

Efficiency of Tm^{3+} -doped silica triple clad fiber laser

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Abstract. We present measurements of the slope efficiency and the pump power at threshold of a Tm^{3+} -doped silica triple clad fiber laser emitting at $2.02 \mu\text{m}$ using different cooling techniques. The slope efficiency of 53.6% was obtained at a temperature of 25°C with a maximum output power of 5 W for 19 W of absorbed power at the pump wavelength of 800 nm and 9.9 W threshold. In a slightly different setup, the output power could be increased to 10 W for an absorbed pump power of 32 W.

1. Introduction

The continuous search for high power light sources has led scientists to look for a suitable device to generate high power laser output. Recent advances in fiber technology have produced demonstrations of fiber lasers that can generate output powers of several kilowatts. To date, the highest power devices have been based on ytterbium (Yb^{3+})-doped silica fibers that operate in the wavelength region centered around 1080 nm. Lasers in this wavelength region pose serious hazard for eyes since their beams are invisible but the power can be imaged onto the retina. Currently the power scaling of thulium-(Tm)-doped fiber lasers, emitting in the so-called eye-safe wavelength region around $2 \mu\text{m}$, is of particular interest [1]-[4]. Tm-doping is especially interesting for high power laser operation due to the possibility of cross relaxation process (Figure ??), in which two excited ions can be produced with only one pump photon [5]-[6].

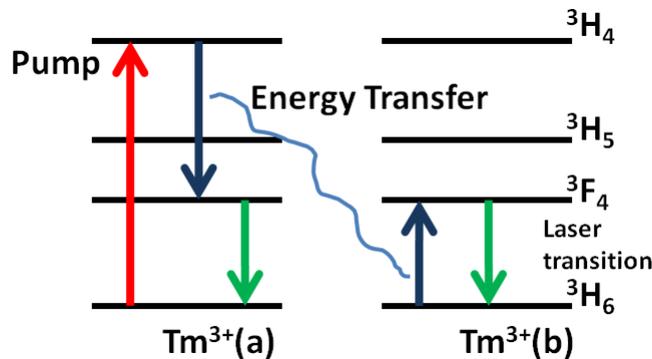


Figure 1. Energetic diagram of Tm^{3+} doped fiber between two thulium ions.

Thus, in theory one can obtain a quantum efficiency of 80 % [1], which increases the power scaling possibilities due to reduced heat extraction problems. In this work, we investigate

the efficiency of newly developed triple-clad Tm³⁺ doped fiber manufactured by the Canadian company CorActive. A fiber laser was constructed, at the Laser Research Institute (LRI), to investigate the efficiency of the fiber, and different cooling techniques were used to investigate the occurrence of the cross-relaxation process and the results are presented and discussed.

2. Experiments

The Tm³⁺-doped silica fiber had a Tm³⁺ concentration of 5 % by weight, an inner core diameter of 18.1 μm (effective NA = 0.11) surrounded by a second core with 48.5 μm diameter. The cladding had 403 μm diameter. At a wavelength of 800 nm the measured absorption coefficient was 2.75 dBm⁻¹. Experiments were conducted using a pump diode laser (JOLD-75-CPXF-2P W) which delivers a maximum output power of 75 W at 800 nm. A coherent FieldMaster power meter was used to measure the output power. The output beam from the diode is collimated by a lens ($f = 15$ mm), reflected with two dichroic mirrors, M₁ and M₂ (HR@ 800 nm, HT@ 2 μm). The beam is then focused inside the Tm-doped fiber (NA = 0.11, length = 4 m) with a second lens ($f = 8$ mm). During the experiments, the fiber was required to be immersed in water in order to control the temperature to achieve maximum efficiency. Experiments were conducted at 25°C, 0°C and -15°C. The temperature of 0°C and -15°C were achieved by using ice water and by mixing salt with ice, respectively. A schematic diagram of the laser setup is shown in Figure ???. Feedback for laser oscillations was provided by a plane gold mirror, M₃, with high reflectivity at 2 μm .

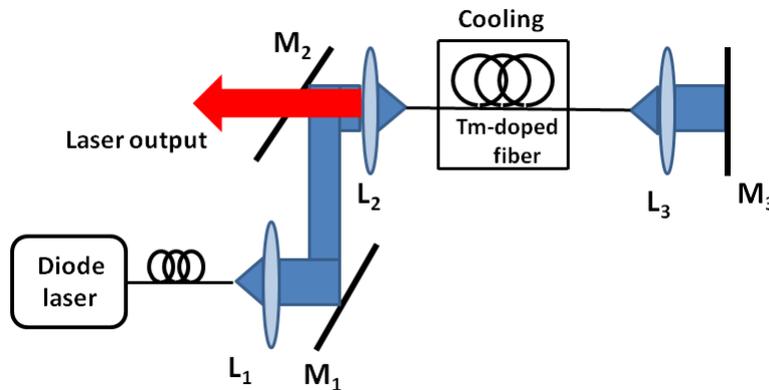


Figure 2. Typical setup used for the characterization of the Tm-doped fiber; M₁, M₂, M₃ are mirrors and L₁, L₂, L₃ are lenses.

