Power amplifier for 1064 nm using Yb^{3+}-doped double-clad fiber

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A master-oscillator fiber power amplifier (MOPA) system is presented, which consists of a single mode laser as the master oscillator and an Yb^{3+}-doped large-mode-area double-clad fiber as the power amplifier. The system emits up to 6 W of amplified radiation at a wavelength of 1064 nm. The slope efficiency and extracted pulse energy as a function of pulse repetition rate are analyzed.

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Laser systems based on double-clad rare-earth doped fibers are an attractive technology for compact and efficient high-energy short pulse generation with excellent beam quality, The main performance advantages relative to conventional solid-state lasers arise from the combination of beam confinement and excellent heat dissipation due to the large surface area-to gain volume ratio of doped fiber. One way to increase the pulse energies in fiber is to increase the mode area, although it cannot be increased indefinitely without comprising the modal quality of the output. In 2000, a Q-switched, 5-W average output power amplifier using Yb^{3+}-doped double-clad fiber was reported[1]. Further, single-frequency master-oscillator fiber power amplifier (MOPA) emits up to 20 W[2], picosecond fiber amplifier is capable of generating 51.2 W[3], nanosecond fiber amplifier can even produce up to 100-W average power at 50-kHz repetition rate, corresponding to pulse energy of 2 mJ[4]. In this paper, a MOPA that could emit up to 6 W using Yb^{3+}-doped double-clad fiber is reported.

The setup of fiber amplifier is shown in Fig. 1. As a seed source a Q-switched single mode 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 backreflections. The length of double-clad fiber is 25 m that has low numerical aperture (NA) large mode area with a 30-μm diameter, a 0.06-NA step-index Yb^{3+}-doped core, and 400/350-μm D-shaped inner cladding with NA of 0.38. The doping Yb^{3+}-concentration is 500 ppm(mol) Yb_2O_3. The small ratio of the inner cladding area to the active core area of $\sim$ 170 ensures that more than 90% of the launched pump light is absorbed in the fiber, which is coiled by 32-cm diameter cylindrical mandrel in air, without any special cooling device. Polishing both fiber ends at an angle of $5-10$ degrees 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 and the operating temperature from 18 to 22 °C, 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 $\sim$ 60%. 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 reflect 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.

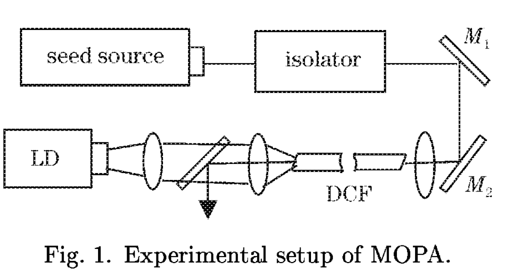

Fig. 1. Experimental setup of MOPA.

Average power up to 6 W of amplified pulses at 18-W launched pump power can be realized when the double-clad fiber is seeded with 0.3 W of power. The incident seed power is 0.5 W, actually the power coupled into the core is only 0.3 W which is measured with the truncation method. The slope efficiency of this Yb^{3+}-doped fiber amplifier yields 46.2% with respect to the launched pump power, as shown in Fig. 2. The launched pump power means the power in the input end of the fiber, which is detected using the truncation method[5]. Seed power of only a few hundred milliwatts is sufficient to saturate this fiber[6], therefore the portion of amplified spontaneous emission in the output is negligible even at low

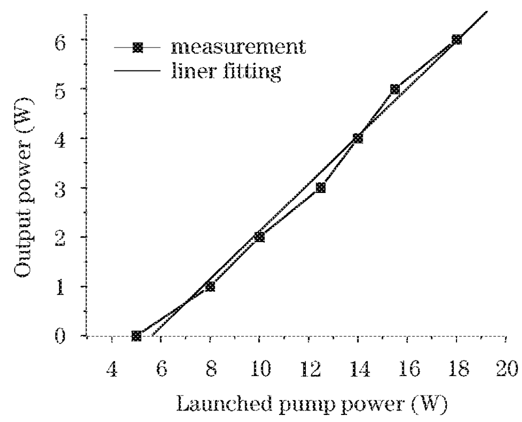

Fig. 2. Output power of amplifier against launched pump power.

