Monolithic-YDFA Based CEP-Stable OPA with Broad Tunability

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Abstract *We demonstrate an efficient broadband difference-frequency converter emitting carrier-envelope-offset-free seed pulses for chirped-pulse parametric amplification and pumped by a monolithic femtosecond Yb-doped fiber amplifier that simultaneously provides passive optical synchronization for an OPCPA pump pulse source.*

The rapidly rising technology of optical parametric chirped pulse amplification (OPCPA) [1] offers unique advantages, among others, such as high broadband gain, including frequency ranges inaccessible to direct laser amplification, and efficient energy conversion using narrowband picosecond pump pulses. The perennial problems of OPCPA, significantly slowing down its development into a mainstream amplifier technology, are pump–seed pulse synchronization and generation of a frequency-detuned compressible broadband seed pulse for the optical parametric amplifier (OPA). Demonstrated approaches to the synchronization of pump pulse sources include active locking of two master oscillators [2], nonlinear frequency shifting in a photonics crystal fiber (PCF) [3] and simultaneous seeding of the pump pulse laser and the OPA from an ultrabroadband Ti:sapphire oscillator [4]. IR OPCPA systems with passive carrier envelope phase (CEP) stabilization were realized using a broadband difference-frequency-generation (DFG) seed produced from a spectrally broadened output of full-fledged Ti:sapphire [5, 6] and Yb [7] CPA systems. In this letter we demonstrate a drastically simplified seeding/synchronization approach based on an environmentally stable µJ-energy 200-fs 100-kHz Yb-doped fiber amplifier (YDFA) that generates a white light continuum in bulk sapphire, pumps a DFG OPA and provides an optical seed compatible with most Nd and Yb ~1-µm pump pulse amplifiers.

The experimental layout, consisting of the YDFA, grism pulse compressor, and a Type II collinear CEP

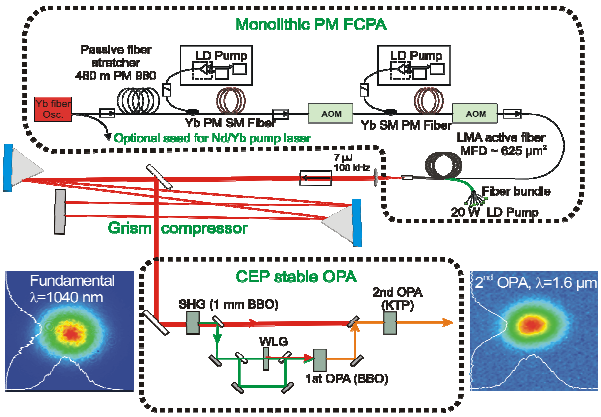

Fig. 1 Experimental layout and far-field modes of the fundamental and CEP-stable outputs.

stable OPA is shown in Fig. 1. The front end of the system is an all polarization maintaining (PM) monolithic fiber chirped pulse amplifier (MFCPA). It consists of a fiber oscillator, two PM single mode fiber (SMF) preamplifiers and a PM large mode area (LMA) fiber amplifier. The oscillator delivers 150 fs pulses at a repetition rate of 76 MHz. Before being amplified to 1.6 nJ at the full repetition rate in the first preamplifier, the pulses are stretched to ~350 ps in 480 m of PM SMF. In the second preamplifier, after reduction of the repetition rate to 100 kHz by using an acousto-optic modulator (AOM), the pulses are further amplified to 50 nJ. A second AOM is used after the second preamplifier for suppression of amplified spontaneous

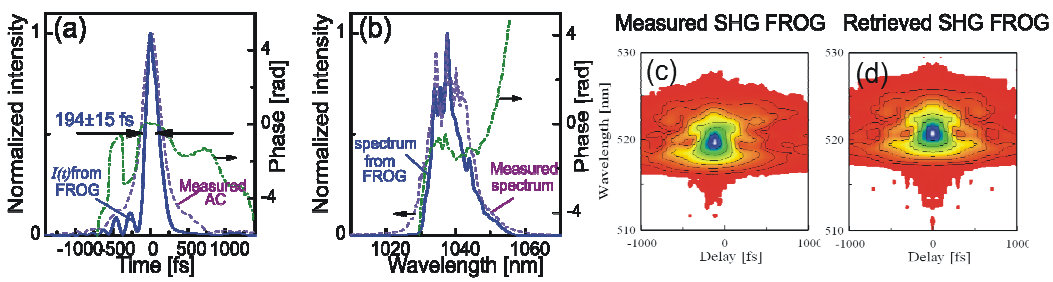

Fig. 2 Fundamental pulse profile retrieved from FROG and amplified spectra before and after grism compressor.

