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Non-linear amplification to 200 W of an electro-optic frequency comb with GHz tunable repetition rates

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Abstract. We present a monolithic Yb-doped fiber laser system delivering 200 W average power of femtosecond pulses at tunable GHz repetition rates. The system is based on a GHz electro-optic (EO) frequency comb operating in the nonlinear regime. The EO comb pulses at 1 µm wavelength are initially pre-compressed to sub-2 ps, amplified to 2.5 W, and finally boosted to 200 W in a newly designed large-mode-area, Yb-doped photonic crystal fiber. Continuously tunable across 1-18 GHz, the picosecond pulses experience nonlinear propagation in the booster amplifier, leading to output pulses compressible down to several hundreds of femtoseconds. To push our system deeper into the nonlinear amplification regime, the pulse repetition rate is further reduced to 2 GHz, enabling significant spectral broadening at 200 W. Characterization reveals sub-200 fs duration after compression. The present EO-comb seeded nonlinear amplification system opens a new route to the development of high-power, tunable GHz-repetition-rate, femtosecond fiber lasers.

1 Introduction

Fiber lasers delivering ultrashort pulses are desirable for various applications in both industry and scientific research. Compared to solid-state type, fiber lasers feature high-beam quality, easier thermal management, robust all-fiber integration and so on. In recent years, ultrafast fiber lasers with multiple GHz repetition rate are becoming more and more attractive, since they deliver pulses two orders of magnitude faster than conventional mode-locked lasers and have much larger line spacing between two longitudinal modes, which could benefit applications such as high-efficiency material processing [1], comb resolved spectroscopy [2] for instance.

In this contribution, we report on high-power nonlinear amplification of an ultrafast EO comb up to 200 W in an all-fiber configuration. The repetition rate of the system can be freely adjusted between 1 GHz up to 18 GHz simply by tuning the synthesizer frequency and/or the division factor of the pulse picking module. The pulses from the EO comb are first spectrally shaped and compressed down to sub-2 ps near the Fourier-transform (FT) limit. They are then amplified to 2.5 W in conventional amplifiers and finally boosted to 200 W in a newly designed Yb-doped large-mode-area (LMA) photonic crystal fiber (PCF). Gain accompanied by self-phase modulation (SPM) in the last amplifier leads to output pulses compressible to hundreds of femtoseconds. Frequency division down to 2 GHz is further implemented to increase the pulse peak power, pushing the all-fiber amplification process deeper into nonlinear regime, and allowing to generate pulses compressible down to sub-200 fs.

2 Experimental setup

Fig. 1 depicts the experimental setup for the EO comb seeded ultrafast fiber amplifier system. The EO comb seed consists of a single-frequency diode laser at 1030 nm, two EO phase modulator and one Mach-Zehnder modulator. All three modulators are driven by GHz radio-frequency signals derived from a common synthesizer. The seed pulses propagate through several modules including frequency division, pulse shaping and pre-

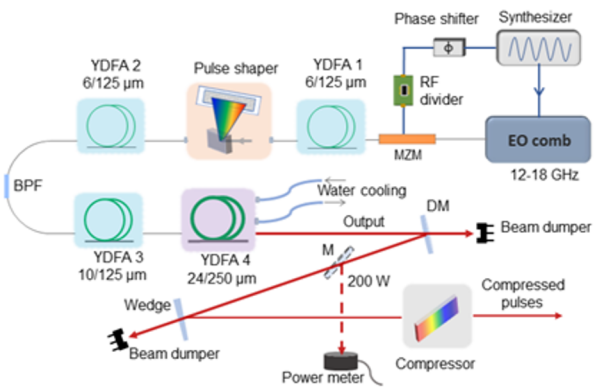

Fig. 1. Experimental setup for the laser system. BPF: band-pass filter; DM: dichroic mirror; MZM: Mach-Zehnder modulator.

compression, as well as four stages of Yb-doped fiber amplifiers (YDFAs). While the first three YDFAs are made of commercial gain fibers, the last one involves a newly developed Yb-doped PCF. The PCF has a hexagonal core with a mode field diameter of ~24 μm [3]. Different from air-hole PCFs, the micro-structure of this PCF is formed and filled with silica. With 357 W pump

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power at 976 nm, we were able to generate 200 W output pulses at 1030 nm from the last amplification stage.

