0.41. In order to investigate the impact of 405 nm on the laser behaviour the experiment was divided in four steps: (A) simultaneous irradiation at 976 nm and 405 nm, (B) irradiation only at 976 nm, (C) simultaneous irradiation at

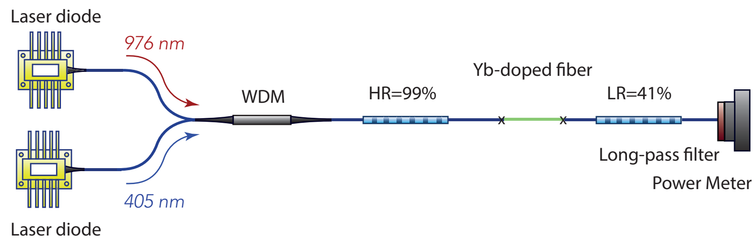

Fig. 1. Laser scheme to evaluate the impact of 405 nm on a Yb-doped fiber laser. HR-High Reflectivity and LR-Low Reflectivity.

976 nm and 405 nm, (D) only 405 nm radiation. In all steps the laser diodes were switched on or off stepwise at the their maximum available powers: 240 mW at 976 nm and 2 mW at 405 nm. The temporal evolution was observed continuously for about 33 hours (2000 minutes) and a laser power characteristic was measured in each equilibrium state. As shown in Figure 2.a, in step (A), both 976 nm and 405 nm radiations were switched on simultaneously and

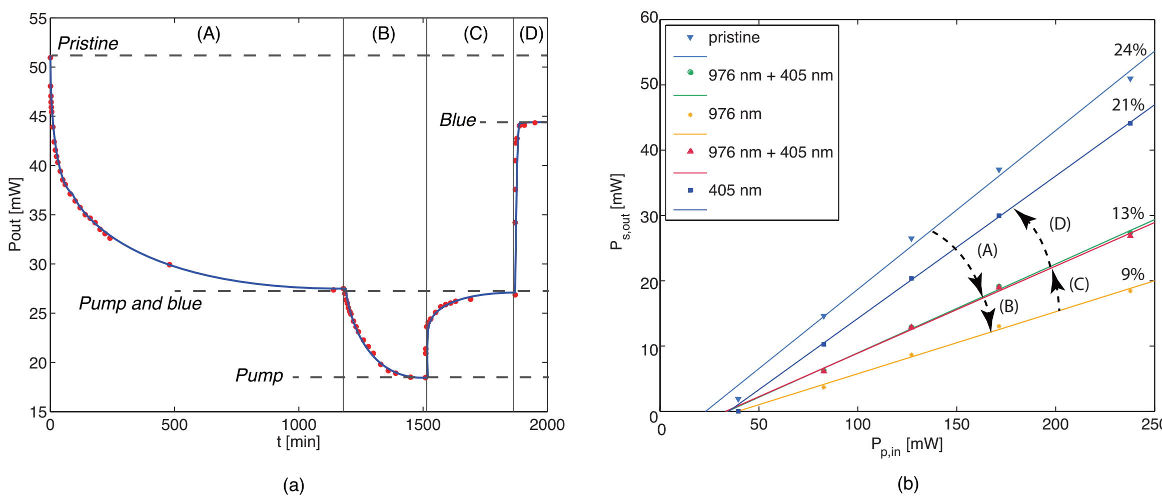

Fig. 2. a) Laser maximum output power evolution at 1070 nm. b) Laser power characteristics at each equilibrium level.

the output power continued to decrease. We observed that after several hours the output power reached an equilibrium level and we suggest it was due to the balance between the PD induced by 976 nm and the PB effect by 405 nm. In step (B) (once reached the equilibrium level) the 405 nm laser diode was switched off. Hence, there was no longer the PB effect caused by 405 nm radiation and output power further decreased due to the increase of the PD induced loss. Similarly, the process continued until a new equilibrium level was reached by the only pump radiation [1]. In step (C), to confirm the existence of an equilibrium level due to contrast between PD and PB phenomena, we again switched the 405 nm diode on. We observed the output power level returns to almost exactly the same equilibrium level observed after step (A) due to the reintroduction of the PB effect induced by 405 nm radiation. Finally, to evaluate the only bleaching features of 405 nm radiation, in step (D), the pump was definitively switched off. The laser output power increased rapidly in few seconds but without reaching its starting value (pristine). Further, a laser power characteristic was measured at each equilibrium level as shown Figure 2.b and the trends of the slope efficiency and threshold confirm again the existence of an equilibrium level risen from a balance between PD and PB effects. The limited power recovery obtained with simultaneous irradiation (step A) was not very dissimilar from the previous results with 633 nm radiation [7]. A strong absorption (in about 1 cm) of the 405 nm radiation observed as soon as the Yb-population is inverted could be one of the main limiting factor for an the effective PB effect. In order to investigate the origin of this absorption we measured separately on a pristine fiber the rise time transmission at 405 nm when 976 nm was switched off stepwise. In this way we found a value comparable with the Yb^{3+} ions lifetime that confirms that the strong absorption is caused by the ions on the excited state ($^2F_{5/2}$) [8]. In order to understand the origin of the laser behaviour we also investigated how each wavelength influences both PD and PB effects on a pristine fiber. Therefore, 976 nm (pump), 405 nm and 633 nm (probe) were combined together into the doped fiber under test by the series of two WDMs and the induced loss was monitored at 633 nm by an optical spectrum analyzer [2]. Starting always from a pristine fiber we evaluated the PD induced loss in three cases: only 976 nm, 976 nm and 405 nm, only 405 nm. The PD induced loss progression was comparable with the laser output power evolution and confirmed the existence of an equilibrium level risen form the balance between PD and PB effects. The PD induced equilibrium losses were about: 363 dB/m, 252 dB/m and 88 dB/m, respectively. PD phenomenon induced by 488 nm radiation was already demonstrated [3] and, to the best of our knowledge, this is the first report of 405 nm induced PD. This can be further limitation of PB effect as residual PD loss related to defects generated by direct ground-state absorption of 405 nm. However, a possible explanation could be that a two-photon absorption process (around 220 nm absorption peak) leads to CCs generation and PD loss by the release of free electrons [3]. More details will be reported at the conference and further investigation is planned.

