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Yb:YAG single crystal fiber power amplifier for femtosecond sources

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We demonstrate a versatile femtosecond power amplifier using a Yb:YAG single crystal fiber operating from 10 kHz to 10 MHz. For a total pump power of 75 W, up to 30 W is generated from the double-pass power amplifier. At a repetition rate of 10 kHz, an output energy of 1 mJ is obtained after recompression. In this configuration, the pulse duration is 380 fs, corresponding to a peak power of 2.2 GW. The M^2 beam quality factor is better than 1.1 for investigated parameters. © 2013 Optical Society of America

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Ultrafast lasers are now a common tool for scientific and industrial applications. Over the past decade, many technological developments of diode-pumped solid-state laser systems have allowed tremendous improvements of their performance, reliability, and cost. In order to achieve high energy per pulse in the femtosecond regime, master oscillator power amplifier systems are commonly used. Regenerative amplifiers based on bulk or thin disk Yb-doped crystals can amplify ultrashort pulses to several tens of millijoules [1,2]. They can provide high gain and high output energy at a low repetition rate, but they are limited in terms of repetition rate to a few hundreds of kilohertz due to the high-voltage-driven switch speed. Ytterbium-doped optical fibers can also be used to amplify ultrashort pulses. Their high surface-to-volume ratio provides good thermal management and allows attainment of high average powers of several hundreds of watts [3]. However, the signal confinement in small-cross-section cores induces nonlinear effects, such as self-phase modulation and self-focusing, which limit the peak power and the pulse energy. Femtosecond pulses with an energy of 2.2 mJ were obtained using the well-known chirped pulse amplification technique together with large-core-diameter photonic crystal fibers [4]. Another approach consists in amplifying femtosecond pulses directly in Yb-doped crystals using multipass amplifiers without active elements. Although it requires quite complex systems, the slab geometry has proven to be a very successful approach. Up to 1.1 kW [5] average power and 20 mJ [6] energy were obtained with an Yb:YAG Innoslab amplifier. Significant improvement of the emission cross section and the thermal conductivity can be observed at cryogenic temperatures in most Yb-doped crystals. 40 mJ output energy was obtained using a cryogenic Yb:YAG double-pass amplifier [7]. However, stronger spectral narrowing at low temperatures induces longer optical pulses of several picoseconds. Finally, the single crystal fiber (SCF) concept lies between fibers and crystals and can contribute to original performance for femtosecond systems.

SCFs are long, thin crystal rods with a diameter lower than 1 mm and a typical length of a few centimeters.

SCFs are designed for free-space propagation of the laser signal, as in bulk lasers together with a guidance of the pump beam, which depends on the pump brightness. This concept has recently been successfully implemented in Yb:YAG lasers and demonstrated continuous emission of 250 W from an oscillator based on a 1% doped Yb:YAG SCF pumped by a 600 W laser diode [8]. This clearly shows the potential of this approach for high-power extraction. Furthermore, Yb:YAG SCF also demonstrated high single-pass gain with very simple amplifier geometries.

In the context of ultrashort pulse amplification, SCF provides several advantages that clearly benefit the amplification of ultrashort and intense pulses. Among them, the mitigation of nonlinear effects thanks to the short length of interaction together with the large beam diameter is probably the most interesting. Also, the high gain per pass prevents the use of a regenerative amplifier and therefore significantly expands the range of operation at a high repetition rate. Consequently, Yb:YAG SCF has attracted attention as a potential simple, robust, and cost effective amplifier of ultrashort pulses. In a proof-of-principle experiment, femtosecond pulses were directly amplified from 400 mW to 12 W average power in a double-pass architecture while maintaining the duration of the 30 MHz repetition rate pulses below 400 fs [9].

In this Letter, we demonstrate a femtosecond power amplifier using a diode-pumped Yb:YAG SCF operating from 10 kHz to 10 MHz. For a total pump power of 75 W out of a fiber-coupled high-brightness laser diode, up to 30 W is generated from the double-pass power amplifier. At a repetition rate of 10 kHz, an output energy of 1 mJ is obtained after recompression.

The experimental setup is shown in Fig. 1. The seed source provides a train of stretched and amplified pulses with a repetition rate ranging from 10 kHz to 10 MHz, a maximum energy per pulse of 150 μ J, and a maximum average power of 10 W. The optical spectrum is 4.3 nm at full width at half-maximum (FWHM) and is centered around 1030 nm to match the gain bandwidth of the Yb:YAG SCF booster placed downstream after optical isolation. A 500 mm focal length lens (L1) is used to focus

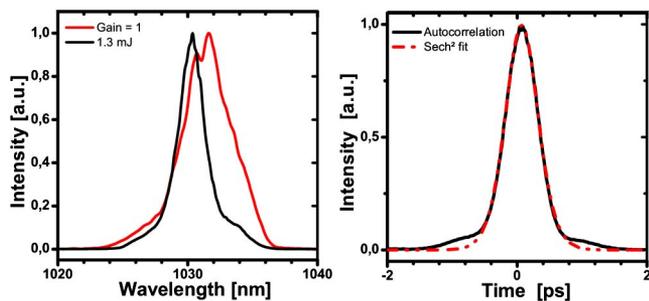


Fig. 4. (Color online) (a) Input and output spectrum, and (b) pulse autocorrelation for 1 mJ output at 10 kHz after recompression.

