High-Energy, Diode-Pumped Ytterbium-Based Chirped-Pulse Amplifier

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A diode-pumped chirped-pulse amplifier system based on Yb:glass and Yb:YAG as a picosecond pump source for an ultra-high peak-power optical parametric chirped-pulse amplifier has been developed. When operating at nanosecond pulses a maximum output pulse energy of 2.9 J and a maximum average output power of 15 W have been achieved. At a small-signal gain of 10^3 in Yb:YAG the seed pulse bandwidth of 4 nm (FWHM) has been gain-narrowed to 2.5 nm, which allows the re-compression to < 1 ps.

The goal of the Petawatt Field Synthesizer (PFS) project of the Max-Planck Institute for Quantum Optics (Garching, Germany) is the construction of a unique, few-cycle light source in the petawatt range with absolute phase stabilization. Few-cycle waveform-controlled light pulses are of great interest for recent research, for example for the generation and characterization of single attosecond XUV pulses. However, further interesting applications such as plasma physics at ultrafast time scales and particle acceleration require higher pulse energies than provided by existing sources. In order to achieve these ambitious goals the PFS design is based on an OPCPA scheme for operation in the wavelength band between 800 and 1600 nm. The amplifier stages employing DKDP crystals will be pumped by ultra-short pulses with a pulse duration of at least 1 ps at a center-wavelength of 515 nm. Therefore, a high energy, diode-pumped CPA system as a powerful pump source is currently under development. A final output pulse energy of 15 J in each of four beams before frequency-doubling and a repetition rate of 10 Hz are desired.

A prototype laser was constructed for a maximum pulse energy of 1.5 J at a center wavelength of 1030 nm and a pulse duration of 2 ns (stretched pulses of a CPA system), which represents a 1/10[th] scale of the pump laser. The CPA system is based on diode-pumped Ytterbium-doped solid-state gain media such as Yb:glass and Yb:YAG. Preliminarily, the seed pulses are generated in a commercial Yb:glass oscillator with a pulse duration of 300 fs, a pulse energy of 6 nJ and a pulse bandwidth of 4 nm at a center-wavelength of 1030 nm. Later, a broadband Ti:Sa oscillator serves as common for both the OPCPA and the pump laser system, in order to synchronize the pump and signal pulses. A photonic-crystal fiber is then used to shift the center-wavelength from 790 nm (Ti:Sa front-end) to 1030 nm for the seed-pulse generation of the CPA system.

The first amplifier of the CPA system employing a low-gain broadband laser material (Yb:glass) is designed as a regenerative amplifier. Up to now, chirped pulse amplification to the 500 mJ-level has been demonstrated using the regenerative amplifier and an Yb:YAG booster. At a small-signal gain of 10^3 in Yb:YAG the initial pulse bandwidth of 4 nm (FWHM) has been gain-narrowed to 2.5 nm (FWHM), which allows the re-compression to 630 fs.

The feasibility of high-energy pulse amplification employing Yb:YAG has been tested with nanosecond pulses which have been generated in a Q-switched oscillator. With a multi-pass Yb:YAG amplifier which has been seeded by sub-10-nanosecond pulses an output pulse energy of 2.9 J has been achieved. Taking into account the scaling of the damage threshold fluence with the pulse duration, this result translates to more than 1.5 J at 2 ns. In quasi-cw-mode a peak output power of 7.6 kW and a tuning range of 5 nm have been obtained. The foot-print-size of the multi-pass amplifier is 0.8 m×1.1 m, which illustrates the degree of system compactness. To our knowledge the amplification of nanosecond pulses as well as chirped-pulses with an output pulse energy of more than 50 mJ using Yb:YAG has not been demonstrated elsewhere. Future work is now in progress to accommodate and operate the presented CPA system with expected pulse duration of 1 ps and a peak power in excess of 1 TW after re-compression. Subsequently, the data and experience gathered will allow the construction of the full-scale (4×15 J) pump laser for the PFS.

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