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Few-Cycle Parametric Amplifiers and Sub-Cycle Waveform Synthesizers

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Parametric amplification of ultrashort optical pulses has recently emerged as key enabling technology, e.g., for the realization of bright coherent tabletop high-harmonic sources in the water-window and keV X-ray region [1] and for the control of strongly correlated electron systems using mid-IR pulses and strong THz transients [2]. In particular, the coherent synthesis of sub-optical-cycle waveforms $E(t)$ from separate parametric amplifiers [3] covering different spectral regions has attracted enormous attention. Intense sub-cycle waveforms open the door to the new research field *Waveform Nonlinear Optics*, which aims to study and control the nonlinear interactions of matter with extremely short optical waveforms custom-tailored within a cycle of light. Many new applications arise in attoscience and strong-field physics [4]. In this talk, we discuss the underlying physics, challenges and fascinating opportunities of high-energy sub-cycle parametric waveform synthesizers.

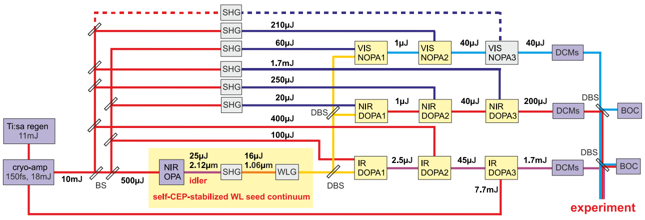

Fig. 1. Multi-mJ sub-cycle parametric waveform synthesizer [5].

We discuss a carrier-envelope phase (CEP)-stable 3-channel multi-mJ sub-cycle parametric waveform synthesizer (see Fig. 1) driven by a non-CEP-stable cryogenically cooled Ti:sapphire amplifier [5]. In this system, a passively CEP-stable white-light seed continuum (0.5-2.5 μm) is split and amplified in three parallel parametric amplification channels (VIS NOPA, NIR DOPA, IR DOPA) up to the multi-mJ level. The amplified spectra [5] (not shown here) support 1.9-fs FWHM waveforms. Preliminary FROG characterization results shown in Figs. 2 and 3 demonstrate the feasibility to recompress all three channels simultaneously close to the Fourier limit. Finally, the relative timing of the pulses can be locked with sub-cycle precision using balanced optical cross-correlators [3].

The next step will be the waveform synthesis from all three channels at the mJ level. In Fig. 4 we show some examples of synthesized waveforms from the second OPA

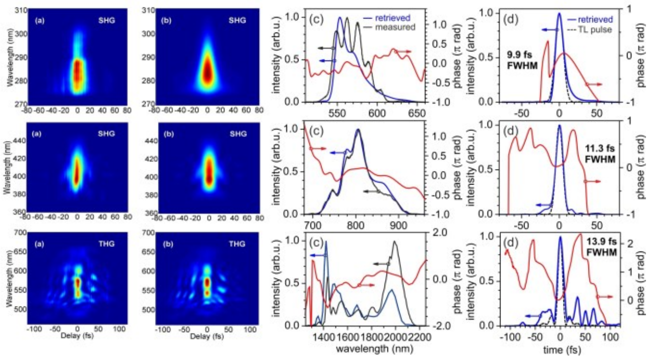

Fig. 2. FROG characterization of the second-stage OPA outputs. The VIS NOPA (top row) and NIR DOPA (middle row) are characterized by means of SHG-FROG, the IR DOPA (bottom row) using surface THG-FROG (no marginal correction applied).

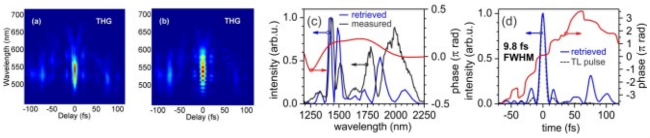

Fig. 3. Same as Fig. 2 for the third-stage output of the IR DOPA.

stages for different relative phases, as computed from the measured spectral amplitudes and phases shown in Fig. 2(c). Waveforms as short as 2.7 fs FWHM can be obtained.

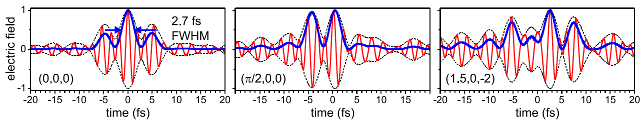

Fig. 4. Synthesized waveforms computed from Fig. 2(c). Field amplitudes of the pulses are the same, phases (VIS NOPA, NIR DOPA, IR DOPA) as indicated. Red curve: electric field $E(t)$; black dashed: field envelope; blue: intensity $I(t)$.

References

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