Optical parametric chirped pulse amplifier at 1600 nm with all-optical synchronization

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Abstract: We demonstrate the amplification of 1.6 µm pulses by a KTA optical parametric chirped-pulse amplifier based on an all-optical synchronization scheme as a scalable approach to generation of high power tunable mid infrared.

With ultrafast mid-infrared (MIR – 2 µm to 20 µm) spectroscopy it is possible to probe structural dynamics of molecules and with sufficient peak power drive strong field control of molecular processes to sample far from equilibrium coordinates. However, generating the high peak power, ultrashort, IR pulses needed in those experiments is challenging as there are few suitable laser mediums and the wavelengths needed cover a broad range. The current MIR systems rely on optical parametric amplifiers (OPAs) pumped by Ti:Sapphire amplified systems [1].Because the pump wavelength is relatively short, the MIR radiation is generated after two cascaded nonlinear processes which greatly limit the efficiency and the scalability of such a scheme. This downfall could be avoided by using a longer pump wavelength.

Erbium-doped fiber lasers (EDFLs) operating at 1.56 µm can generate 100-fs pulses and would be a great candidate for MIR OPA pump laser. However, it is difficult using standard approaches to amplify EDFLs to the watt level while keeping the bandwidth needed for 100-fs pulses. A way around this problem is to use optical parametric chirped-pulse amplifiers (OPCPAs) which exhibit high gain for large bandwidth. Furthermore, since the gain is generated via a nonlinear parametric process, it is possible to tune the amplifier to the desired wavelength.

We report on the performance of an OPCPA based on an all-optical synchronization scheme to couple well established high power amplifiers in the 1 µm range to extend the power class of mid IR systems. OPCPAs require tight synchronization between the pump and the seed lasers. This can be achieved using electronic phase-lock loops controlling the cavity length of the oscillator. Although those systems can be quite good, they are not unconditionally stable and require continuous monitoring and adjustment. All-optical synchronization schemes can be, in principle, made robust enough to facilitate everyday use. In our OPCPA, an all optical synchronization method is achieved by shifting the wavelength of part of the EDFL output to seed the amplifier.
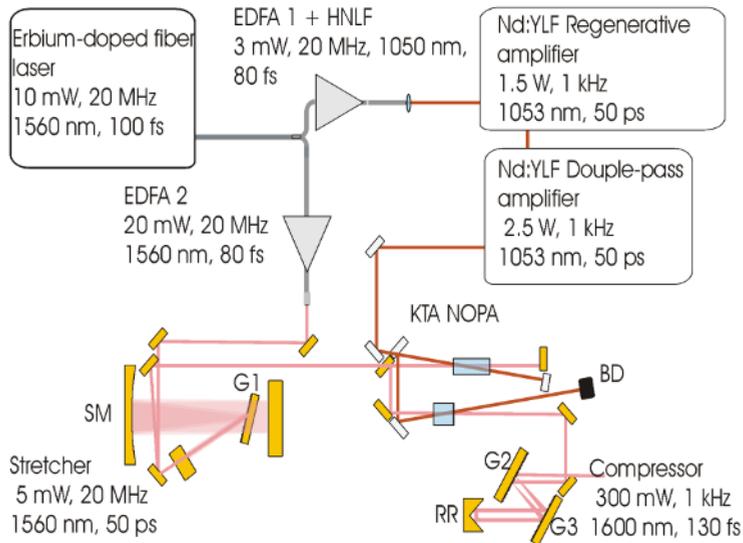
Fig. 1. OPCPA layout. EDFA, Erbium-doped fiber amplifier; HNLF, highly-nonlinear fiber; NOPA, noncollinear optical parametric amplifier; G1, G2, G3, gold gratings; SM, spherical mirror; RR, retroreflector; BD, beam dump.

Figure 1 illustrates the layout of the OPCPA. The oscillator is a commercial EDFL with an output power of 10 mW at 1.56 μm for 100-fs pulses at a 20-MHz repetition rate. The oscillator seeds two independent home-built Erbium-doped fiber amplifiers (EDFAs). The amplifiers consist of a 3-m long Erbium-doped fiber pumped by two 300-mW 980-nm laser diodes. The Erbium-doped fiber has 4-micron core and absorption of 80 dB per metre at 1.56 μm. Each amplifier boosts the power to 40 mW and the pulse duration shortens to 80 fs because of the negative dispersion in the fiber and self-phase modulation. The output of one of the amplifiers is sent to free-space grating stretcher where the pulses are stretched to 50 ps. The output of the stretcher is sent to the OPCPA for amplification

The second amplifier is coupled to a highly-nonlinear fiber (HNLF) to generate 1050 nm light. The HNLF consists of a pre-compensating fiber spliced to a small-core germano-silica fiber [2]. By tweaking the fiber dispersion it is possible to maximise the light generated at 1050 nm [2]. In this case, the output power for a 50-nm bandwidth center at 1050 nm is 3 mW.