2 Results and discussion

We characterized each stage of the system and performed relevant measurements. The EO comb pulses are shaped by a pulse shaper before high-power

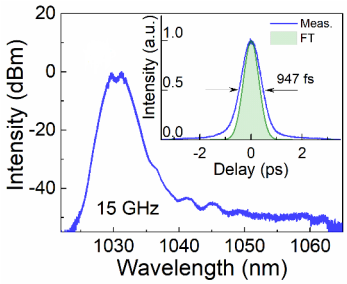

Fig. 2. Measured spectrum of the 200 W EO comb at 15 GHz repetition rate and the corresponding autocorrelation trace of the compressed pulses

amplification, having an autocorrelation (AC) duration of 2.2 ps at 15 GHz. The corresponding spectrum has a Gaussian profile with a width of ~0.9 nm. Fig. 2 shows the measured output spectrum at 200 W. At 15 GHz, the spectrum is slightly broadened by self-phase modulation (SPM) to a 3 dB bandwidth of 2.7 nm. The output pulses are characterized by using a compressor and an autocorrelator with ~4% of the full power extracted by a wedge, showing an AC duration of 947 fs, close to the AC duration of Fourier-transform limited pulses. Similar results are obtained for repetition rates ranging from 12 GHz up to 18 GHz.

With the repetition rate reduced to 2 GHz by the frequency division module, the amplifier system enters a deeper nonlinear regime. Here, the pre-compressed input pulses with moderate peak power accumulate nonlinear phase in the amplifiers. The latter is responsible for enlarging the spectrum by SPM instead of undergoing spectral gain narrowing as expected in linear amplification. Consequently, this process allows to generate pulses compressible down to hundreds of femtosecond level as depicted in Fig. 3 where a train (500 ps delay between pulses) of 270 fs AC duration pulses have been recorded.

3 Conclusion

In conclusion, we have demonstrated a new type of high-power, ultrafast fiber amplifier system seeded by an EO comb, delivering 200 W GHz repetition rate pulses compressible down to hundreds of femtoseconds. More details about the system such as power scaling, beam profile, spectra and AC traces at different repetition rates will be presented.

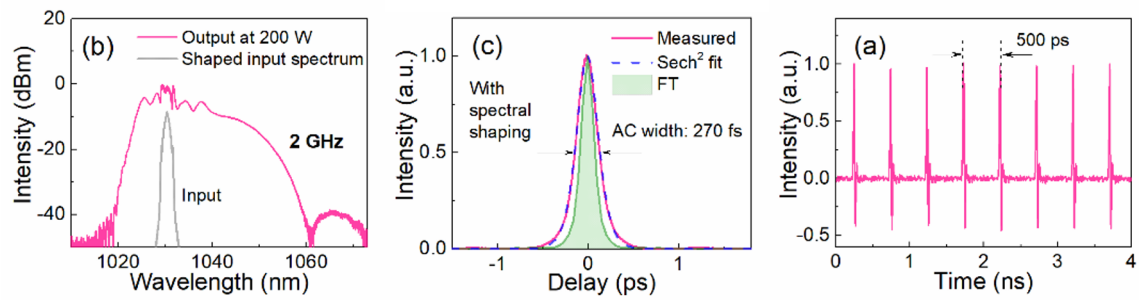

Fig. 3. 200 W EO comb at 2 GHz repetition rate. Measured broadened spectrum (left). Autocorrelation trace (middle). Temporal pulse train (right).

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