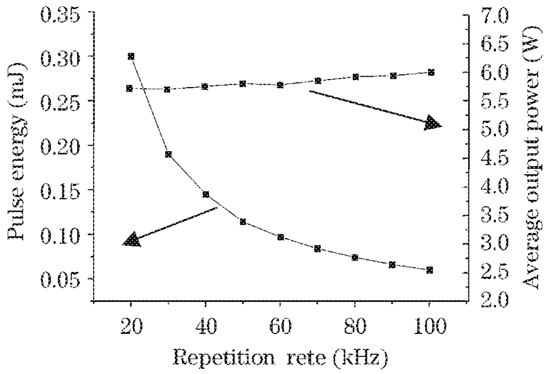

Fig. 3. Extracted pulse energy and average power as a function of pulse repetition rate at maximum launched pump power.

repetition rates. The launched laser pump threshold power is about 5 W. It is very clear that the output power is linear increasing with the launched pump power, and the output power can be further improved by increasing the pump power and optimizing coupling system.

Extracted pulse energy and average power as a function of pulse repetition rate at 18-W launched pump power is shown in Fig. 3. The pulse energy is decreasing with the increasing of repetition rate of seed laser, however, the average output power increases within a short range above 20 kHz. At a repetition rate of 100 kHz we were able to produce an average output power up to 6 W, corresponding to pulse energy of 0.05 mJ. When the repetition rate is reduced to 20 kHz, the extractable energy increases up to 0.3 mJ, at which no fiber facet damage is found. The obtained values are not limited by available pump power but rather by spurious lasing at another wavelength which is observed in the emitted spectrum.

Otherwise, when we continue to increase the pump power, the output fiber facet turns red and the coating begins to burn, which is mainly due to part of the pump power focusing to the coating that is made of silicon resin. The phenomenon demonstrates that the adjustment of the coupling lenes is not precision. It is the next problem has to be resolved.

In conclusion, we have demonstrated a MOPA which could emit up to 6 W output power and possesses 46.2% slop efficiency against launched pump power. Extracted pulse energy and average output power as a function of pulse repetition rate are discussed. The precision of the adjustment system is crucial to the enhancement of output power. We propose to optimize the coupling system, do some work about pulse amplified and spectrum characteristics that might be relevant to nonlinear effects. Higher output power fiber laser will be realized in the near future.

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References

1. J. A. Alvarez-Chavez, H. L. Offerhaus, J. Nilsson, P. W. Turner, W. A. Clarkon, and D. J. Richardson, Opt. Lett. **25,** 37 (2000).
2. S. Hofer, A. Liem, J. Limpert, H. Zellmer, A. Tunnermann, S. Unger, S. Jetschke, H. R. Muller, and I. Freiteg, Opt. Lett. **26,** 1326 (2001).
3. J. Limpert, A. Liem, T. Gabler, H. Zellmer, A. Tunnermann, S. Unger, S. Jetschke, and H. R. Muller, Opt. Lett. **26,** 1849 (2001).
4. J. Limpert, S. Hofer, A. Liem, H. Zellmer, A. Tunnermann, S. Knoke, and H. Voelckel, Appl. Phys. B **75,** 477 (2002).
5. Q. H. Lou, J. Zhou, J. Q. Zhu, Z. L. Wu, L. F. Kong, J. X. Dong, Y. R. Wei, and Z. J. Wang, Chin. Opt. Lett. **1,** 559 (2003).
6. J. Limpert, A. Liem, H. Zellmer, A. Tunnermann, S. Knoke, and H. Voelckel, in *Proceedings of CLEO2002* CTHX3.