All-fiberized Tm-doped fiber MOPA with 30-W output power

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We demonstrate a 30-W all-fiberized laser in a master oscillator power amplifier (MOPA) structure with a central wavelength of 1 950 nm. The laser is a continuous-wave (CW) operation with double-clad Tm-doped silica fiber pumped by pigtailed laser diodes with a central wavelength of 793 nm. The optical-to-optical efficiency of the MOPA system is 37.5% with respect to the total 80-W pump power. The maximal slope efficiency of the system is approximately 43%, which belongs to the main amplifier and exceeds the Stoke limit. No obvious amplified spontaneous emitting (ASE) is observed in the experiment, and the power can be scaled straightforwardly by improving the pump power.

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All-solid-state lasers producing high output power in the 2-μm spectral region have attracted much interest due to their numerous applications in areas such as medicine, lidar, and efficient nonlinear frequency conversion to the mid-infrared (3–5 μm) spectral region[1, 2]. Good high-power and high-efficiency beam quality is often required for many of the above applications. However, conventional all-solid-state lasers are unable to maintain good beam quality with high output power due to the strong thermal effects and thermal lensing which degrade both beam quality and efficiency. Cladding-pumped fiber lasers offer an alternative way to power scaling. High-power thulium-doped fiber laser emitting a near 2-μm laser beam is the latest revolution in laser technology[1−9].

However, the output power of a thulium-doped fiber laser oscillator is limited due to the power handling capability of the fiber components and the available brightness of the pump sources. The master oscillator power amplifier (MOPA) structure offers a way to break through the limit. Using the MOPA structure can boost the output power of the laser oscillator while simultaneously maintain the excellent beam quality of the laser beam from the main oscillator.

Thus far, over 600-W single-mode, single-frequency thulium-doped fiber laser has been realized[11], and over 1-kW non-single-frequency thulium-doped fiber laser has been demonstrated[12], both of which employ the MOPA configuration and bulk optics components. The characteristics of compactness and robustness are extremely important for any kinds of lasers. All-fiberized laser systems are preferred in many application fields due to their good compactness and robustness; furthermore, fiber Bragg gratings (FBG) have been used to build the resonance cavity in the all-fiberized fiber laser.

In this letter, we report an all-fiberized Tm-doped fiber MOPA system that comprises two-stage amplification chains. The center wavelength of the laser beam is 1950 nm. The maximum output power is 30 W, and optical-to-optical efficiency is 37.5%.

In our experiment, the laser system employs the MOPA structure (Fig. 1). The primary purpose of utilizing the MOPA system is to solve the problem of thermal management and beam quality. The pump-dump has been achieved at the end of MOPA structure.

The main oscillator (seed laser), shown in Fig. 2, consists of a section of Tm-doped double-clad fiber, a 105-μm pigtailed 793-nm laser diode (LD), a pair of FBGs (with reflection ratios of 99.5% and 10%, respectively, both of which have a central wavelength of 1 950 nm) as the high-reflection port and the output port. The Tm-doped fiber has a core diameter of 10 μm (NA=0.15) surrounded by hexagonal inner cladding whose diameter is 130 μm (NA=0.46). The length of the active fiber in the main oscillator is approximately 2 m; its absorption coefficient at 793 nm is 3 dB/m.

The laser output power of the main oscillator versus the pump power is charted in Fig. 3. The maximal output power of the seed laser can reach 2.4 W at the full pump power of 7.63 W, and the slope efficiency of the seed laser is approximately 40%, which exceeds the Stoke limit. The seed laser is conduction-cooled in a metal plate to remove the heat induced by the quantum defect.

The pre-amplifier employs a (2+1) ×1 pump combiner and 4-m-long double-clad TDF, which is the same as that used in the main oscillator stage and matches with the output port of the combiner well. In our experiment, two 105-μm fiber pigtailed 13-W LDs with a central wavelength of 793 nm were used in the pre-amplification stage. The maximum output of total pump sources was measured to be 20 W after being fused to the pump combiner.

Due to the absorption of the TDF, the output was approximately 0.8 W when the two pump LDs of the

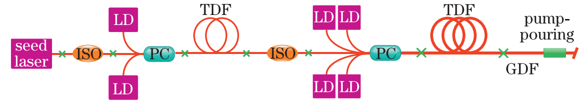

Fig. 1. System configuration of the 30-W all-fiberized Tm-doped fiber MOPA.

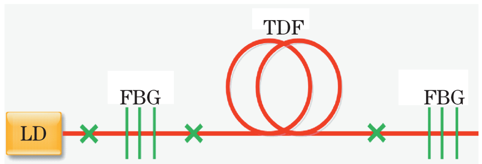

Fig. 2. Setup of the main oscillator.

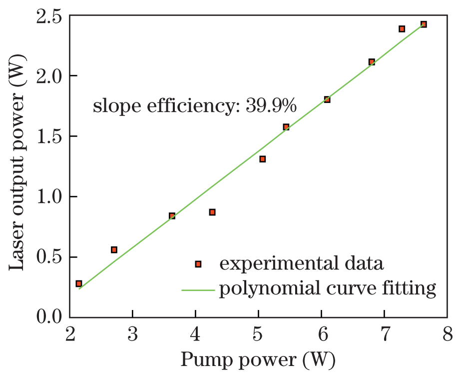

Fig. 3. Output power of the main oscillator versus pump power.

