2-µm central wavelength ultrafast fiber CPA with compact design

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We report on our recent progress in creating a new type of compact laser that uses thulium-based fiber CPA technology to emit a central wavelength of 2 µm. This laser can produce pulse energies of >100 µJ and an average power of >15 W. It is designed to be long-lasting and is built for industrial use, making it a great fit for integration into laser machines used for materials processing. These laser parameters are ideal for working with semiconductors like silicon, allowing for tasks such as micro-welding, cutting of filaments, dicing, bonding and more.

1. Introduction

Regarding cutting-edge ultrafast-laser applications such as silicon processing, longer laser wavelengths are often preferred over 1-µm lasers due to the transparency of semiconductors in this wavelength region. Consequently, there is a strong desire for ultrafast lasers with small footprints and wavelengths around 2 µm [1,2,3]. Thulium-based fiber lasers have shown promise in efficiently producing high average- and peak-power in this wavelength region [4,5,6,7,8, 9]. Here we present recent progress in developing a Tm-based fiber laser that emits >100-µJ pulses at a 1980 nm central wavelength with <400 fs pulse duration at a repetition rate of up to 150 kHz, corresponding to >15 W average power. The system allows to adjust and control important process parameters such as pulse energy, repetition rate and pulse duration. The laser is designed to operate without requiring vacuum equipment and still avoids water-vapor absorption in an elegant way, which allows for nearly diffraction-limited beam quality and excellent pointing stability. It is engineered to be industrial-grade and optimized for long-term operation by using a packaging well-suited for integration into laser machines used for materials processing. The laser parameters are ideal for processing semiconductors like silicon, enabling tasks such as micro-welding or cutting of filaments.

2. System setup and output specifications

This laser system relays on a classical master oscillator power amplifier design. The first component is a home-build Thulium oscillator providing a broad spectrum around 2µm. The focus in the design of the oscillator was a long lifetime as well as a stable spectral output to maintain peak-power stability in the laser output as required by delicate materials processing applications. Subsequently pulses are picked down from the 25MHz oscillator repetition rate and further amplified in Tm-doped fiber pre-amplifiers while also being stretched dispersively to ~1.5ns of pulse duration.

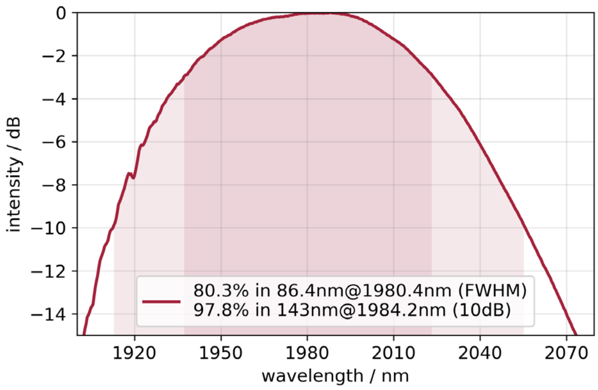

Figure 1: Oscillator spectrum

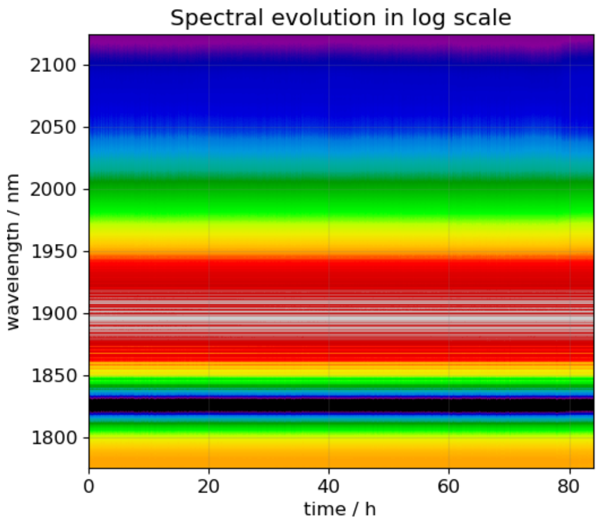

Figure 2: Long-term measurement of spectral stability.

