

# Free-running and imposed-wavelength cavities for high power continuous-wave Tm<sup>3+</sup>, Ho<sup>3+</sup> codoped single-oscillator fiber laser

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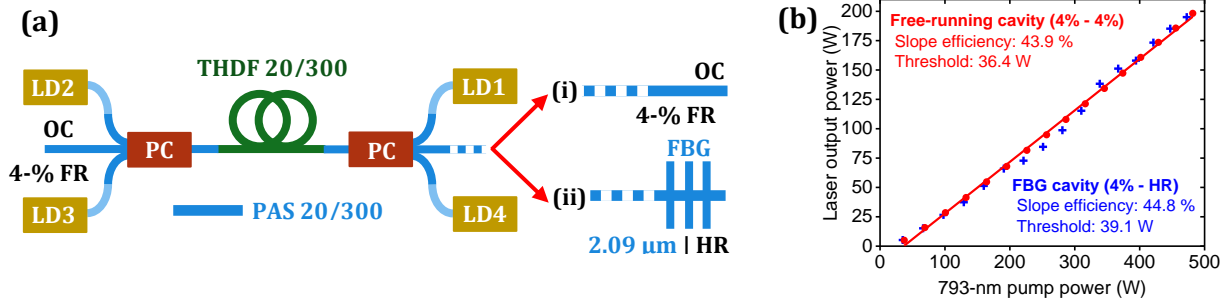
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Fiber lasers emitting at wavelengths around 2  $\mu\text{m}$  in continuous wave (CW) regime are promising sources of laser radiation for both civil (surgery, spectroscopy, lidar) and military applications as infrared countermeasures or laser weapons [1]. Optimizing the size, weight and power of lasers devoted to military activities is a major concern. The need of high power compact and robust laser sources leads us towards all-fiber solutions by using a single-oscillator architecture. In this contribution, we present a high power monolithic fiber laser source based on a Tm<sup>3+</sup>, Ho<sup>3+</sup>-codoped silica fiber emitting at around 2  $\mu\text{m}$  in CW regime.

The laser setup (Fig. 1a) consisted of a 10-m long double-clad polarization-maintaining thulium-holmium doped fiber (THDF), described in [2], with a Tm/Ho concentration ratio of 10 that permits a good energy transfer from Tm<sup>3+</sup> to Ho<sup>3+</sup> ions [3]. Four high-power 793-nm fiber-coupled laser diodes (LDs) were fusion spliced to two 2+1 $\times$ 1 fiber pump combiners (PCs) to symmetrically pump the THDF, with a total pump power of 540 W. The laser operated in two different cavity architectures: (i) the first one was a free-running cavity, with 4-% Fresnel reflection (FR) on both PCs passive fiber (PAS) cleaved at 0°; (ii) in the second architecture, the cavity was formed by a high reflectivity (HR) fiber Bragg grating (FBG) at 2.09  $\mu\text{m}$  and a passive fiber cleaved at 0° as output coupler (OC). In the first architecture, the laser emits on both sides of the cavity. Moreover, its emission is not imposed at a particular wavelength. Conversely, the emission at 2.09  $\mu\text{m}$  is forced by the FBG in the second architecture. In both configurations, the active fiber was cooled by deionized water at 18 °C.



**Fig. 1** (a) Experimental setup for the monolithic single-oscillator fiber laser source for a free-running and a FBG cavity; (b) Laser output power versus 793-nm incident pump power for the free-running (red) and the FBG (blue) cavity.

The output power for the two laser architectures is depicted in Fig. 1b. With the free-running cavity, a maximum CW output power of 198 W has been achieved at 2.12  $\mu\text{m}$ , with 43.9 % slope efficiency and 36.4 W laser threshold. The output power was calculated adding the total output power from both OCs. Using the FBG, we obtained a maximum CW output power of 195 W at 2.09  $\mu\text{m}$ , with 44.8 % slope efficiency and 39.1 W laser threshold. From 200 W to 350 W of pump power we can observe a power drop, which is perfectly reproducible between different measurements, compared to the linear fit whereas the free-running cavity shows a linear power rise. The origin of this phenomenon is attributable to the FBG and will be detailed during the conference.

In conclusion, we report, to the best of our knowledge, the highest output power from a monolithic single-oscillator fiber laser source based on a Tm<sup>3+</sup>, Ho<sup>3+</sup>-codoped silica fiber, with up to 195 W when imposing the emission wavelength. A laser slope efficiency of 45 % has been obtained for a laser setup which was only pump power limited in this experiment.

## Acknowledgments

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## References

- [1] K. L. Vodopyanov, *Laser-based mid-infrared sources and applications*, 1st ed. (Wiley, 2020).
- [2] A. Motard, C. Louot, T. Robin, B. Cadier, I. Manek-Hönniger, N. Dalloz, and A. Hildenbrand-Dhollande, "Diffraction Limited 195-W Continuous Wave Laser Emission at 2.09  $\mu\text{m}$  from a Tm<sup>3+</sup>, Ho<sup>3+</sup>-Codoped Single-Oscillator Monolithic Fiber Laser," *Opt. Express*, doc. ID 416443.
- [3] N. J. Ramírez-Martínez, M. Núñez-Velázquez, and J. K. Sahu, "Study on the dopant concentration ratio in thulium-holmium doped silica fibers for lasing at 2.1  $\mu\text{m}$ ," *Opt. Express* 28(17), 24961-24967 (2020).