122-W high-power single-frequency MOPA fiber laser in all-fiber format

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We demonstrate a high-power single-frequency master oscillator power amplifier (MOPA) fiber laser. The central wavelength of the single-frequency fiber laser seed is 1 063.8 nm, with a linewidth narrower than 20 kHz and output power of 120 mW. By using two-stage amplification, a single-frequency fiber laser with an output power of 122 W is obtained, and the optical-optical conversion efficiency is 72%. No significant amplified spontaneous emission (ASE) or stimulated Brillouin scattering (SBS) is observed. The output power can be further increased by launching more pump power.

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High-power single-frequency lasers have been found widespread applications in science and industries, such as gravitational wave detection, coherent and spectrum beam combining, range finding, and lidar[1−7]. In such cases, the localization of high-power single-frequency fiber laser is extremely important for domestic researchers. The power of single-frequency fiber lasers has increased dramatically in recent years. Most previously presented high-power single-frequency fiber lasers are based on bulk optics configuration, which have big sizes and massive weights. The use of all-fiber-based components can significantly simplify the system configuration and make the system more compact and robust[8−10]. In this letter, we report a high-power single-frequency master oscillator power amplifier (MOPA) fiber laser in all-fiber format. The MOPA fiber laser consists of two-stage amplification architecture. The maximum output power is 122 W, with slope efficiency of 72%.

The MOPA system configuration is depicted in Fig. 1. The seed laser is an ultra-short cavity-based singe-frequency fiber laser using heavily Yb^{3+}-doped phosphate glass as the laser gain medium[11,12]. After passing through a polarization-insensitive isolator, the seed laser power is boosted by a pre-amplifier, which consists of one 9-W, 975-nm pigtailed laser diode (LD, BWT Co., Beijing), a (2+1)×1 pump combiner, and a home-made 4-m-long Yb^{3+}-doped active fiber (YDF, CETC 23 RI, Shanghai). Only one pump port of the pump combiner is used in the pre-amplifier stage. The active fiber is Yb^{3+}-doped large mode area (LMA) double-clad fiber, with core diameter of 11 μm and inner clad diameter of 30 μm; the numerical apertures (NAs) of the core and the inner clad are 0.08 and 0.46, respectively. The absorption coefficient is about 5.5 dB/m at 975-nm pump wavelength. An isolator is set in place after the pre-amplification stage to prevent the frontal stage apparatus from being damaged by backscattering light. A 5/95 coupler (based on the 11/130 double-clad fiber) is spliced after the isolator to detect the backscattering light, and the detected power can be used for evaluating the stimulated Brillouin scattering (SBS) effect.

In the main amplification configuration, a (6+1)×1 pump combiner (Lightcomm Co., Shenzhen) and a YDF are employed. The active fiber is a home-made double-clad Yb^{3+}-doped fiber with a core diameter of 30 μm and clad diameter of 400 μm. The insertion loss of the pump combiner for the signal laser is 0.5 dB, with pump efficiency more than 92%. The fiber parameters for the output port of the pump combiner are 30/400 double-clad fiber. The absorption of the Yb^{3+}-doped fiber at 975 nm is 5 dB/m, while the gain fiber length is 5 m. Four 50-W level LDs are used in the main amplifier stage, with the central wavelength of the LD of 975 nm; the maximum output of the total pump source is measured 169 W after fusing to the pump combiner. A pump stripper is spliced to the end of the gain fiber to strip the unwanted residual pump light in the fiber amplifier. The end of the pump stripper is cleaved with an angle of 8° to minimize back-reflection into the amplifier.

In the experiment, we first tested the performance of the single-frequency fiber laser. The single-frequency radiation was very stable, with no mode hopping during the 1-h observation. The frequency spectrum was analyzed with the aid of a scanning Fabry-Perot interferometer

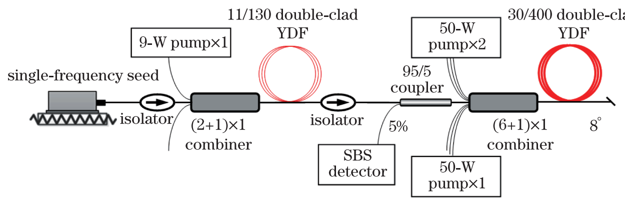

Fig. 1. Schematic of high-power single-frequency MOPA fiber laser.

