Performance of 915 nm pumped LMA Yb fiber designs for long-term reliable multi-kilowatt operation

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ABSTRACT

We report the performance of new LMA Yb fibers with increased cladding absorption for pumping in the 915 nm absorption band. A 0.5 dB/m cladding-absorption Yb20/400 fiber showed negligible photodarkening loss in 400-hour laser operation at 3 kW, with 77% optical-to-optical efficiency. Low-SRS and TMI-free operation at 3.5 kW signal power was achieved with a 0.65 dB/m cladding-absorption and 20.2 µm mode-field diameter Yb fiber, tested in a co-pumped amplifier. The Raman peak was 31 dB below the signal peak at the maximum power.

1. INTRODUCTION

When compared with other solid-state lasers, fiber lasers offer the highest beam quality, electrical-to optical efficiency, increased cutting speed and lowest operation and maintenance cost. The output power of fiber lasers has steadily increased over the past two decades thanks to advancements in fiber design and laser diode technology, displacing other well-established lasers used for industrial applications. Transverse mode instability (TMI)[1] and nonlinear effects[2], namely stimulated Raman scattering (SRS), are the main limitations in scaling the output power of kilowatt-class fiber lasers used in material processing. Efforts to reduce nonlinear effects, including increasing the effective area or increasing the dopant concentration to reduce the length of the fiber laser, will also result in a decreased TMI threshold. The wider availability of pump diodes centered at 976 nm has allowed increasing the SRS threshold by reducing the gain fiber length compared to 915 nm pumped fiber lasers. We recently introduced new Yb doped fibers[3] designed for increasing the effective area for minimizing SRS, while maintaining a high TMI threshold when pumped at 976 nm. However, the cost of 976 nm diodes is still higher than that of 915 nm diodes, and therefore, the latter is still preferred, when minimizing the cost of the system is crucial.

Fiber lasers used in industrial and manufacturing applications are required to run for thousands of hours in factory settings and hence, reliability and stable performance is paramount for maintaining low operating costs. The main obstacle in achieving a sustained signal power over long-term operation of the fiber laser is photodarkening (PD), a phenomenon known to degrade its power, beam quality and TMI threshold[4-7]. The OFS TrueLase™ Yb20/400 fiber[8], designed for pumping at 976 nm with photodarkening-free operation, has been modified with increased cladding absorption and mode field diameter (MFD) for pumping in the 915 nm absorption band.

2. EXPERIMENTAL RESULTS

Two different Yb-doped fibers were evaluated in a co-pumped amplifier, using a broadband seed source at 1070 nm. Pump and signal light were coupled to the Yb fiber using a commercial (36+1)x1 pump-signal combiner (PSC). The output fiber was a 0.06 NA, 25/400 µm passive fiber spliced to the gain fiber. A high-speed photodiode was used to detect TMI, by monitoring the temporal behavior of the laser output. The first fiber, Fiber A, was a 28-meter Yb-doped fiber, with a mode field diameter (MFD) of 17.8 µm and 0.5 dB/m cladding absorption at 915 nm. A 3 kW signal power with 77% o-o efficiency (Figure 1a) was obtained, while the standard deviation of the photodiode trace remained at less than 0.1%, indicating TMI-free operation (Figure 1b). The OSNR, or the signal to SRS peak at 1123 nm, was 32 dB at 3 kW, which limited further power scaling.