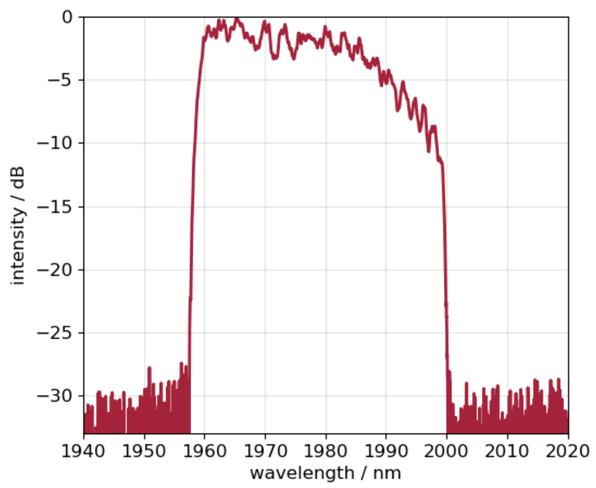

Figure 3: Spectrum behind the last pre-amplifier stage.

Tm-doped silica fibers are also at the heart of this laser system – the main amplifier. These fibers exhibit a broad amplification band spanning from 1800 to 2100 nm. Efficiently pumped by commercially available high-power diode lasers emitting around 790 nm, they achieve slope efficiencies exceeding 70% through cross-relaxation processes [10]. Before entering the pulse compressor unit, the pulses are sent trough an externally controllable AOM and an optical isolator. Both components are now available with the capability to handle high average powers without disturbing the beam profile due to thermal lensing.

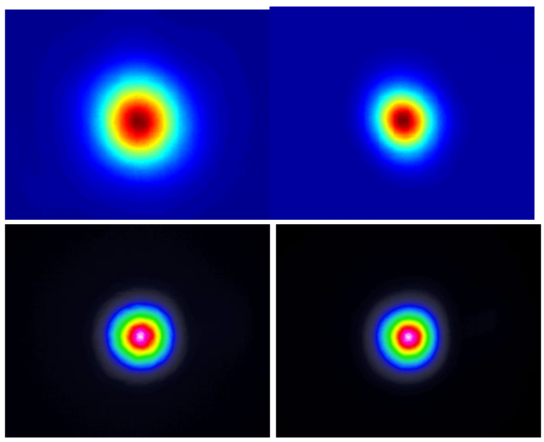

Figure 4: Top left: beam profile behind AOM at 10W. Tow right: Beam profile behind AOM at 40W. Bottom left: beam profile behind isolator at 10W. Bottom right: beam profile behind isolator at 40W:

After the compresser, the laser emits pulses with an impressive energy exceeding 100 µJ. These pulses are centered at a 1980 nm wavelength. Moreover, their pulse duration is remarkably short, clocking in at less than 400 fs. At the full energy, the laser operates at a repetition rate of up to 150 kHz, resulting in a substantial average power output of >15 W. This high repetition rate allows for efficient throughput in industrial applications, making it suitable for continuous production lines.

The device is ingeniously engineered to operate without the need for vacuum equipment. It also deftly avoids water-vapor absorption, ensuring consistent performance. The result as a nearly diffraction-limited beam quality and excellent pointing stability—essential for precision tasks.

To optimize long-term operation, the laser is housed in a packaging specifically tailored for integration into laser machines used for materials processing. Its robust design ensures reliability and durability, even in demanding industrial environments.

The laser's parameters are tailor-made for processing semiconductors, particularly silicon. Whether it's micro-welding delicate components or cutting intricate filaments, this Tm-based fiber laser system delivers exceptional results.

Table 1: List of specifications of the newly developed **active-Two-15** laser system.

	activeTWO-15
Central wavelength	approx. 1980nm
Repetition rate	single shot to 25MHz
Pulse energy	up to 100µJ (at up to 150kHz)
Average power	up to 15W
Pulse duration	<400fs - 5ps adjustable, or up to 1.5ns
Polarization	Linear
Beam quality	close to diffraction-limited, $M^2 < 1.3$
RIN slow (average power)	<1% RMS [1/ (24hours - 1Hz]
RIN fast (pulse energy)	<2% RMS [1Hz - f_{rep}/2]
Beam pointing	<10µrad RMS
Dimensions & Mass	800mm x 300mm x 400mm, <100kg
Logging	logging of all operation parameters via control software, remote monitoring and service access
Additional features	Turnkey reliability, software-controlled parameters, optical isolation, shutter, RTC6 interface, software-API

