Passively CEP-stable front end for frequency synthesis

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Abstract: We demonstrate a passive CEP-stable two-octave wide front-end for a high-energy optical waveform synthesizer driven by slightly sub-picosecond pump pulses from a multi-mJ regenerative amplifier.

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1. Introduction

Strong field physics requires high-energy pulses with multi-octave bandwidth to trigger efficiently sub-cycle events, most prominently isolated attosecond pulse generation. A laser driver based on frequency synthesis is a well-suited source for its flexibility in spectral shaping and scalability in spectrum and energy, as demonstrated in [1-3].

Energy scaling by amplification through optical parametric amplifiers (OPA) requires a broadband seed source and a high-energy pump. Due to the direct electric field driven processes, carrier envelope phase (CEP) stability of the seed is required. The front-end has thus to be CEP stable before the amplification with follow-on OPA´s, typically at kHz repetition rate. The main methods to achieve CEP stability are either active stabilization [2], requiring several feedback loops increasing system complexity or passive CEP stabilization [3,4]. The latter scheme is based on white-light generation amplified by 2 OPA stages, and difference frequency generation by using the idler of one of the OPA´s.

The particular concept realized here uses slightly sub-picosecond pulses [5] from a multi-mJ regenerative amplifier, which greatly simplifies timing stabilization of seed and pump pulses in follow on OPAs or OPCPAs. We demonstrate CEP stability and two-octave coverage of the white light continuum generated by long-driver pulses.

2. Experimental setup

The experimental setup, shown in Fig. 1, is driven by a high-energy Yb:KYW regenerative-amplifier, delivering 700 fs pulses after the first amplification stage [5]. The main part of this output will later be used to seed high energy amplifiers to pump the follow-on OPCPA stages, and a minor portion, here 0.65 mJ, was used in the front-end. First, white-light was generated in a 10-mm long YAG crystal X1, then a spectral bandwidth of 200 nm centered at 2.18 µm was amplified to 3 µJ through two nearly degenerate OPA stages in BBO (X2 and X3). The passively CEP stable idler of the second OPA centered at 1.96 µm was then used to generate white-light super-continuum in a 3 mm YAG crystal (X4). CEP stability was confirmed by interfering the fundamental spectrum at 960 nm with the SHG of the remaining idler in an f-2f setup.

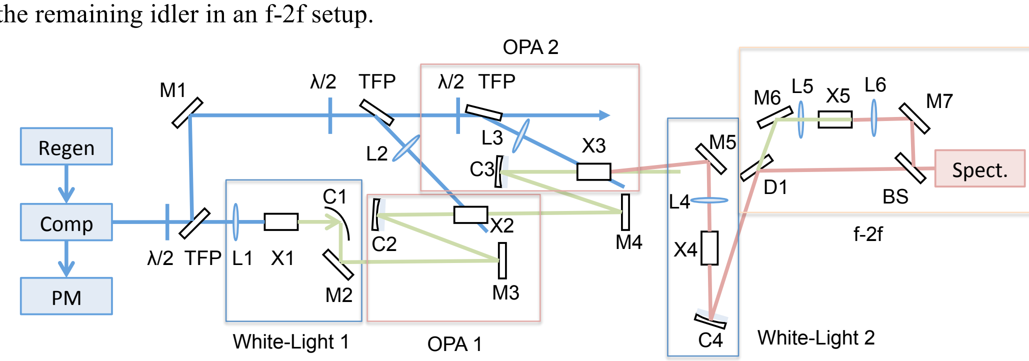

Fig. 1: Layout of the setup consisting two white-light super-continuum, OPA and f-2f setups. λ/2 stands for half-waveplate, TFP for thin-film polarizer, M1 to M7 flat mirrors (dielectric high reflectors for the pump and silver mirrors for the broadband beams), X1 to X5 non-linear crystals and PM for power meter blocking the main output of the compressor. L1-L3 and L4-L6 are focussing lenses for the 1 and 2 µm beams, respectively, whereas the broadband beam is collimated and focused through the parabolic mirror C1 and curved mirrors C2-C4. D1 and BS stand for dichroic mirror and beam combiner, respectively.