3. Results

The measured fiber output power against the absorbed pump power is shown in Figure ??. In previous experiment (not shown), at room temperature, the threshold for laser oscillation was reached for 15.2 W of absorbed pump power with an output power ~ 4 W for 25 W of absorbed pump power. The characterization of the diode-pumped Tm-doped fiber in Figure ?? shows the measured slope efficiencies at room temperature (25°C) and ice water ($\sim 0^\circ\text{C}$). An output power of ~ 4.7 W (~ 19 W of absorbed pump power) was obtained at 0°C with a slope efficiency of 49.3 %. A slope efficiency of 53.6 % was obtained at 25°C, with 9.9 W threshold. An output power of > 5 W was obtained for ~ 19 W of absorbed pump power. The decrease of the threshold, from 9.9 W to 7.8 W, is due to the cross relaxation process taking place inside the Tm-doped fiber which becomes more efficient at lower temperature. A maximum output power of 10 W was obtained by increasing the input power of the diode laser (32 W of absorbed pump power).

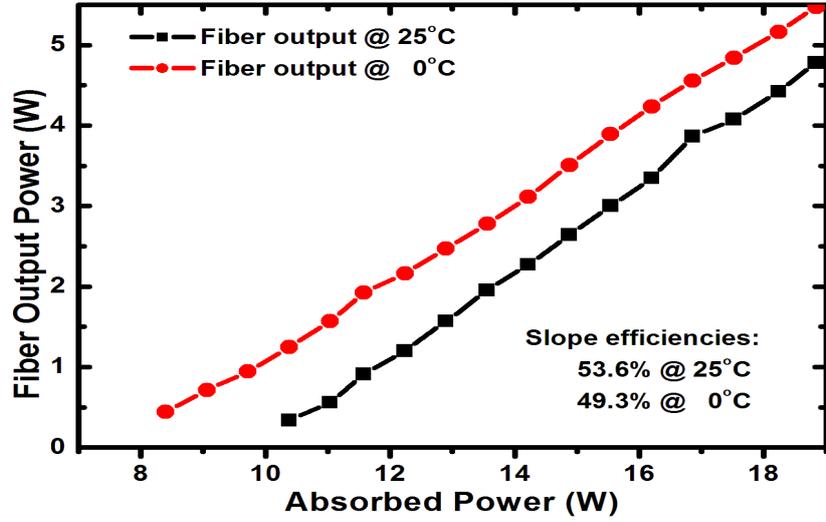


Figure 3. Measured slope efficiency of the Tm^{3+} -doped fiber at 25°C and 0°C.

The maximum output power was limited by thermal effects and damage inside the fiber and the optics. The spectral output was recorded using a 0.5 m monochromator with a 300 lines per mm grating blazed at 2 μm and an InGaAs detector. The recorded spectrum at 25°C is shown in Figure 4. We observe a spectral output with multi-wavelength around 2.02 μm .

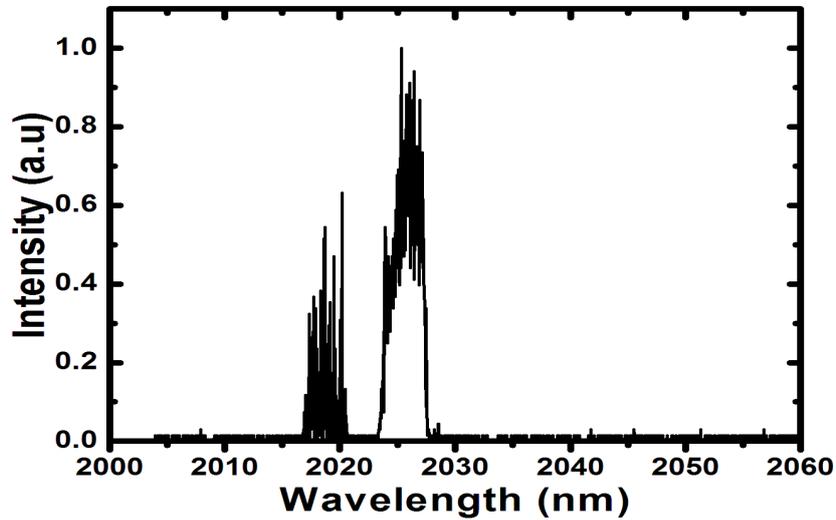


Figure 4. The measured spectral output of the Tm^{3+} -doped silica fiber at 25°C.

4. Conclusion

We have produced a continuous wave (CW) laser with optimal output power of ~ 4 W at room temperature, ~ 5 W in ice water (for ~ 19 W of absorbed power) from a diode-pumped Tm^{3+} -doped silica fiber laser that operated at a slope efficiency of 49.3 % at 25°C, 53.6 % at 0°C, and a spectral output with multi-wavelengths around 2.02 μm . An output power of 10 W was obtained in high power pumping regime (for ~ 32 W of absorbed power).

Acknowledgments

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