Tm-doped fiber laser resonantly diode-cladding-pumped at 1620 nm

OPEN ACCESS
IOP Publishing | Astro Ltd
Laser Physics Letters
Laser Phys. Lett. **14** (2017) 125101 (3pp)
https://doi.org/10.1088/1612-202X/aa8b80

Letter

Tm-doped fiber laser resonantly diode-cladding-pumped at 1620 nm

G A Newburgh, J Zhang and M Dubinskii

US Army Research Laboratory, 2800 Powder Mill Road, Adelphi, MD 20783, United States of America

E-mail: mark.dubinskiy.civ@mail.mil

Received 26 August 2017
Accepted for publication 28 August 2017
Published 6 November 2017

Abstract

We report the first demonstration of an efficient, high power, resonantly (in-band) diode-cladding-pumped Tm-doped fiber laser operating on the $^3F_4 \Rightarrow {}^3H_6$ transition of Tm^{3+} ion. The laser, pumped by a fiber coupled laser diode module at ~1620 nm, delivered ~15 W of power at 1930 nm with a slope efficiency of 67% versus the absorbed pump power. This presents, to the best of our knowledge, the highest slope efficiency and the highest output power reported so far for resonantly diode-cladding-pumped 2 μm fiber lasers based on double-clad Tm-doped silica fibers. These very preliminary results, obtained with commercial double-clad Tm-doped fibers, unoptimized for in-band pumping at the peak of resonant absorption, indicate a very high potential of resonantly diode-cladding-pumped Tm fiber lasers for major power scaling unaffected by photodarkening. Fiber optimization for resonant pumping at the maximum of the Tm^{3+} $^3H_6 \Rightarrow {}^3F_4$ absorption band in silica (1610–1710 nm) can lead to a new generation of Tm fiber lasers with power and wall-plug efficiency, competing with those of high power tandem-pumped Tm-doped fiber lasers, but potentially with a lighter weight and smaller dimensions.

Keywords: fiber laser, Tm-doped fiber, diode pumped laser, in-band pumping, cladding pumping

(Some figures may appear in colour only in the online journal)

1. Introduction

Pumping wavelength is a critical consideration in the designing of a Tm-doped fiber laser from the standpoint of power scaling and/or the laser's practical longevity. This wavelength, eventually, defines all major fiber fabrication parameters. For example, for the most established Tm-doped fiber laser development based on laser diode pumping at ~790 nm a high dopant concentration is the most critical requirement for achieving a highly efficient 'two-for-one' process feeding the laser operation of Tm in the 1.9–2.1 μm spectral range [1, 2]. On the other hand, high Tm concentration leads to a pump-induced formation of optically absorbing color centers in the fiber (photodarkening) [1], which seriously undermines the long-term stability of the laser operation. It is also widely perceived that fiber fabrication with a high dopant concentration, at least in the most common cases of commercial solution doping, usually happens with a sacrifice of fiber quality (higher background loss). In order to mitigate this, resonant (in-band) pumping of Tm-doped fiber can be used as a viable alternative.

Direct resonant pumping of Tm at the maximum of the Tm^{3+} $^3H_6 \Rightarrow {}^3F_4$ absorption band in silica (1610–1710 nm) should substantially reduce the requirement for a high dopant concentration, which is necessary for maximizing the 'two-for-one' process efficiency. Meanwhile, it is commonly perceived that, in contrast to the ~790 nm laser diode technology (mature due to the large market), there are no adequate diode pumping sources in the 1610–1710 nm spectral range. Therefore, until

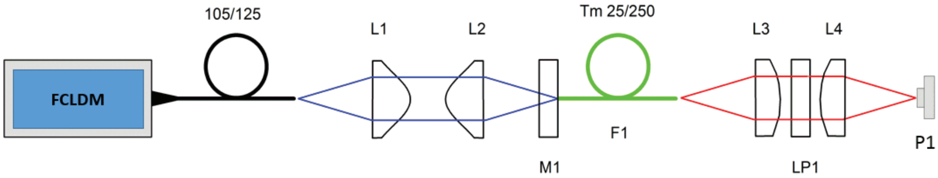

Figure 1. Simplified optical layout of the Tm-doped fiber laser resonantly diode-cladding-pumped by a fiber coupled laser diode module (FCLDM) at ~1620 nm.

now, successful resonant pumping of Tm-doped fiber lasers has been limited to the pumping of the Tm-doped fiber laser by another fiber laser (tandem pumping) [3].

