MW-Class Femtosecond Er-Doped Tapered Fiber Amplifier

G Granger, R Dauliat, B Debord, Y Leventoux, I Tilouine, B Leconte, A Schwuchow, K Wondraczek, F Benabid, Frédéric Gérôme, et al.

To cite this version:

G Granger, R Dauliat, B Debord, Y Leventoux, I Tilouine, et al.. MW-Class Femtosecond Er-Doped Tapered Fiber Amplifier. Advanced Solid State Lasers Conference, Dec 2022, Barcelone, Spain. pp.ATu5A.3. hal-03843201

HAL Id: hal-03843201

https://hal-cnrs.archives-ouvertes.fr/hal-03843201

Submitted on 8 Nov 2022

MW-Class Femtosecond Er-Doped Tapered Fiber Amplifier

G. Granger[1], R. Dauliat[1], B. Debord[1], Y. Leventoux[1], I. Tilouine[1], B. Leconte[1], A. Schwuchow[2], K. Wondraczek[2], F. Benabid[1], F. Gérôme[1], R. Jamier[1], P. Roy[1], and S. Février[1]
[1] *Univ. Limoges XLIM UMR CNRS 7252, 123 avenue Albert Thomas, France*
[2] *Leibniz Institute of Photonic Technology, Albert-Einstein-Strasse 9, 07745 Jena, Germany*
sebastien.fevrier@unilim.fr

Abstract: We report on high-energy amplification in tapered Er-doped fiber fabricated by the REPUSIL technique. We generate near diffraction-limited 90 fs MW-class pulses at 1600 nm, without any stretcher and compressor units. © 2022 The Authors

1. Introduction

Many applications such as nonlinear microscopy [1] and high-harmonics generation in solid targets [2] require high-energy (> 100 nJ) ultrashort (< 100 fs) pulses above 1.55 µm from singlemode fiber lasers. Contrary to Yb^{3+}, the weak solubility of Er^{3+} clusters in silica matrix hinders energy scaling by direct amplification of ultrashort pulses in the telecom band. Recently, tapered fiber has emerged as an attracting amplification medium to allow high-energy pulse amplification in a singlemode fashion at 1.03 µm [3] and 1.56 µm [4]. In the tapered fiber amplifier, the signal is launched into the thin (quasi-) singlemode end. The slow, adiabatic increase of the fiber diameter along the propagation distance inhibits coupling to high-order core modes, thus preserving the near-diffraction limited feature of the seed signal. The increasing diameter of the doped core contributes to a higher amplification volume towards the end of the backward pumped amplifier, thus favoring efficient amplification, while, at the same time, keeping nonlinearities to an acceptable level. Direct amplification of femtosecond pulses is made possible by the very large mode area of the amplifying fiber, with the aim to realize a fully fusion-spliced source of MW-class ultrashort pulses. However, preforms fabricated by chemical vapor deposition techniques often exhibit radial inhomogeneities in the index profile, likely to localize light and therefore to reduce the effective mode area towards the end of the taper, thereby ruining the advantage of the taper. In this communication, we fabricate an erbium-doped tapered fiber from a preform elaborated by the powder technique REPUSIL. The very good radial homogeneity of the index profile allows us to generate 90 fs pulses with 900 kW peak power level in 100 µm core diameter fiber while preserving a near diffraction-limited beam.

2. Fabrication and characterization of the tapered fiber

We have adapted the REPUSIL technique to realize Er^{3+}-doped fibers. Two materials were prepared. The first one based on SiO_2-Al_2O_3-Er_2O_3 will constitute the core of the fiber, while the second one based on SiO_2-Al_2O_3 will be used for the cladding. Aluminum was incorporated in the core to favor solubility of Er^{3+} ions with high concentration ($\sim 1.5\times 10^{25}$ ions/m^3). The concentration in Al_2O_3 in the cladding material was optimized to achieve low index contrast of 6.5×10^{-3} between the highly-doped core material and the cladding material, leading to quasi-singlemode guidance in the thin 20 µm diameter end of the taper. The pump cladding was given a hexagonal shape for efficient pump modes' mixing.

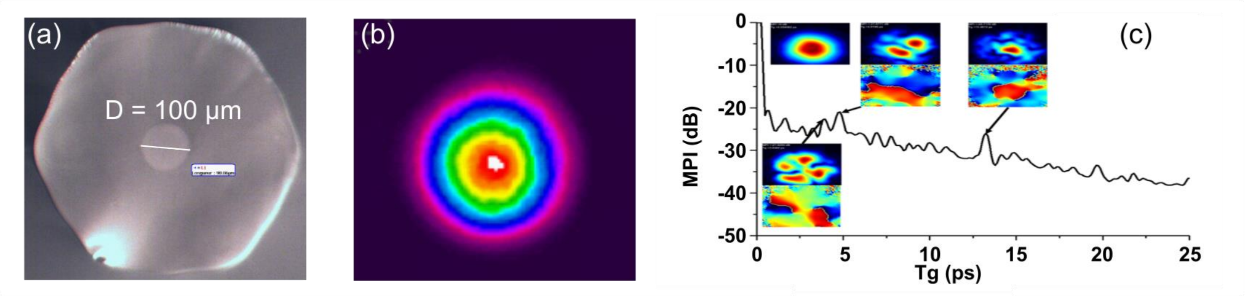

Fig. 1. (a) Optical microscope image of the thick, 100-µm core diameter, end of the taper. (b) Near-field intensity distribution measured at the output of the taper. (c) S^2 characterization of the tapered fiber at 1.9 µm.

