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Christophe Louot, Arnaud Motard, Thierry Ibach, Thierry Robin, Benoit Cadier, et al.. Passive Fiber with Pedestal in a 213-W Continuous Wave Monolithic Tm³⁺ -Doped Fiber Laser at 1.94 μm . *Advanced Solid-State Lasers (ASSL)* 2022, Dec 2022, Barcelone, Spain. hal-03907992

HAL Id: hal-03907992

<https://hal.science/hal-03907992>

Submitted on 20 Dec 2022

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Passive Fiber with Pedestal in a 213-W Continuous Wave Monolithic Tm³⁺-Doped Fiber Laser at 1.94 μm

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Abstract: The output of a 43%-efficient continuous-wave monolithic single-oscillator Tm³⁺-doped fiber laser emitting 213 W at 1.94 μm is made by a passive fiber with pedestal to improve its beam quality by reducing the pedestal-to-cladding coupling. © 2022 The Author(s)

1. Introduction

In order to emit above 2.05 μm, the laser configuration consisting in a Tm³⁺-doped fiber pumped at 793 nm is not the most efficient. A solution is to use a Tm³⁺, Ho³⁺-co-doped fiber. Motard et al. reported 195 W of output power at 2.09 μm and 44.8 % of slope efficiency at the output of a monolithic single-oscillator codoped fiber laser source [1]. With a free-space pumping system, Forster et al. reported a maximum output power of 262 W at 2.1 μm and a slope efficiency of 49 % [2]. Another solution is to pump directly a Ho³⁺-doped fiber with a Tm³⁺-doped fiber laser. The highest output power recorded in this configuration was 407 W at 2.12 μm in 2013 [3]. More recently, Le Gouët et al. reported 90 W corresponding to a 50-% slope efficiency, limited by the free-space pumping configuration of their 2.12-μm Ho³⁺-doped laser using a commercial 1.94-μm pump laser source [4]. Increasing the output power requires to pump the fiber by several 1.94-μm pump laser sources. This can be done by using a fiber pump combiner, particularly adapted to monolithic all-fiber development. Nevertheless, the splices between active and passive fibers that we need in monolithic design are still an issue. As demonstrated by Simakov et al. in 2015 [5], the geometry mismatch between the fibers and particularly the presence of a pedestal around the core of active fibers creates a light coupling from this pedestal to the cladding of the passive fiber when spliced together [5]. This signal light propagating in the cladding can damage the combiner and results also in a beam degradation that reduces the laser stability [1].

In this communication, we report on a 1.94-μm Tm³⁺-doped fiber laser delivering 213 W, dedicated to pump a Ho³⁺-doped fiber through a home-made pump combiner. To avoid the propagation of light in the cladding of the output passive fiber of the laser, we replaced the standard passive fiber by a specific passive fiber with pedestal. Spliced to the active fiber, this new fiber maintains the signal light in its pedestal area and limits the beam degradation.

2. Experimental setup

A schematic of the laser setup is depicted in Fig. 1. It consists of a 3.6-m long piece of silica double-clad active fiber provided by *iXblue Photonics*. The fiber is composed of a 20-μm Tm³⁺-doped core, surrounded by a 60-μm Ge-doped pedestal to maintain a singlemode propagation of the signal in the core. The 250-μm cladding of the fiber is octagonal for efficient clad-pumping. Two 2+1×1 fiber pump combiners (FPC1 and FPC2) are spliced on both sides of the active fiber. Each combiner is also spliced to two 793-nm laser diodes emitting 135 W. The total pump power injected in the active fiber is 452 W, taking into account the 16-% pump losses created both by the FPC1 and the FPC2. Due to the high 793-nm absorption (8.4 dB/m) of the active fiber, the pump is well absorbed after 3.6 m of fiber (less than 1 W at the output). Fiber and combiners are placed in a cavity made by a 1.94-μm high reflectivity (HR) fiber Bragg grating (FBG) and a 0°-cleaved angle of the output fiber (passive fiber of the FPC2) to provide the 4-% Fresnel reflection.

