Multi-mJ few cycle mid-infrared OPCPA system

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Abstract

Mid-infrared ultrafast lasers provide access to molecular vibrational and rotational modes, playing a major role in modern science. One of the most well-established methods of producing high-energy mid-infrared sources is Optical Parametric Chirped Pulse Amplification (OPCPA). Such sources have paved the way for cutting-edge applications such as harmonic generation and attosecond pulse generation.

In this work, we describe the current stage of a high-energy, ultrafast mid-infrared laser, designed for 5 mJ, 85 fs, and 3 μm operation. This system is based on multi-stage parametric amplification pumped by a 100 kHz, 1030 nm Yb-based system. This driver seeds a commercial OPCPA generating CEP-stable 65 μJ, 40 fs pulses at 3 μm. The output will be amplified up to 5 mJ, 85 fs, 10 Hz in a custom OPCPA consisting of three parametric amplifiers pumped by a home-built Chirped Pulse Amplification (CPA) system, seeded by the Yb driver.

We discuss the architecture of this source and its potential for driving next-generation mid-infrared applications such as high harmonic generation, attosecond science, and particle acceleration.

High energy, few cycle 3 μm amplifier design

The main driver of this system is a high repetition rate (100 kHz), high power (100 W) diode-pumped Innoslab Yb-based source. It is then split (25/75) between a home-built CPA system [2] and a commercial OPCPA [3].

-CPA
This stage amplifies the 0.25 mJ of the driver up to 75 mJ with a pulse duration of 6 ps after compression.

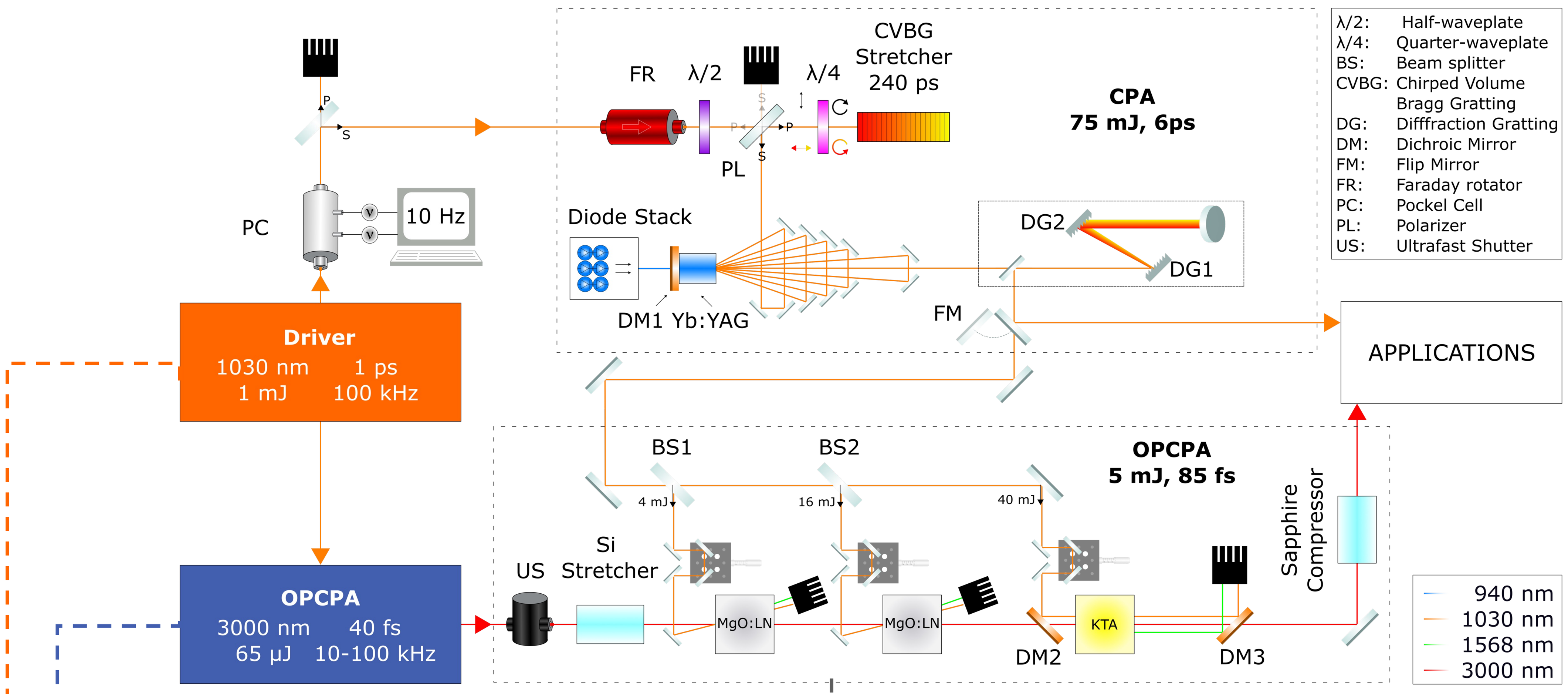
Pulses are first stretched to 240 ps; then amplified by multiple passes in a diode-pumped Yb:YAG crystal; and finally compressed with gratings.