Several tapered fibers were produced with various lengths between 5 and 15 m. The cladding diameter varies from 125 µm to 550 µm. The core diameter then increases from 20 µm to 100 µm. Fig. 1a shows an optical microscope image of the thick, 100-µm core diameter, end of the taper, while Fig. 1b shows the near-field intensity distribution measured at the output of the taper. We then evaluated the modal content of the tapered fiber by S^2 using an ASE Tm source at 1.9 µm. Multipath interference (MPI) factor is plotted in dB versus the differential group delay (Tg) in Fig. 1c. High-order modes propagate less than 1% of the power.

3. Direct amplification of ultrashort pulses

The tapered fiber was then used to amplify a sub-picosecond seed source (1560.5 nm, 11.8 MHz, 6 nm). Results are plotted in Fig. 2. Due to the ultrashort duration of the seed pulse (430 fs) amplification of the unchirped pulse soon leads to pulse break-up. A fundamental soliton is ejected from the amplified signal and is frequency-shifted by intrapulse stimulated Raman scattering in the amplifier. We observed various amounts of frequency-shift depending on the level of backward 980 nm pump power (Fig. 2a). We have selected the longest-wavelength ejected soliton by means of a long-pass filter at 1580 nm and measured an energy of 81 nJ (Fig. 2b, red curve). We have also measured the autocorrelation trace of the solitonic pulse (Fig. 2c) and deduced an FWHM duration of 90 fs, assuming sech^2-shaped pulse intensity, which indicated that the peak power of the pulse is equal to 900 kW. With this simple and more integrated architecture, we obtain performances similar to that achieved with chirped pulse amplifier and very large mode area fiber [5]. The performance of the system are adequate to three-photon microscopy of deep tissues.

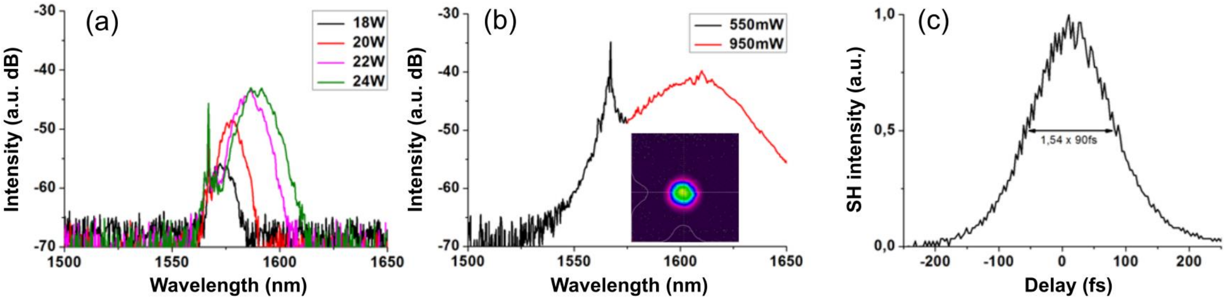

Fig. 2. (a) Spectrum measured at the thick output end of the tapered fiber for various backward pump levels. The spectrum developping at 1600 nm corresponds to ejection of a high-energy soliton. (b) Spectrum measured with a long-pass filter at 1580 nm (red curve) and without filter. The average power measured with the long-pass filter is 950 mW. The total power measured without filter is 1.5 W. (c) Autocorrelation trace of the solitonic pulse after the long-pass filter.

4. References

[1] N. Horton, K. Wang, D. Kobat, C.G. Clark, F.W. Wise, C.B. Schaffer, and C. Xu "In vivo three-photon microscopy of subcortical structures within an intact mouse brain," Nature Photon **7**, 205 (2013).

[2] S. Ghimire, A. D. DiChiara, E. Sistrunk, P. Agostini, L. F. DiMauro, and D. A. Reis, "Observation of high-order harmonic generation in a bulk crystal," Nat. Phys. **7**, 138 (2011).

[3] K. Bobkov A. Levchenko, T. Kashaykina, S. Aleshkina, M. Bubnov, D. Lipatov, A. Laptev, A. Guryanov, Y. Leventoux, G. Granger, V. Couderc, S. Février, and M. Likhachev, "Scaling of average power in sub-MW peak power Yb-doped tapered fiber picosecond pulse amplifiers," Opt. Express **29**, 1722 (2021).

[4] A.V. Andrianov, M.Yu. Koptev, E.A. Anashkina, S.V. Muravyev, A.V. Kim, D.S. Lipatov, V.V. Velmiskin, A.E. Levchenko, M.M. Bubnov, M.E. Likhachev, "Tapered erbium-doped fibre laser system delivering 10 MW of peak power," Quantum Electron. **49** 1093 (2019).

[5] H. Delahaye, C.-H. Hage, S. M. Bardet, I. Tiliouine, G. Granger, D. Gaponov, L. Lavoute, M. Jossent, S. Aleshkina, M. Bubnov, M. Salganskii, D. Lipatov, A. Guryanov, M. Likhachev, F. Louradour, and S. Février, "Generation of megawatt soliton at 1680 nm in very large mode area antiresonant fiber and application to three-photon microscopy," Journal of Optics **23**, 115504 (2021).