110 MW Thin-Disk Oscillator

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Deep UV and XUV frequency combs can enable new applications in high precision spectroscopy and metrology. For instance, a low-lying isomer transition of thorium around 150 nm is an excellent candidate for a nuclear clock [1]. Additionally, the precise measurement of the 1s-2s transition in He^+ can facilitate important tests of quantum electrodynamics. These are just two applications to name. One promising approach to generate the required deep UV and XUV combs is high-harmonic generation driven by a femtosecond high power thin-disk laser-oscillator.

Here we present a driving thin-disk oscillator with 110 MW output peak power. Our compact, tabletop femtosecond Kerr-lens mode-locked thin-disk oscillator delivers the highest peak power among all mode-locked oscillators [2]. The system represents a diode-pumped Kerr-lens mode-locked Yb:YAG thin-disk laser (fig. 1a). The thin-disk is pumped by a 900 W, 940 nm fiber-coupled diode laser at a pump intensity of approximately 12 kW/cm^2. The resonator implements a telescope with two concave mirrors of -2500 mm radius of curvature, a 5 mm thick crystalline quartz plate placed under Brewster's angle close to the telescope's focus, and a hard aperture of 5 mm diameter (see fig. 1a). The laser is operated under low pressure to reduce the parasitic Kerr-lensing in the ambient air. 200 mbar of residual air pressure was the optimal working point to obtain an average output power of 202 W. The dispersion management is governed by two dispersively coated mirrors, introducing approximately -10000 fs^2 of total group delay dispersion (GDD) per round trip. Hence, it was possible to mode-lock the oscillator with 115 fs-long and 10 nm-wide (FWHM) bandwidth-limited pulses (fig 1b). The resonator operates at a repetition rate of 14 MHz resulting in 14.4 µJ pulse energy and, therefore 110 MW of extra-cavity peak power (0.6 GW intra-cavity). Single-pulsed operation is proven by a 1 m long (3.4 ns delay), home-built autocorrelator, and a fast photodiode (175-ps rise time, 2-GHz bandwidth) combined with a 2.5 GHz oscilloscope. The autocorrelation trace of the pulse was measured with a commercial ps-range autocorrelator (fig. 1b, inset). The beam quality factor M^2 was measured in accordance with ISO 11146 to be $M^2 = 1.1$. Additionally, the oscillator showed excellent average output power stability measured for 1 hour with 0.5 % RMS. A KLM oscillator with 102 MW peak power and 50 fs output pulse duration was recently demonstrated [3]. However, the oscillator can operate only for two minutes, making it impractical for applications.

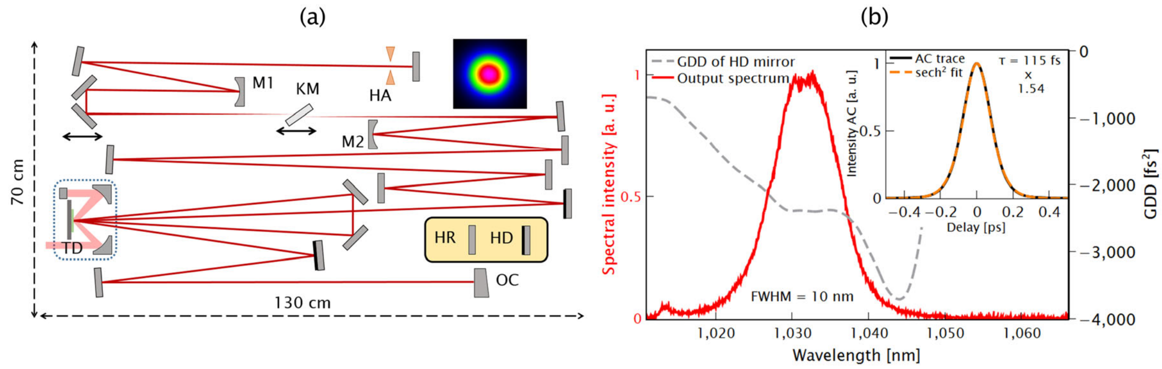

Fig. 1 (a) Schematics of the thin-disk oscillator: KM, 5 mm thick crystalline quartz; M1, M2, concave mirrors with radius of curvature -2500 mm; OC, 19 % transmission output coupler; HA, hard aperture; HR, high reflective mirrors; HD, highly-dispersive mirrors (-2400 fs^2 each); TD, thin-disk; **inset:** beam profile at 110 MW. **(b)** Spectrum of the output pulses with 110 MW peak power (red line) and GDD curve of HD mirrors (grey line), **inset:** intensity autocorrelation trace with sech^2-shaped fit.

This simple and compact high peak power thin-disk oscillator is the first step towards high repetition rate XUV frequency comb system. CEP stabilization of this oscillator in combination with highly efficient and robust spectral broadening and pulse compression in a multi-pass cell [4] are in progress. A GW-level peak power laser system delivering sub-20 fs pulses at 14 MHz rep. rate is in reach. Therefore, we believe our laser system will meet the highest demands of advanced spectroscopy in the XUV region in the near future.

References

[1] Seiferle, Benedict, et al. "Energy of the 229 Th nuclear clock transition." Nature **573**.7773: 243-246 (2019).
[2] Saraceno, Clara J., et al. "The amazing progress of high-power ultrafast thin-disk lasers." Journal of the European Optical Society-Rapid Publications **15**.1: 1-7 (2019).
[3] Fischer, Julian, et al. "Efficient 100-MW, 100-W, 50-fs-class Yb: YAG thin-disk laser oscillator." Optics Express **29**.25: 42075-42081 (2021).
[4] Weitenberg, Johannes, et al. "Nonlinear Pulse Compression to Sub-40 fs at $4.5~\mu $ J Pulse Energy by Multi-Pass-Cell Spectral Broadening." IEEE Journal of Quantum Electronics **53**.6, pp. 1-4, (2017).