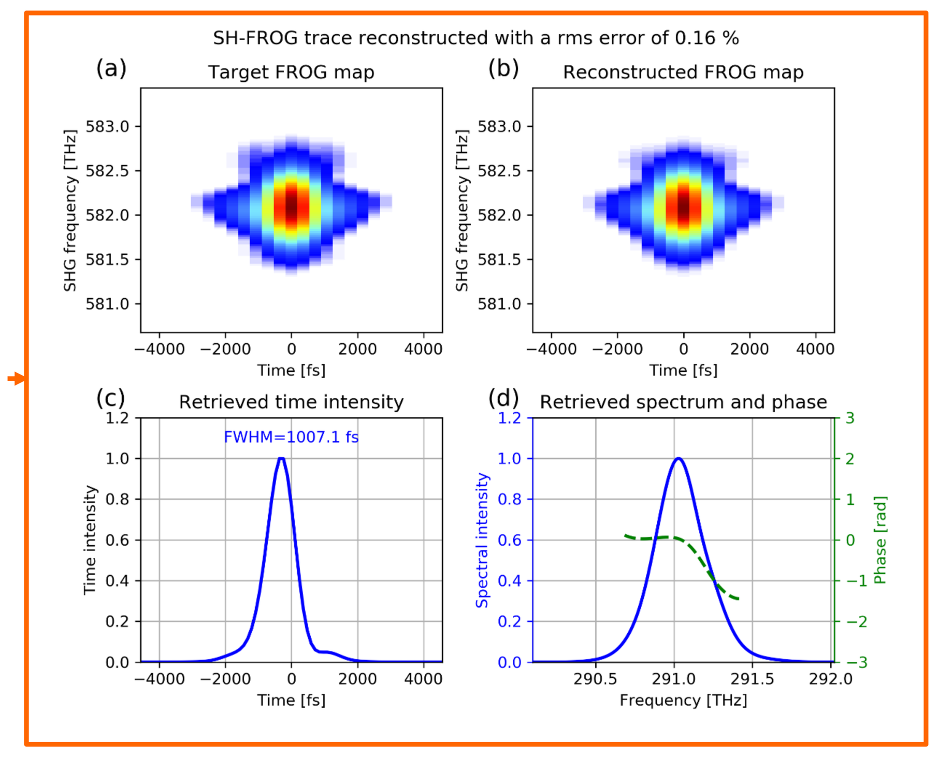
Due to damage limitations, the repetition rate is lowered with a pulse-picker synchronized with the driver.