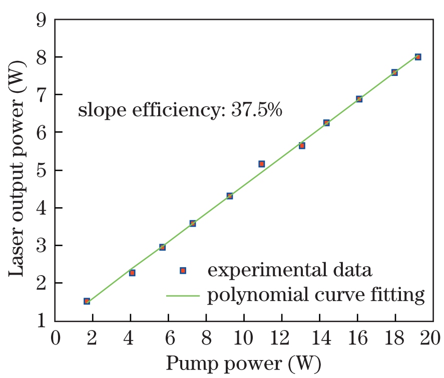

Fig. 4. Output power of the pre-amplifier versus pump power.

pre-amplifier were turned off. The dependence of the output power of the signal on the pump power when the two pump LDs were turned on is plotted in Fig. 4. The maximal output signal power was 8.0 W at the maximal pump power of 20 W, and the slope efficiency of the pre-amplifier was 37.5%. Considering that the cross-relaxation (CR) is an exothermic process in the host glass of silica and that the Stoke limit is approximately 80%[13], approximately half of the pump energy is converted to heat; hence, the efficient thermal management is very necessary for the system. In our experiment, the main part of the amplifier was water-cooled in the heat sink.

In the power main-amplification configuration, a (6+1) ×1 pump combiner and 2.5-m-long 25/250 double-clad TDF were employed. The active fiber matched with the output port of the pump combiner well, and the absorption coefficient of the fiber at 793 nm was 9.7 dB/m. Four 15-W LDs were utilized in the main amplification stage with a central wavelength of 792 nm, and the maximum output of total pump sources was approximately 55 W after fused to the pump combiner.

The output power was approximately 6 W after the main amplification stage with all the pump sources turned off. When the four pump LDs were turned on, the maximal output signal power of the MOPA was approximately 30 W at the maximal pump power of 55 W. The dependence curve between the output signal power and the pump power is charted in Fig. 5. The slope efficiency of the main amplifier was approximately 43%. Under the maximal pump, the all-fiberized MOPA operated continuously without any anomaly. In the same way as the pre-amplifier, the main amplifier was water-cooled by placing it in the heat sink.

The spectrum of the seed laser and the main amplifier are depicted in Fig. 6. No significant spectrum broadening was observed. In addition, no significant ASE was observed in the experiment due to the relatively high-power seed laser.

In conclusion, we build a 30-W high-power Tm-doped all-fiberized MOPA. The advantages of the all-fiberized MOPA structure are proven in the experiment. Due to the relatively high absorption of the fiber, thermal management is very necessary to maintain the all-fiberized

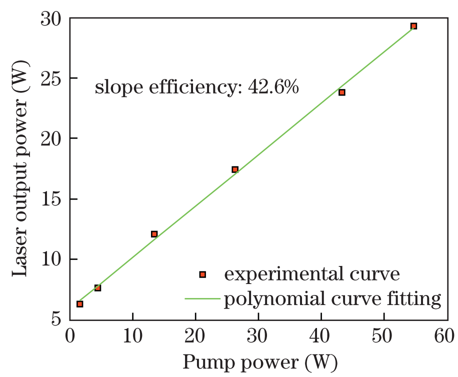

Fig. 5. Output power of the amplified laser versus pump power.

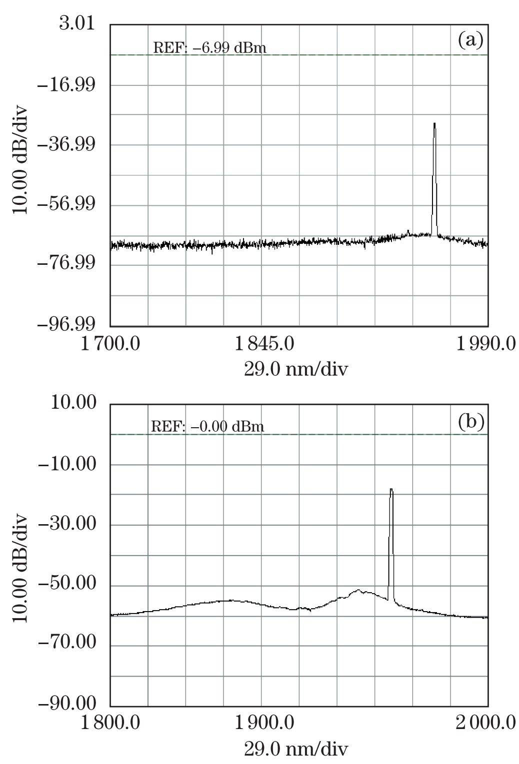

Fig. 6. Laser spectra of (a) seed laser and (b) amplifier laser.

MOPA configuration stability and efficiency; however, such stability and efficiency are much more easily achieved than that in all-solid-state laser system. The output laser power is only limited by the available pump source; We believe that much higher output laser power can be achieved with additional pump sources employing all-fiberized MOPA configuration.

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