3. Experimental results

The generation of the white-light super-continuum with sub-picosecond pulses has been carefully studied for different materials such as YAG and Sapphire, with different lengths, focusing conditions and pulse durations. Optimized parameters to achieve a two-octave continuum as well as excellent pulse-to-pulse stability were determined. We also studied the influence of chirp on the long driver pulses on the WLG. The supercontinua obtained for compressed, negatively and positively chirped pulses, are shown on Fig. 2 (a). The pulse-to-pulse energy stability of the supercontinua reached 3.4 % and 2.8 % for spectra below and above the driver wavelength, respectively: the chirp on the driving pulses did not influence the spectral bandwidth. Fig. 2 (b) shows signal and idler spectrum at the end of the second amplification stage at 2.18 µm. The signal spectrum was centered at 2178 nm with a spectral bandwidth of 210 nm (FWHM), while the idler spectrum had 153-nm bandwidth at 1956 nm, corresponding to 26 fs transform limited pulses. The pulse amplitude fluctuations of the signal at the end of the second OPA was measured to be less than 2 % (rms), which enabled stable white-light continuum generation. Fig. 2 (c) shows the beating of the white-light in the range of 950-1000 nm with the second harmonic of the remaining idler after super-continuum generation. The spectrum of the beat signal was averaged over 100 pulses. The fringes show clearly the CEP stability of the white-light continuum between 950 and 1000 nm. Over a 15 min acquisition time, the phase slowly drifted by only 1.5 rad, which can be easily stabilized with a slow feedback loop. Previously, phase stability of white-light continua in bulk has only been shown for driver pulses with durations below 550 fs [4,6,7]. The measured spectral interferences confirmed that the CEP of the continuum was conserved for both short and long driver pulses.

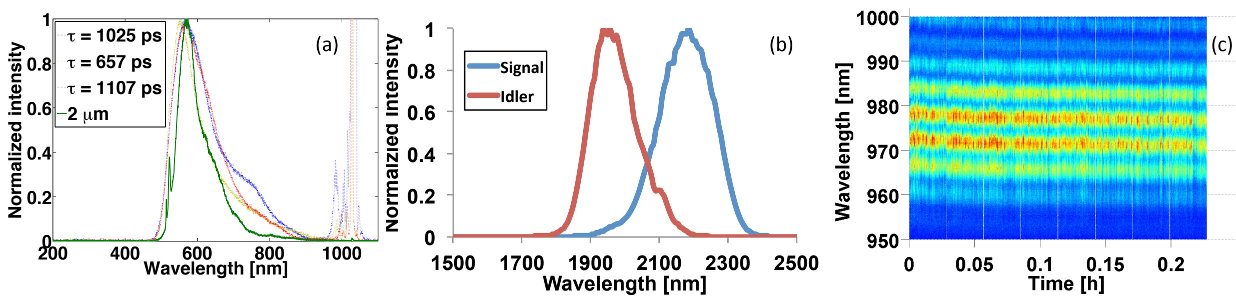

Fig. 2 : (a) White-light continuua generated in YAG; the spectrum shown as green solid curve is generated by CEP stable 1.95 µm pulses shown as red in (b); the other, dashed, curves correspond to the white-light driven by compressed, negatively and positively chirped 1 µm pulses. (b) Spectra out of the 2nd OPA before the CEP stable white-light generation. (c) Fringes confirming the CEP stability of the white-light super-continuum in the range 950-1000 nm.

4. Conclusion

In summary, we demonstrated passive CEP stable two-octave wide white-light continuum generation from 500 nm to 2 µm using slightly sub-picosecond pulses; the optimal parameters for white-light generation with long driver pulses has been identified. This source of CEP stable continuum is ideal for a two-octave wide high energy optical waveform synthesizer since it can be driven by the intermediate regenerative pre-amplifier for a high energy OPCPA pump line providing ultimately 1J driver pulses at kHz repetition rate.

References

[1] A. Wirth et al., " Synthesized Light Transients," Science 34, 195, (2011)
[2] S-W. Huang et al., " High-energy pulse synthesis with sub-cycle waveform control for strong-field physics," Nature photonics, 5, 475 (2011)
[3] O.D. Muecke, et al., "Millijoule-Level Parametric Synthesizer Generating Two-Octave-Wide Optical Waveforms for Strong-Field Experiments," San Jose, CLEO (2013)
[4] G. Cerullo, A. Baltuska, O.D. Mucke, C.Vozzi, "Few-optical-cycle light pulses with passive carrier-envelope phase stabilization,“ Laser&Photonics Reviews. 5, 323-351, (2011).
[5] A-L Calendron, H.Cankaya, F.X. Kärtner, "High-energy Yb:KYW regenerative amplifier for OPCPA pumping,“ UP, Okinawa, (submitted).
[6] M. Bradler ·P. Baum ·E. Riedle, " Femtosecond continuum generation in bulk laser host materials with sub-µJ pump pulses,“ Applied Physics B. **97** 561–574 (2009).
[7] P. Malevich. et al., " High-Repetition-Rate Multi-Millijoule Femtosecond 2.1-µm Ho:YAG Laser," Paris, ASSL (2013)