Due to the high-power fiber laser wavelengths available for pumping, tandem pumping usually happens in the wings of the main Tm^{3+} ion absorption peak in silica glass. Recently there has been a significant increase of activity in tandem-pumped Tm-doped fiber lasers, where the power oscillator (or amplifier) is pumped either by the Er-doped fiber laser, in the short-wavelength fringe of the main peak of Tm absorption band (e.g. 1567 nm [4]), or by the Tm-doped fiber laser, in the long-wavelength fringe of this absorption band (e.g. 1908 nm [5], or 1942 nm [6]). Using resonant pumping in the wings of the absorption band means that, though high Tm^{3+} concentration is no longer required to make the 'two-for-one' process work efficiently, it is still required to allow for sufficient absorption per unit fiber length, in order to constrain a fiber to a reasonable length as required for power scaling. The only alternative to this is the resonant (in-band) pumping of the Tm-doped fiber at the peak of the $^3H_6 \Rightarrow {}^3F_4$ absorption band.

Presented here are the first results obtained with a double-clad (DC) Tm-doped fiber laser operating on the $^3F_4 \Rightarrow {}^3H_6$ transition of the Tm^{3+} ion, which was an in-band cladding-pumped by a fiber coupled laser diode module near the peak of the $^3H_6 \Rightarrow {}^3F_4$ absorption band, at 1620 nm. The laser, operating in a quasi-continuous wave (Q-CW) mode, delivered ~15 W of Q-CW power at 1930 nm with a slope efficiency of 67% versus the absorbed pump power. We believe that this first result, obtained with a commercial DC Tm-doped fiber developed for pumping at ~790 nm, is very promising from both a simplicity and efficiency standpoint. Further major performance improvements of Tm-doped fiber laser efficiency and power scalability can be expected with the development of the specialty DC fiber optimized for pumping at the peak of the resonant absorption band.

2. Experimental setup

Figure 1 presents a simplified optical layout of the Tm-doped fiber laser pumped at ~1620 nm. As shown in figure 1, a fiber coupled laser diode module (FCLDM) is used to pump the Tm fiber laser. The output of the module was coupled into a commercial delivery fiber (105/125 μm, NA = 0.22) and was spectrally centered at ~1620 nm. The output spectral bandwidth was measured to be about 15 nm at full-width-half-maximum. The FCLDM was designed to reliably operate in the Q-CW regime only, and it is for that reason that our first experiments were conducted in a Q-CW mode of operation with the 'power on' time of 5 ms and a 10 Hz pulse repetition frequency. As the upper laser level lifetime of Tm^{3+} in silica glass is about 540 μs [1], the Q-CW operating regime of our Tm-doped fiber laser is physically equivalent to the true CW regime in terms of the measured output power during the pump 'power on' and measured laser efficiency.

The DC fiber used in our experiments was a commercial Tm-doped large-mode area LMA-TDF-25/250 by Nufern, with the core of NA—0.10 and the cladding NA—0.46. The output from the pigtail end of the FCLDM was re-imaged onto a cleaved end of a 5.5 m long fiber F1 (figure 1) using a pair of 15 mm focal length aspheric lenses, L1 and L2. The laser cavity was formed by the dichroic mirror, M1 (high transmission at 1610–1660 nm, high reflection at 1910–2200 nm), and the straight cleave on the output end of the Tm-doped fiber F1. The M1 mirror was butt-coupled to the fiber F1 pump end, and measured to have 89% transmission at the pump wavelength, and 95% reflectivity at the laser wavelength of 1930 nm. The laser output from the cleaved end of the fiber F1 was collimated (by the lens L3) and then slightly focused (by the lens F4) in order to fit within the aperture of the pyroelectric energy meter P1 (Ophir PE25BF-DIF-C). Lenses L3 and L4 were anti-reflection (AR) coated (1900–2100 nm, 98% transmission at 1930 nm). A commercial germanium long pass filter, LP1, was placed between the lenses L3 and L4. The LP1 had a measured transmission of <0.1% at 1620 nm and 23% at 1930 nm (over 30 dB suppression for the unabsorbed pump power).

