27-fs, 166-MW pulses at 98 W average power from highly efficient thin-disk oscillator driven nonlinear compressor

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Ultrafast thin-disk lasers (TDLs) have consistently been at the forefront of progress in the performance of ultrafast laser sources in the last decades. Modelocked TDLs are particularly attractive for applications calling for high (MHz) repetition rates and high pulse energy, from a compact one-box oscillator. Average powers of several hundreds of watts and pulse energies approaching 100 µJ have been demonstrated [1], surpassing any other modelocked oscillator technology. However, their long pulse duration remains a problem for many applications, and pulse durations <<100 fs remain undemonstrated with average powers of >20 W. An alternative approach is to use external pulse compression. Previously, high-throughput (>60%) external pulse compressors have been demonstrated based on (1) gas-filled Kagome-type fibers where P_{peak}=105 MW (at P_{avg}=46 W) have been achieved, but with a pulse-width Δt =108 fs [2], and (2) multi-pass cells, where P_{peak}=67 MW with P_{avg}=75 W, Δt=40 fs [3], and 60 MW peak power with P_{avg}=60 W, Δt=16 fs have been demonstrated [4]. Here, we compress our 13.4 MHz, 123 W(9µJ), 534 fs (P_{peak} =15.7 MW) thin-disk oscillator down to 27 fs at 98 W average power, reaching 166 MW of peak power at 80% overall efficiency, which is to the best of our knowledge, the highest peak power amplifier-free source so far demonstrated.

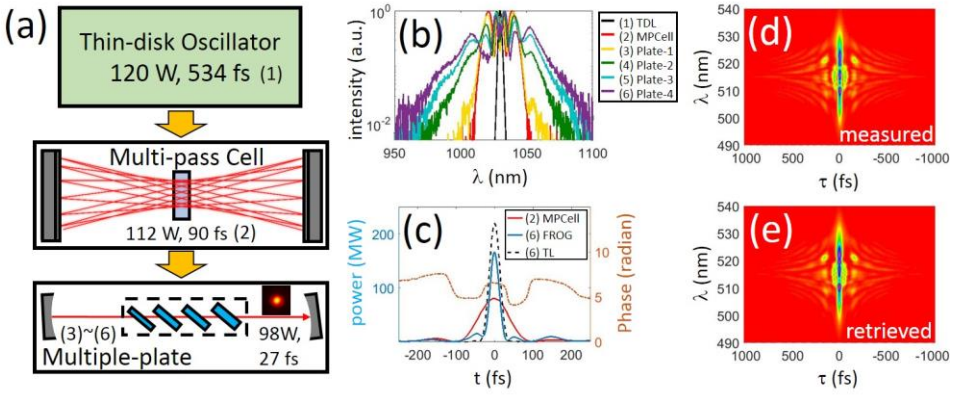

Fig. 1 (a) Experimental setup (b) Power spectra measured along the setup as labelled in (a), showing the very large spectral broadening achieved. (c) Reconstructed E-field of the pulses after the multi-pass cell (red), multiple plates (blue), and TL pulse after multiple plates (dashed). (d-e) Measured and retrieved FROG traces of the final compressed pulses.

The modelocked TDL used for driving the compression setup [5] delivers soliton-shaped 534 fs pulses, with 120 W of average power, at 13.4 MHz repetition rate. Our compressor is based on two stages: one Herriott-type multi-pass cell which reduces the pulse duration to 90 fs, and subsequent compression using the multiple-plate technique [6], with which we reach down to 27 fs [Fig. 1(a)]. Fig. 1(b) shows the power spectra measured after the TDL, multi-pass cell, and different locations along the multiple-plate stage. The temporal pulse shape [Fig. 1(c)] retrieved by SHG FROG exhibits 27 fs duration (FWHM) and 166 MW peak power, about 19× shorter and >10× higher peak power than the driving oscillator. The fidelity of pulse retrieval is endorsed by the excellent agreement between measured [Fig. 1(d)] and retrieved [Fig. 1(e)] FROG traces. To the best of our knowledge, this is the highest peak power demonstrated from a MHz-repetition rate amplifier-free source. Additionally, this is the first time that the multiple-plate technique has been applied to a 100 W-class MHz source with sub-10 µJ input pulse energy. In the near future, we will exploit the source for broadband THz generation and explore an additional multiple-plate setup to reach the few-cycle regime.

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