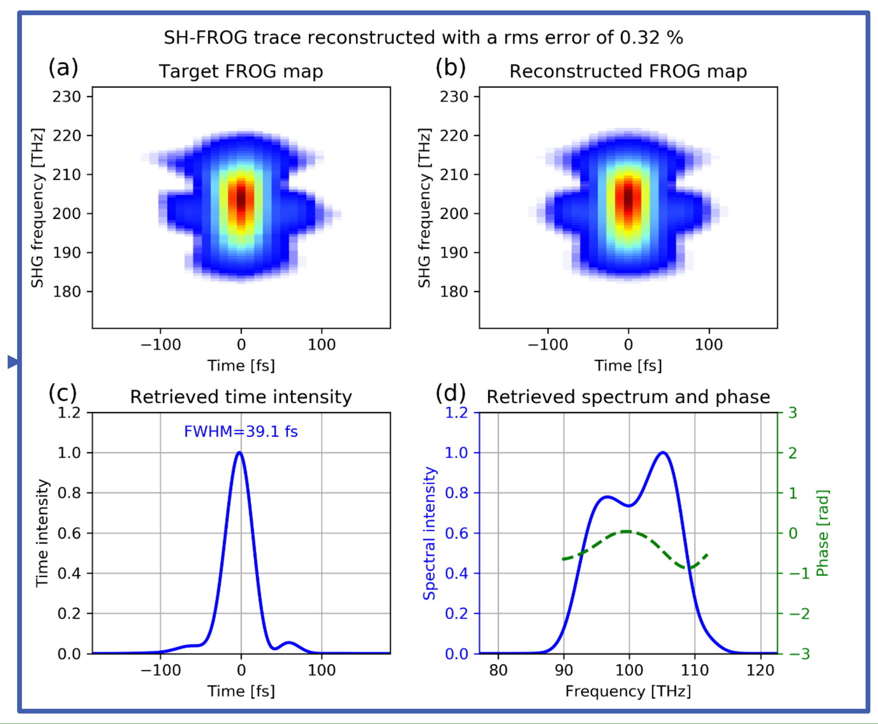
-OPCPA
This stage takes 0.75 mJ of the driver and down-converts it to 3 μm, delivering 65 μJ and 40 fs.

The pulses will be stretched to 2 ps and then amplified with three OPA stages, which were numerically validated [3]. The first two use a non-collinear OPA geometry providing broadband gain, while the latter provides higher gain by using a collinear geometry. Finally, the pulses will be compressed down to 85 fs.

The repetition rate will be lowered to match the CPA stage, and delay stages are used to ensure temporal synchronization. The signal to pump duration ratio (2 ps/ 6 ps= 1/3) is purposely selected to avoid gain-band narrowing.



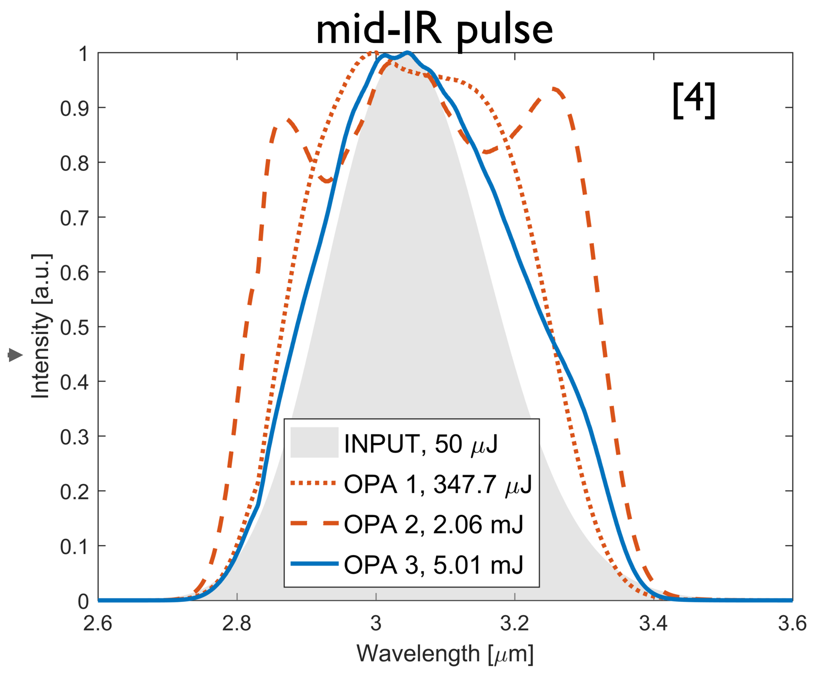




OPA parameters

Stage	OPA1	OPA2	OPA3
Crystal	MgO:LN		KTA
Length (mm)	3.6	2	1.4
θ	46.7°		41.6°
α	5.1°		–
Output (mJ)	0.35	2.06	5.01
FTL (fs)	53	47	52