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emission. Both preamplifier stages use highly Yb-doped PM-SMF as active medium. Pre-amplified pulses are launched into the final LMA fiber amplifier via a mode field adaptor. The last amplifier is based on 3 m of Yb-doped LMA double clad fiber (Nufern PASA-YDF-30/250-7x1, 30 µm core, ~625 µm^2 mode field diameter). It is fully monolithic and is pumped by 7 laser diodes capable of delivering up to 6 W pump power each. After the final stage, >9 µJ pulses are generated at total pump power of ~20 W. Generated pulses are compressed to 200 fs in a negative dispersion compressor based on a pair of grisms designed from F2 glass prisms and 1480 lines/mm reflection gratings. Compressed pulses were characterized with SHG FROG (the results are presented in Fig. 2). Far field beam profile of the MFCPA output is given in the left inset of Fig. 1.

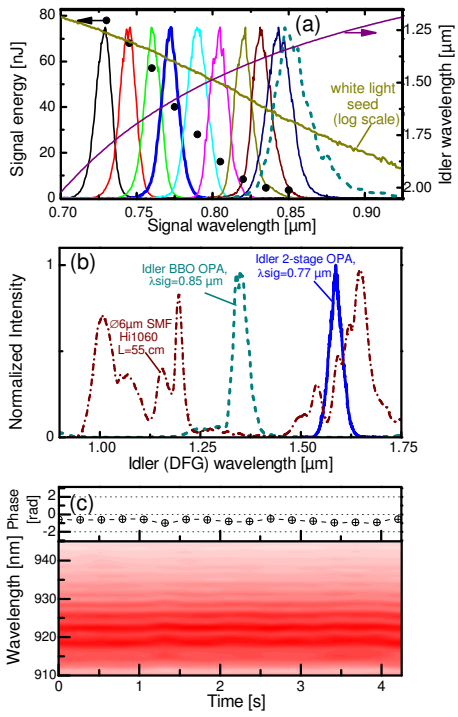

Fig. 3 OPA performance. (a) Tunability of 1st stage OPA (4-mm Type II BBO seeded with 520-nm-generated white light from a 5-mm-thick sapphire plate. (b) CEP-stable idler spectra at selected wavelengths and results of spectral broadening of 1.6-µm pulse in negative-dispersion PCFs (zero dispersion point 750 nm) and SMF (Hi1060). (c) Measured phase stability with an f-to-2f interferometer after broadening the spectrum in a 55-cm SMF.

Generation of temporally compressible white light in bulk media requires high-fidelity ≤200 fs pulses to minimize the impact of delayed (Raman) nonlinearities. Due to a large amount of higher-order linear and nonlinear dispersion, such pulses are difficult to obtain from YDFA, prompting the use of solid-state oscillators [8] or highly nonlinear fibers [9] for OPA seeding. Successful white-light seeding of an YDFA-driven OPA was demonstrated in [10], where the fidelity of the 1040-nm pulse was ensured by the use of free-space stretcher/compressor optics. In a bid for a robust turn-key alignment-free design, our YDFA system consists of a spliced chain of PM fibers and pigtailed AOM. This architecture allows us to completely dispense with free-space signal and pump coupling. Generation of a tunable CEP-stable IR seed pulse follows the recipe in [7], using DFG in a 4-mm-long Type II BBO between a 1.2-µJ 520-nm pulse and the red wing of the white-light continuum pulse generated with a 0.9-µJ 520-nm pulse, and resulting in signal and idler pulse energies of up to 80 and 40 nJ, respectively. The IR pulse is then optionally ×4 amplified in a 2nd OPA (6 mm Type II KTP) using residual 1040-nm fundamental pump light. The tuning properties of the first OPA stage are summarized in Fig. 3a. The CEP stability is demonstrated with an f-to-2f interferometer after spectrally broadening the first OPA output pulses in a 40-cm SMF (see Fig 3b and c). Phase deviations are caused by instabilities of the OPA-arms and the two arms of the f-to-2f interferometer.

In conclusion, we present a robust directly diode-pumped OPCPA front-end that provides straightforward optical synchronization with Nd/Yb pump lasers and emits tens of nJ of CEP-stable and pulse-pedestal-free DFG light, which is sufficient for overriding the superfluorescence background in multi-mJ OPCPA. The presented air-cooled system uses only ~20 W of optical diode power – significantly less than a CW-green-laser-pumped Ti:sapphire oscillator capable of delivering several nJ at 800 nm and merely several pJ in an IR DFG pulse.

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