3. Experimental results

Presented in figure 2 are the laser power and efficiency measurement results obtained with the optical layout presented in figure 1 with the fiber (F1) length of 5.5 m. The results are plotted as the Q-CW Tm-doped fiber laser output at 1930 nm (i.e. the laser power when the pump is 'on') versus the absorbed pump power. The pump power was varied through the current control of the laser diodes inside the FCLDM, and the output power from the FCLDM pigtail was measured and calibrated as a function of the diode current. The absorbed pump power was derived as the difference between the pump power at 1620 nm launched into the fiber F1 and the unabsorbed fraction of the pump power coming out the output cleaved end of fiber F1. Calibration parameters for the launched pump power measurements included the transmission of the AR-coated lenses L1 and L2 and the transmission of the mirror M1 at the pump wavelength. Calibration parameters for the unabsorbed power measurements included the transmission of the

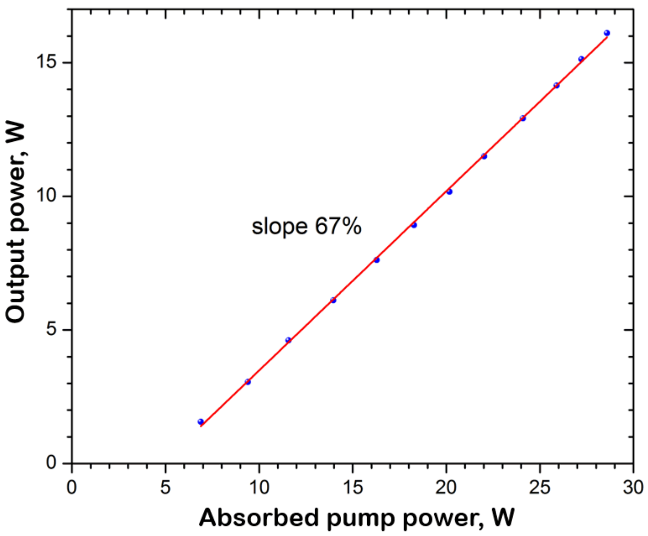

Figure 2. Q-CW laser output power at 1930 nm versus absorbed pump power at 1620 nm for the resonantly diode-cladding-pumped Tm-doped fiber laser. The length of the DC Tm-doped fiber is 5.5 m.

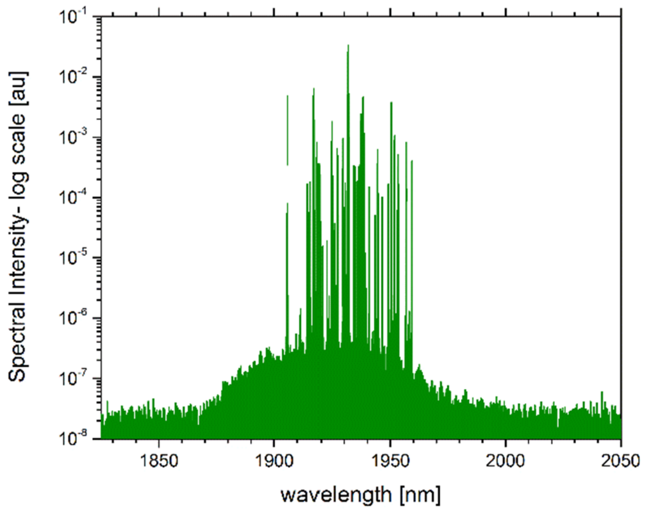

Figure 3. Spectrum of the Tm fiber laser output (on the log intensity scale).