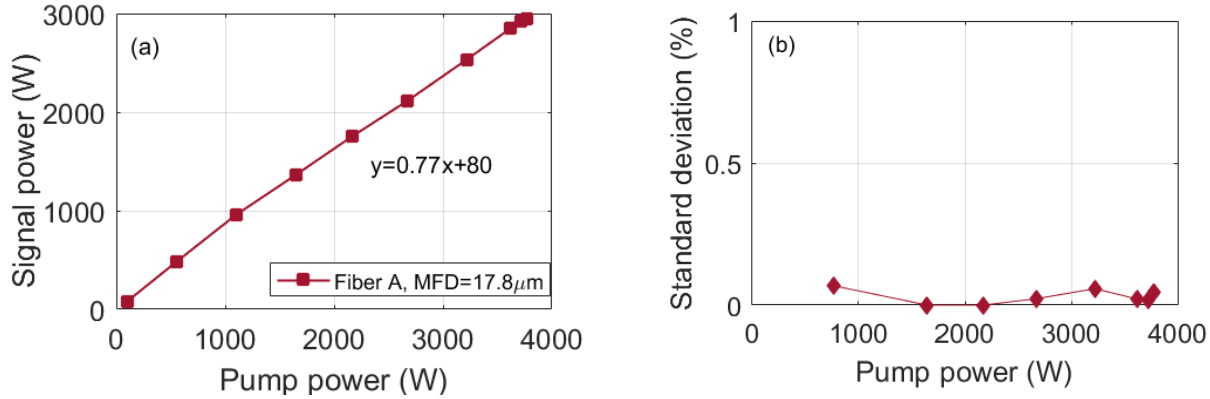

Figure 1: (a) Output power vs. pump power of the co-pumped amplifier using Fiber A: MFD=17.8µm-MFD Yb fiber, and (b) the standard deviation of the output photodiode vs. pump power of Fiber A, showing TMI-free operation.

We compared long-term operation at 2.1 kW signal power with a conventional Yb20/400 fiber with similar cladding absorption. No signal power decay was observed in Fiber A in 50 hours, while a 3% power drop was measured after a 50-hour operation of a conventional Yb20/400 fiber (Figure 2a). Additional testing of Fiber A at 3 kW signal power for 400 hours showed stable operation and no signal power loss.

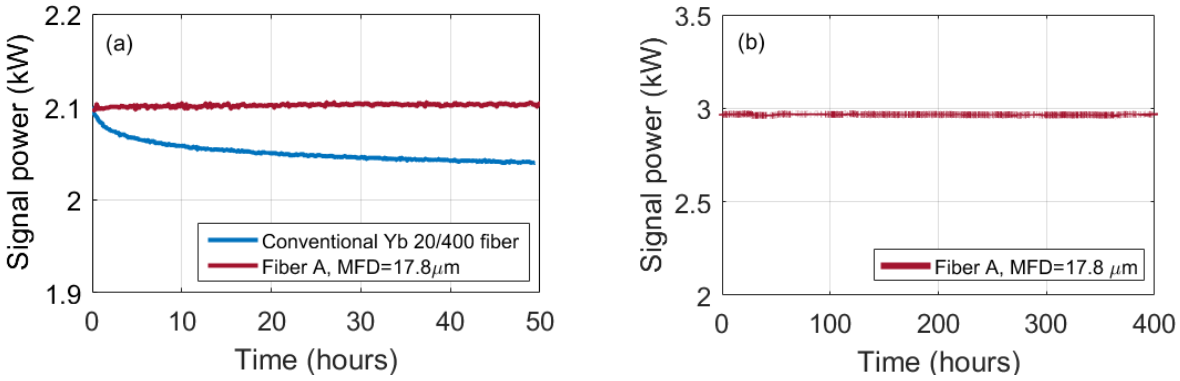

Figure 2: (a) Long-term operation to test for PD, comparing a conventional Yb20/400 fiber and Fiber A, and (b) Long-term operation of Fiber A at 3 kW.

The second Yb fiber, Fiber B, designed to decrease nonlinear limitations, was a 22-meter sample with MFD=20.2 µm and 0.65 dB/m cladding absorption. A TMI-free 3.5-kW signal was achieved with 76% optical-to-optical efficiency (Figure 3a). Figure 3b shows the standard deviation of the photodiode used to detect TMI, which remained at less than 0.1%.