(SFPI) as shown in Fig. 2(a), which shows a scan over one free spectral range (FSR) and confirms the oscillation of only one longitudinal laser mode. The spectrum of the seed laser is plotted in Fig. 2(b). The central wavelength of the single-frequency fiber laser seed is 1 063.8 nm. In order to further investigate the laser spectral characteristics, the linewidth of the fiber laser was measured by

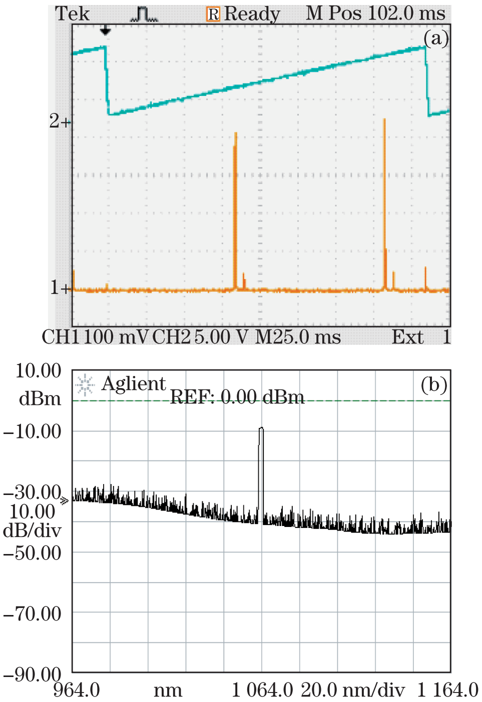

Fig. 2. Character of the single-frequency fiber laser. (a) Scanning SFPI traces and (b) the spectrum of the seed laser.

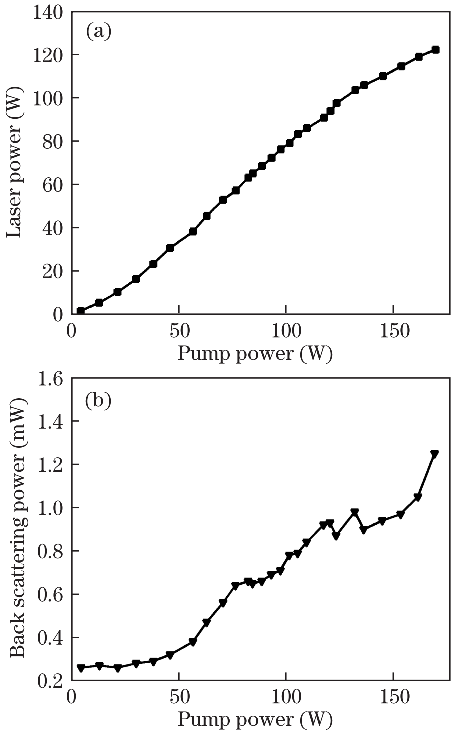

Fig. 3. Detected power of the output laser and backscattering light.

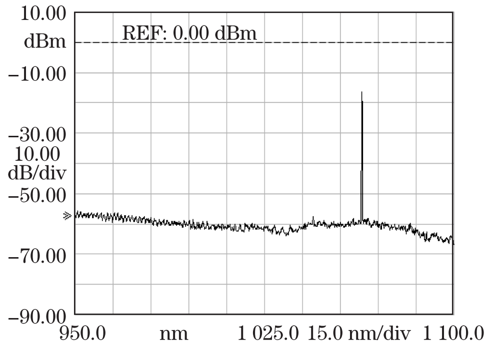

Fig. 4. The spectrum of the amplifier output at 122 W.

self-heterodyne method using a 10-km fiber delay. The linewidth is 20 kHz with −20 dB from the peak.

The output power of the seed laser is more than 120 mW under a 400-mW pump power. The seed laser was pre-amplified to be 3.5 W in the pre-amplification stage. Due to the absorption of the laser power of the double-clad active fiber in the main amplification stage, the output power is about 1.3 W when the pump source in the main amplification stage is turned off. The dependence of the power of the output signal and the backscattering beam power on the pump power when all the four pump sources are turned on is shown in Fig. 3. The maximal output power is 122 W at the maximal pump power of 169 W, which denotes an optical to optical efficiency of 72%. The laser output power was linearly enhanced by increasing the pump power without any power roll. From the chart, we can find that the backscattering light power almost linearly increased with the pump power and that no SBS was observed. Due to the limitation of the available LD, only four ports of the (6+1)×1 pump combiner were used. The output power can be further increased by launching more pump power. The spectrum of the main fiber amplifier output is depicted in Fig. 4. It can be seen that the pump laser was almost totally absorbed and that the amplified spontaneous emission (ASE) was suppressed by a factor of more than 40 dB.

In conclusion, we report a high-power single-frequency MOPA fiber laser, which consists of two-stage amplification architecture. The maximum output power is 122 W, with slope efficiency of 72%. The ASE is suppressed by a factor of ~40 dB, and no SBS effect is observed. The maximum output of the total pump source is measured to be 169 W after being fused to the pump combiner. The output power is only limited by the available pump source; it is believed that scaling the pump power may achieve much higher output power.

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