AR-coated lenses L3 and L4, the transmission of the germanium long-pass filter at the pump and laser output wavelength and the Fresnel reflection at the output cleaved end of the fiber F1. The Tm-doped fiber laser output power at 1930 nm was derived as a differential between the pyroelectric energy meter P1 readings with the long-pass filter LP1 *in* and *out* of the output beam path.

The Tm fiber laser testing results plotted in figure 2 clearly indicate a slope efficiency of 67% versus the absorbed pump power and the threshold absorbed pump power of ~5 W. The absorbed fraction of the pump power was measured at 82% at a low pump power and plateaued at 80% at the maximum pump power.

Due to the nature of our experiments, which were mostly intended for determining how efficient the Tm-doped fiber laser could be with the in-band pumping at the peak of the resonant absorption band, no additional effort was made to implement control over the laser spectrum. Consequently, the laser operated in the spectrally free-running, broadband regime (see figure 3). The spectrum of the laser output, averaged over 20 min of laser operation, is presented in figure 3, with the spectral intensity on the log scale. It is evident that the laser output is at least 40 dB above the amplified spontaneous emission level. Laser beam quality was estimated to have an M^2 of ~1.2.

These very preliminary results, obtained with a commercial double-clad Tm-doped fiber unoptimized for in-band pumping at the peak of resonant absorption, indicate a very high potential of resonantly diode-cladding-pumped Tm fiber lasers for major power scaling unaffected by photodarkening. Fiber optimization for resonant pumping at the maximum of the Tm^{3+} $^3H_6 \Rightarrow {}^3F_4$ absorption band in silica (1610–1710 nm) can lead to a new generation of Tm fiber lasers with power and wall-plug efficiency competing with those of high power tandem-pumped Tm-doped fiber lasers, but potentially with a lighter weight and smaller dimensions.

4. Conclusions

In conclusion, we have demonstrated what is believed to be the first resonantly-cladding-diode-pumped Tm-doped fiber laser operating on the $^3F_4 \Rightarrow {}^3H_6$ transition of Tm^{3+} ion. The laser was pumped by a fiber coupled laser diode module at ~1620 nm, near the peak of the resonant absorption band, in a quasi-continuous regime. We achieved ~15 W of Q-CW laser power at 1930 nm with a slope efficiency of 67% versus the absorbed pump power using a commercial double-clad Tm-doped fiber unoptimized for in-band pumping at 1620 nm. This presents, to the best of our knowledge, the highest slope efficiency and the highest output power reported so far for a resonantly diode-cladding-pumped ~2 μm fiber laser based on a double-clad Tm-doped silica fiber.

References

[1] Moulton P F, Rines G A, Slobodtchikov E V, Wall K F, Frith G, Samson B and Carter A L G 2009 Tm-doped fiber lasers: fundamentals and power scaling *IEEE J. Sel. Top. Quantum Electron.* **15** 85

[2] Jackson S D 2004 Cross relaxation and energy transfer upconversion processes relevant to the functioning of 2 μm Tm^{3+}-doped silica fibre lasers *Opt. Commun.* **230** 197

[3] Christensen S, Frith G and Samson B 2008 Developments in thulium-doped fiber lasers offer higher powers *SPIE Newsroom* (https://doi.org/10.1117/2.1200807.1152)

[4] Meleshkevich M, Platonov N, Gapontsev D, Drozhzhin A, Sergeev V and Gapontsev V 2007 415 W single-mode CW thulium fiber laser in all-fiber format *European Conf. Lasers Electro-Optics (CLEO Europe) 2017, OSA Conf. Digest* p CP2-3

[5] Creeden D, Johnson B R, Rines G A and Setzler S D 2014 High power resonant pumping of Tm-doped fiber amplifiers in core- and cladding-pumped configurations *Opt. Express* **22** 29067

[6] Wang Y, Yang J, Huang C, Luo Y, Wang S, Tang Y and Xu J 2015 High power tandem-pumped thulium-doped fiber laser *Opt. Express* **23** 2991