The 1050-nm output of the HNLF is sent to a homemade Nd:YLF regenerative amplifier. To avoid damaging the optics two etalons (1 mm and 0.75 mm) were introduced into the amplifier cavity to stretch the amplified pulses from 15 ps to 50 ps. The amplifier output power is 1.5 W at 1 kHz with a shot-to-shot fluctuation of 0.5 %. A double-pass Nd:YLF brings the final output power to 2.5 W.

The 1.56-μm pulses from the fiber laser are amplified in a two-stage noncollinear optical parametric amplifier (NOPA). In order to optimize the amplifier bandwidth, the two beams, pump and seed meet in the crystals at an internal noncollinear angle of 3.2 degrees [3]. The first NOPA stage consists of a 15-mm long crystal and is set in a double-pass geometry whereas for the second stage the crystal is shorter (10 mm) and only one pass is needed. The energy of the pulses before the amplifier is only 140 pJ. After the first pass, it reaches 1.4 μJ for a gain of 10^4. The second pass boosts the energy to 320 μJ and the pass in the second stage brings it to 520 μJ. Saturation explains the gains of 228 and 1.62 for the last two passes. The shot-to-shot fluctuation after the third pass is 1%. When unseeded, the super-fluorescence power is 5 mW, which is less than 1% of the seeded output power.

The stretched pulses are recompressed by a grating compressor. A BBO second-harmonic-generation frequency-resolved optical gating (SHG-FROG) is used to characterize the pulses. Figure

2(a) shows both the retrieved and the measured spectra. There is a good agreement between the two spectrums; both have similar bandwidth and exhibit modulation. The retrieved temporal profile of the pulse is showed in figure 2(b). From it the pulse duration is estimated to be 130 fs.
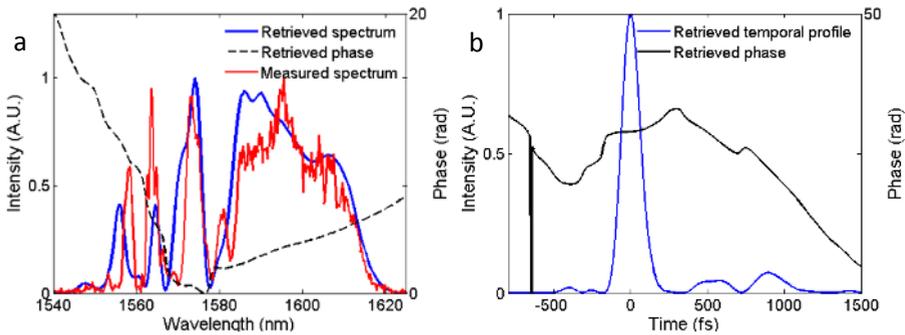

Fig. 2. Showing the FROG results. (a) Retrieved spectrum and phase as well as the measured spectrum.(b) Retrieved pulse shape and phase.

The timing jitter was characterized at the first crystal position using sum-frequency generation (SFG) between the pump and the seed. The timing jitter is obtained by measuring the noise on the resulting 619-nm signal. The delay between the two beams is set to be at the half-maximum of the SFG signal where the signal strength is almost linear with displacement. By taking a full cross-correlation trace it is possible to convert amplitude noise to timing jitter. The SFG noise was 1.3% which translates to a maximum timing jitter of 380 fs. This is less than 1% of the pump pulse duration.

In summary, we described a KTA OPCPA based on an all-optical synchronization scheme. The compressed output power is 300 mW for 140-fs pulses at 1 kHz with shot-to-shot fluctuation around 1%. The synchronization keeps the timing jitter to 380fs. Shorter and cleaner pulses at a longer wavelength could be produced by adding a HNLF in the seed arm. The output power is mainly limited by the power of the pump of our present system. 1-μm pump lasers now reach the 100 W level such that this optical synchronization approach provides a robust solution to attain tunable mid IR in the 10 W range as an alternative to IR FELs in this average power class..

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