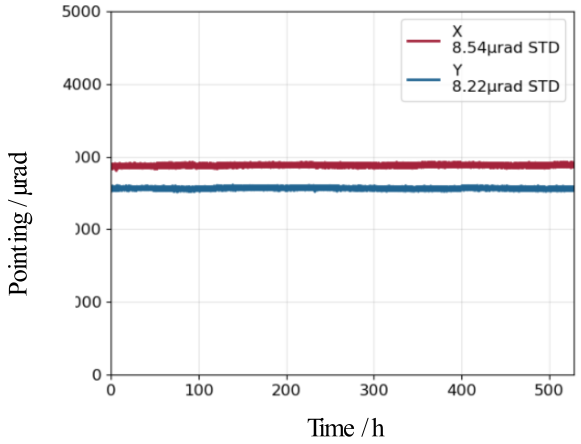

Figure 5: Long term measurement of Pointing fluctuations at full output power

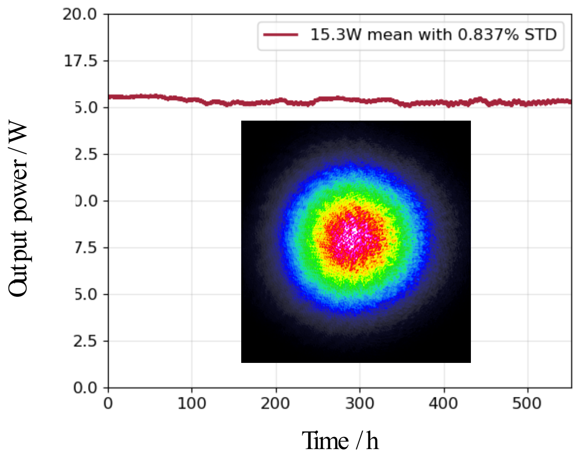

Figure 6: Long term measurement of output power. Inset shows beam profile at full output power

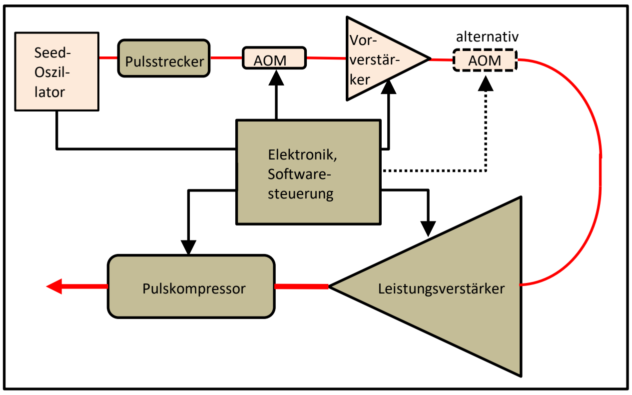

Figure 3: Schematic design of the F-CPA system

Figure 7: Rendered view of the second generation of our compact 2-µm laser featuring a volume of approx. 800 × 300 × 350mm³ only.

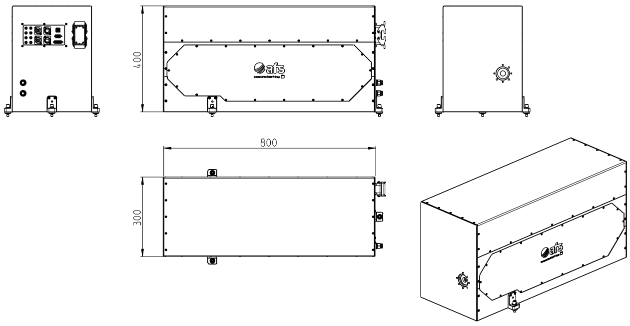

Figure 8: Technical drawing of the laser system.

3. Summary

In summary, this Tm-based fiber laser represents a significant leap in ultrafast laser technology. Its combination of high pulse energy, short duration, and industrial-grade reliability opens up exciting possibilities for precision manufacturing and scientific research.

Danksagung / Angaben zu Fördermittelgebern

Wir bedanken sich für die Unterstützung durch das PTJ & BMBF im Rahmen von RUBIN-UKPiño (03RU2U031A), sowie durch das DLR und BMBF im Rahmen des Projektes MIRROR (01DR20009B).

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Figure 9: Photograph of the laser housing.

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