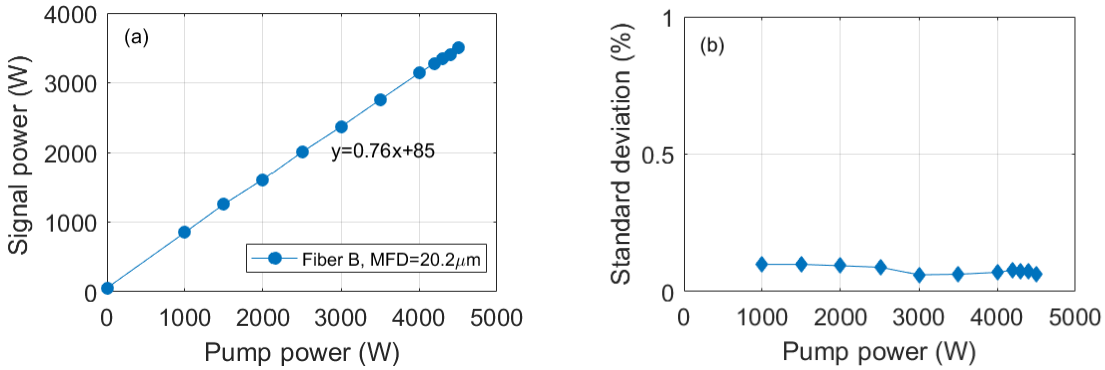

Figure 3: (a) Output power vs. pump power of the co-pumped amplifier using Fiber B: MFD=20.2µm Yb fiber, and (b) Standard deviation of the output photodiode vs. pump power of Fiber B, showing TMI-free operation.

Figure 4 shows the optical spectra measured at maximum power for the two fiber samples. The OSNR was 31 dB at 3.5 kW for the amplifier built with Fiber B, the larger MFD and cladding absorption Yb fiber. This allowed scaling the signal power by 500 W for the same OSNR attained with fiber A at 3 kW.

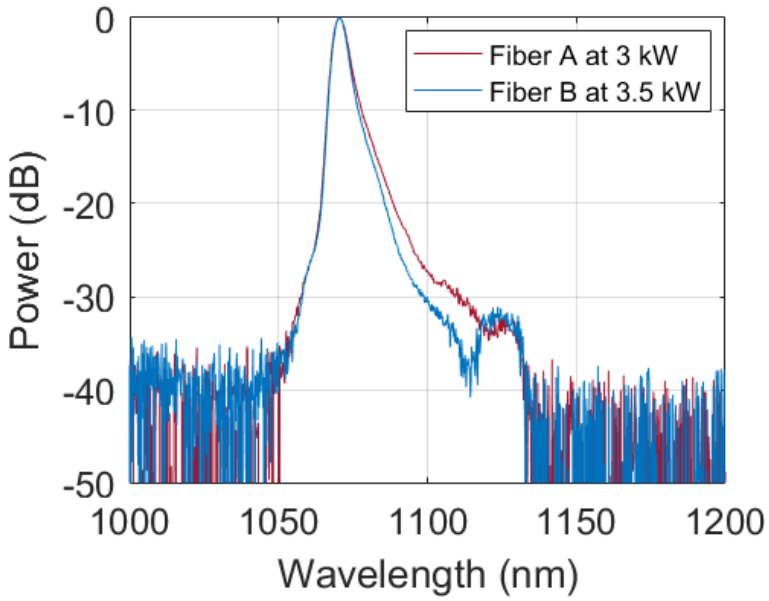

Figure 4: Comparison of output spectra at maximum power for Fiber A and Fiber B. Fiber A (28 meter, MFD=17.8 µm and 0.50 dB/m cladding absorption) at 3 kW and Fiber B (22 meter, MFD=20.2 µm and 0.65 dB/m cladding absorption) at 3.5 kW.

3. CONCLUSIONS

In conclusion, the performance of new LMA Yb-doped fiber designs in a co-pumped amplifier and powered by 915 nm diodes was presented. Negligible photodarkening loss was observed in 400-hour fiber laser operation at 3 kW with a 17.8 µm MFD and 0.5 dB/m cladding absorption TrueLase^{TM} Yb20/400 fiber, maintaining a 77% optical-to-optical efficiency. To reduce SRS limitations, a 20.2 µm MFD and 0.65 dB/m cladding absorption Yb fiber was evaluated, achieving 3.5 kW signal power with an OSNR of 31 dB. These designs allow long-term reliable diffraction-limited, multi-kilowatt operation required for industrial fiber lasers when pumped at 915 nm.

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