In order to counteract the output beam degradation that we observed previously in similar single-oscillator made with Tm³⁺, Ho³⁺-codoped fiber [1] and attributed to the light coupling from the pedestal of the active fiber to the cladding of the passive fiber, we designed for the first time a specific passive fiber with pedestal (PFP). This pedestal is optically not needed for the signal propagation into the core of passive fiber but it is mandatory to avoid multimode propagation by keeping the light of the pedestal of the active fiber in a pedestal area with a shorter diameter than the cladding. This PFP has a 20-μm core, a 60-μm pedestal and a 250-μm circular cladding. Two bore stress rods are also implemented for polarization maintaining (PM) in order to make this PFP also usable in a polarized setup. Technological difficulties met during the fabrication process lead to an elliptic deformation of both the core and the

pedestal. This particular shape may have an impact on the beam profile and we assume that the output beam will be elliptical too.

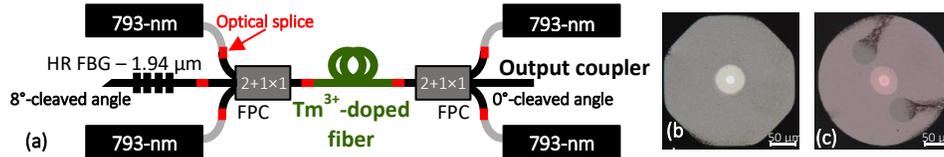


Fig. 1 : (a) Schematic of the setup; Microscope photography of the Tm³⁺-doped fiber (b) and the PFP (c) cross sections.

3. Results

The output power of the laser is depicted in Fig. 2a. A maximum output power of 213 W was obtained at 1.94 μm with 452 W of maximum injected pump power. The laser setup was only pump power limited in this experiment. The emission power threshold is about 22 W and the laser slope efficiency is 42.6 %. The Fig. 2b shows the output spectrum measured at 185 W of signal power. It is composed of two different peaks and centered at 1940 nm thanks to the FBG. We assume that the two peaks are the result of the birefringence created by the PM fiber of the FPC2.

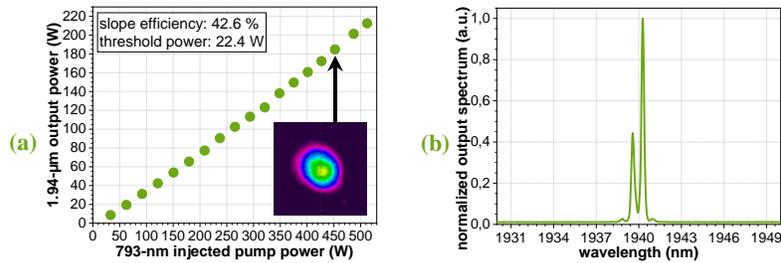


Fig. 2 : (a) 1.94-μm continuous wave output power versus 793-nm injected pump power. Inset: output beam profile (185 W); (b) Normalized output spectrum measured at 185 W of output power.

As expected, the elliptic shape of both the core and the pedestal of the output passive fiber impacted the output beam profile (Fig. 2a inset). One can notice that no speckle was present on the beam. It suggests that the pedestal added on this passive fiber played correctly its role of limiting the beam degradation. During this presentation, we will focus particularly on this innovative solution and how it can help to maintain a good beam profile.

4. Conclusion

In conclusion, we report on a monolithic single-oscillator Tm³⁺-doped fiber laser source delivering 213 W of optical power at 1.94 μm. The output of the source was made using a specific passive fiber with a pedestal around its core, to avoid the beam degradation generally created by splicing active fibers to passive fibers without pedestal. This first test showed promising results that encourage us to develop in the future an entire setup with pedestal.

Acknowledgments

This work was partially funded by the French *Direction Générale de l'Armement* (DGA).

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