3. Conclusion

For the first time the influence of 405 nm radiation on photodarkening kinetic in Yb-doped fiber laser was investigated. Laser maximum output power, threshold and slope efficiency evolutions were evaluated for about 33 hours under different irradiation conditions and three equilibrium levels were found. These equilibrium states suggest the existence of a balance between PD and PB phenomena depending on the different combination of 976 nm and 405 nm radiations. We observed a significant photobleaching effect due to 405 nm radiation but not complete recovery and we performed a set of further measurements. Hence, we observed a very strong absorption of the 405 nm radiation by the excited Yb ions (almost complete absorption within 1 cm) that could be one of the main limiting factor for the PB performance. Afterwards, in order to understand the laser behaviour, PD exceeded loss evolution induced by each wavelength was also evaluated starting from a pristine fiber. The loss temporal evolutions induced by 976 nm, 976 nm and 405 nm, and 405 nm, confirm again the existence of three equilibrium levels, respectively. In particular, for the first time, PD loss induced by the only 405 nm radiation was demonstrated and the observed absorption from the Yb-ground state could be further limitation of PB effect. We might achieve operation of a laser system with no PD-induced degradation by reducing the 405 nm absorption from the Yb ions both on the excited and on the ground states.

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References

1. S. Jetschke, S. Unger, U. Röpke, and J. Kirchhof, "Photodarkening in Yb doped fibers: experimental evidence of equilibrium states depending on the pump power", Opt. Express **15** (22), 14838-14843 (2007).
2. S. Taccheo, H. Gebavi, A. Monteville, O. Le Goffic, D. Landais, D. Mechin, D. Tregoat, B. Cadier, T. Robin, D. Milanese, and T. Durant,"Concentration dependence and self-similarity of photodarkening losses induced in Yb-doped fibers by comparable excitation", Opt. Express **19** (20), 19340-19345 (2011).
3. S. Yoo, C. Basu, A. J. Boyland, C. Sones, J. Nilsson, J. K. Sahu, and D. Payne, "Photodarkening in Yb-doped aluminosilicate fibers induced by 488 nm irradiation", Opt. Letter **32** (12), 1626-1628 (2007)
4. A. D. G. Chávez, A. V. Kir'yanov, Y. O. Barmenkov, and N. N. Il'ichev, "Reversible photo-darkening and resonant photobleaching of ytterbium-doped silica fiber at in-core 977-nm and 543-nm irradiation", Laser Phys. Lett. **4**, 734 (2007).
5. H. Gebavi, S. Taccheo, D. Tregoat, A. Monteville, and T. Robin, "Photobleaching of photodarkening in ytterbium doped aluminosilicate fibers with 633 nm irradiation", Opt. Mater. Express **2** (9), 1286-1291 (2012).
6. I. Manek-Hönninger, J. Boullet, T. Cardinal, F. Guillen, S. Ermeneux, M. Podgorski, R. B. Doua, and F. Salin, "Photodarkening and photobleaching of an ytterbium-doped silica double-clad LMA fiber", Opt. Express **15**, 1606 (2007).
7. H. Gebavi, S. Taccheo, L. Lablonde, B. Cadier, T. Robin, D. Méchin, and Denis Tregoat, "Mitigation of photodarkening phenomenon in fiber lasers by 633 nm light exposure", Opt. Letter **38**, 196-198, (2013).
8. M. Engholm, "Strong excited state absorption (ESA) in Yb-doped fiber lasers", Proc. SPIE **8601** (2013).