Simulated spectrum of amplified mid-IR pulse



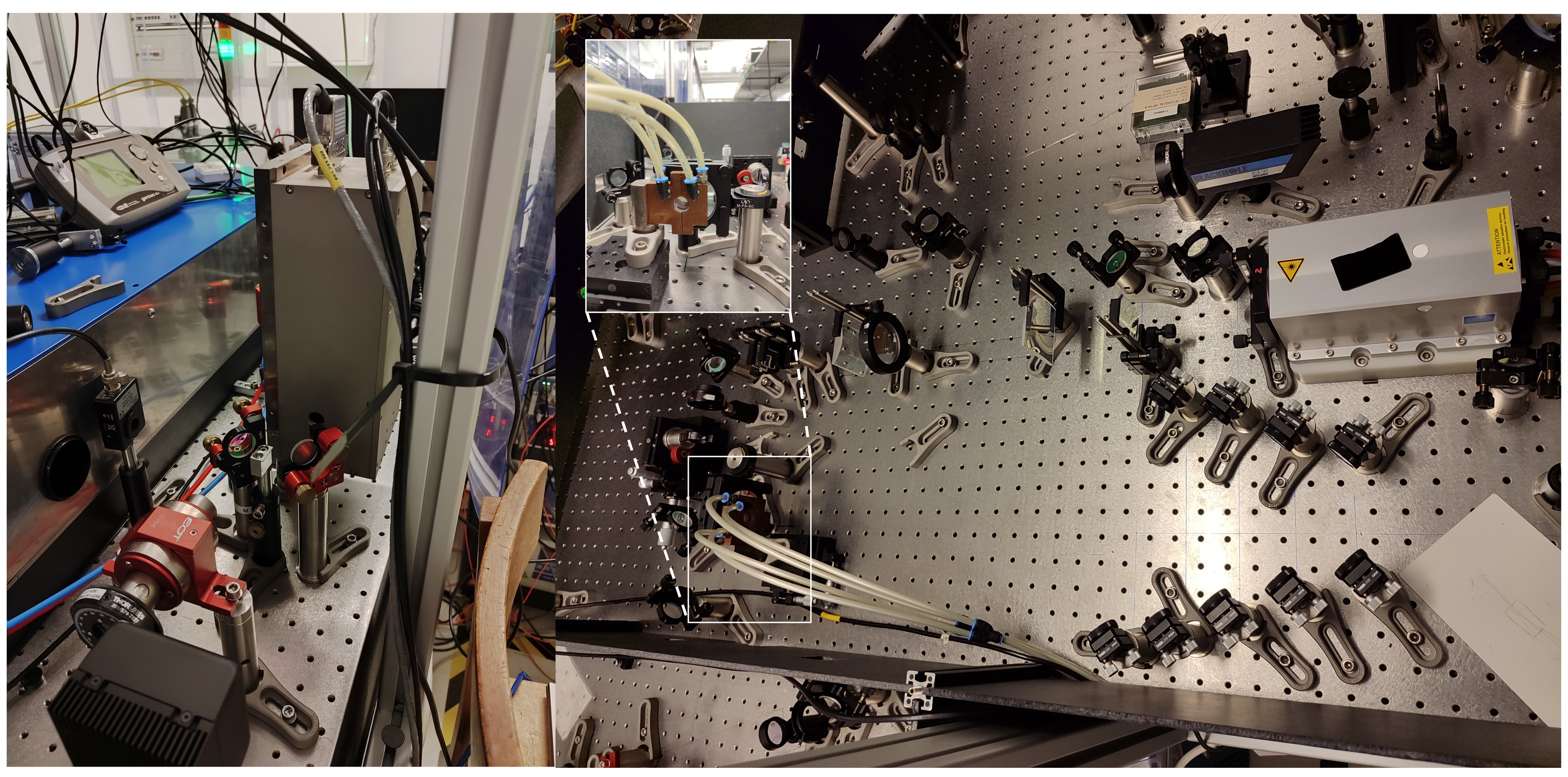
Current status and work plan

The laser front-end is fully operational and ready for pulse selection.

This is achieved with a pulse-picker capable of supporting 25 W in average power (0.25 mJ, 100 kHz), synchronized with the driver's trigger with a tunable repetition rate and delay. Several other applications requiring a lower repetition rate and fine energy/shot control are now also seeded with this front-end.

Pulse stretching by the CVBG was verified in a home-built autocorrelator/FROG system.

Next steps:
- Seeding the CPA laser with 10 Hz pulse train.
- Characterisation of pulse amplification and compression.
- Assembly of OPCPA stages and characterization.



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