133-W pulsed fiber amplifier with large-mode-area fiber

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Abstract. A master-oscillator fiber power amplifier (MOPA) system with a 4-m-long Yb³⁺-doped homemade large mode area (LMA) double-clad fiber is reported. The system emits up to 133.8 W of amplified radiation at a wavelength of 1064 nm and a repetition rate of 100 kHz, limited only by the available pump power. Peak power of 300 kW at 20 kHz with a pulse duration of 15 ns is obtained. © 2006 Society of Photo-Optical Instrumentation Engineers. [DOI: 10.1117/1.2160520]

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1 Introduction

Recent development of techniques for multimode core fibers and advances in high-power and high-brightness diode lasers have made it possible to dramatically increase output signal powers from Yb-doped fiber lasers. For the increasing number of applications demanding high average powers at high repetition rate, MOPA with LMA double-clad fiber represents an attractive solution. With a combination of beam confinement and excellent heat dissipation due to the large surface area to gain volume ratio of doped fiber, MOPA system is beginning to compete with conventional solid state lasers in many application areas. Difficulty in scaling pulse energies originates in the limited size of the fiber core and relatively long pulse propagation length. Increasing the size of the core appears to be one of the main directions of the technological advancement toward high energies and powers, however, it can eventually lead to the significant degradation of the beam quality.

The output signal powers from MOPA system are increased rapidly in recent years. A 20.1-W single-frequency MOPA radiation at 1064 nm with diffraction-limited beam quality ($M^2 \le 1.3$) was reported in 2001. The LMA fiber core was 30 μ m with a NA of 0.06, and the D-sharp inner cladding was 400/350 μ m with a NA of 0.38. Several months later, 51.2 W of average power was obtained from

the 24-m fiber MOPA system, and a power of 60 kW was achieved. In 2002, 100-W nanosecond MOPA radiation was realized, with a 400- μ m coreless end cap spliced on the output side of the fiber to avoid fiber facet damage. Subsequently, 100-W single frequency was presented with 9.4-m LMA fiber, where the core was only 28 μ m. The short-length LMA fiber is preferable to realize high power output as the effects of Raman scattering can be reduced and stimulated Raman scattering threshold increased.

In this letter we report a 975-nm diode-pumped MOPA system with 133.8 W of pulsed amplified radiation at 1064 nm based on a 4-m homemade LMA double-clad fiber without a coreless end cap at output end, limited only by the available pump power.

2 Experiments and Results

The double-clad Yb-doped LMA fiber used in the experiment was designed by our independent technology and fabricated by standard modified chemical-vapor deposition (MCVD). The fiber has a 43- μ m diameter Yb-doped core with a NA of 0.08, centered in the preform and a 650/600 μ m D-shaped inner cladding with a NA of 0.37. The doping Yb³⁺ concentration is evaluated to ~6500 ppm.

The setup of the MOPA system is shown in Fig. 1. As a seed source a Q-switched laser is applied. The laser delivers average powers up to 1 W between 20 and 100 kHz repetition rate at 1064 nm. A Faraday isolator protects the seed laser from back-reflections. The length of double clad fiber is 4 m. The small ratio of the inner cladding area to the active core area of \sim 200 ensures that more than 90% of the launched pump light is absorbed in the fiber, which is coiled by 10-cm-diameter cylindrical mandrel in air, without any special cooling device. Polishing both fiber ends at an angle of $5 \sim 10^{\circ}$ suppresses laser operation and seeding of amplified spontaneous emission of the high-power fiber amplifier as a result of Fresnel reflections. The fiber amplifier is pumped by a laser diode which is water-cooled. The operating temperature is 18° to 22°C, and the central wavelength is about 975 nm. Two lenses, which have short focal length, are used to couple the pump light into the inner cladding with a coupling efficiency of $\sim 90\%$. A high transmission for pump light and high reflection for amplified light dichroic mirror is placed by an angle of 45° to separate the pump and amplified light. Two reflecting mirrors are used to shorten the length of the system. An aspheric lens is used to couple the seed light into the active core with high efficiency.

The output signal power characteristics are shown in Fig. 2. At a repetition rate of 100 kHz, we were able to produce an average output signal power up to 133.8 W at

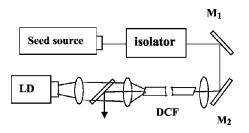


Fig. 1 Experiment setup of MOPA.

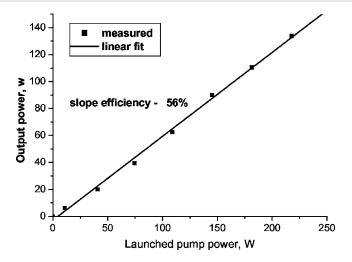


Fig. 2 Output signal power against launched pump power.

the maximum diode driven current. The slope efficiency with respect to the launched pump power was 56% and the output signal power increased linearly with the launched pump power. We have not found any facet damage at the maximum power. So more output signal power can be realized if we increase pump power. Due to transient gain of the MOPA system,⁵ the amplified pulse duration is reduced from 30 to 15 ns at the repetition rate of 20 kHz, corresponding to a peak power of 300 kW. The pulse shortening factor increases with a decrease of repetition rate. Figure 3

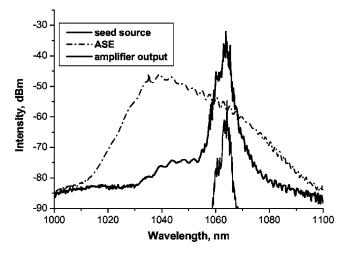


Fig. 3 Emitted spectrum of seed source, amplifier, and ASE.

shows the emitted spectrum at the maximum output signal power, plotted against the seed source spectrum and amplified spontaneous emission (ASE) on a logarithmic scale at the repetition rate of 100 kHz. When we pumped the fiber without the injection of seed source, the output spectrum was ASE spectrum and centered at 1040 nm with a 3-dB bandwidth of 20 nm, but when the seed source was coupled into the core, the output peak spectrum shifted to 1064 nm due to mode competition. The ASE spectrum was suppressed effectively and no stimulated Raman scattering occurs.⁶ Coiling the fiber in a diameter less than 10 cm discriminates against the higher order transversal mode through bending losses, and only lower order modes are amplified. The M^2 is characterized to be 3.2; the value could be improved with a smaller diameter cylindrical mandrel.

3 Conclusions

We have demonstrated a MOPA system that could produce a 133.8-W pulsed amplified output with M^2 beam quality of 3.2 at 1064 nm, using a 4-m homemade Yb-doped double-clad fiber, and the repetition rate is 100 kHz. The slope efficiency is 56% with respect to launched pump power. The maximum output signal power is limited by the available pump power. More powerful MOPA systems are expected in the near future, which will exploit new fields of application.

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