FWHM decreases from 4.3 to 2.3 nm at maximum energy. Consequently, the pulse duration decreases during amplification and is calculated to be about 150 ps at 1.3 mJ, leading to an extracted peak power close to 10 MW. This peak power is remarkably high and never could have been reached in a silica-based fiber amplifier, where self-focusing usually destroys the gain medium for a peak power not higher than 4 MW. Even if it does not limit the output peak power in our case because of the short crystal length, we can also expect self-focusing in Yb:YAG, inducing a decrease of the beam size on the output facet and potential damage of the antireflective coating. Aware of this effect, we monitor the beam size on the output facet while increasing the seed power at a constant repetition rate. We do not observe any decrease of the beam size that would indicate self-focusing due to higher peak power. Furthermore, no modification of the beam profile is observed, and M^2 values below 1.1 were measured for all parameters investigated in the article (see beam profile in the inset of Fig. 3).

In order to recover the femtosecond regime, the pulses are recompressed using a transmission-grating-based compressor with an efficiency of 76%. Figure 4(b) shows the autocorrelation trace of the output pulses at a 10 kHz repetition rate and a pulse energy of 1 mJ. It has an FWHM of 590 fs, corresponding to a pulse duration of 380 fs, assuming a sech^2 pulse shape. The corresponding peak power is estimated to be in excess of 2.2 GW after taking into account the fact that more than 95% of the total energy remains in the central pulse. As expected from the gain narrowing, the pulse duration is increasing for large gain values but it remains below 550 fs. Considering the upper state lifetime of Yb in YAG and the total energy storage capacity, the output energy should continue to increase if we reduce the repetition rate below 10 kHz. However, the antireflection coating of the output

facet degrades at 1.3 mJ of extracted energy, corresponding to an energy density of 1.1 J/cm² on the output facet. The authors believe that this value can be increased by an order of magnitude by applying different coatings or by using a Brewster-cut gain sample.

In conclusion, we have shown that Yb:YAG SCF pumped by a high-brightness laser diode can be used as a power amplifier for a wide range of seed powers and repetition rates. Sub-550 fs pulses with excellent beam quality ($M^2 < 1.1$) have been obtained with average powers between 10 and 23 W for repetition rates ranging from 10 kHz to 10 MHz. The amplifier is also able to produce high energy pulses, the best performance being 1 mJ pulses at 10 kHz with a duration of 380 fs. Considering the versatility of this amplifier and its simplicity and compactness, the Yb:YAG SCF demonstrates a strong potential to boost femtosecond systems in the millijoule range with average powers in the several tens of watts range. Further development of SCF amplifiers will concern power scaling with higher power pump laser diodes and energy scaling with improvement of the damage threshold of the amplifier faces.

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References

1. A. V. Okishev, *Opt. Lett.* **37**, 1199 (2012).
2. T. Metzger, A. Schwarz, C. Y. Teisset, D. Sutter, A. Killi, R. Kienberger, and F. Krausz, *Opt. Lett.* **34**, 2123 (2009).
3. T. Eidam, S. Hanf, E. Seise, T. V. Andersen, T. Gabler, C. Wirth, T. Schreiber, J. Limpert, and A. Tünnermann, *Opt. Lett.* **35**, 94 (2010).
4. T. Eidam, J. Rothhardt, F. Stutzki, F. Jansen, S. Hädrich, H. Carstens, C. Jauregui, J. Limpert, and A. Tünnermann, *Opt. Express* **19**, 255 (2011).
5. P. Russbuehdt, T. Mans, J. Weitenberg, H. D. Hoffmann, and R. Poprawe, *Opt. Lett.* **35**, 4169 (2010).
6. M. Schulz, R. Riedel, A. Willner, T. Mans, C. Schnitzler, P. Russbuehdt, J. Dolkemeyer, E. Seise, T. Gottschall, S. Hädrich, S. Duesterer, H. Schlarb, J. Feldhaus, J. Limpert, B. Faatz, A. Tünnermann, J. Rossbach, M. Drescher, and F. Tavella, *Opt. Lett.* **36**, 2456 (2011).
7. K. Hong, J. T. Gopinath, D. Rand, A. M. Siddiqui, S. Huang, E. Li, B. J. Eggleton, J. D. Hybl, T. Y. Fan, and F. X. Kärtner, *Opt. Lett.* **35**, 1752 (2010).
8. X. Délen, S. Piehler, J. Didierjean, N. Aubry, A. Voss, M. Abdou Ahmed, T. Graf, F. Balembois, and P. Georges, *Opt. Lett.* **37**, 2898 (2012).
9. Y. Zaouter, I. Martial, N. Aubry, J. Didierjean, C. Hönninger, E. Mottay, F. Druon, P. Georges, and F. Balembois, *Opt. Lett.* **36**, 748 (2011).