# High-energy pulse synthesis of optical parametric amplifiers

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The coherent synthesis of custom-tailored, intense, sub-cycle optical waveforms is promising for attosecond science and strong-field physics, e.g., for precision control of strong-field interactions in atoms, molecules and solids, for the generation of intense isolated attosecond pulses, and for attosecond pump-probe spectroscopy.

Recently, coherent pulse synthesis based on supercontinuum generation in a hollow-core fiber compressor allowed the generation of sub-cycle ~300-μJ optical pulses [1]. However, in this case ionization losses in the gas medium prevent further scaling to the mJ level. In contrast, parametric synthesizers [2-5] do not face an energy-scaling limit, and allow for spectral extension into the particularly appealing MIR region [6]. In previous works we demonstrated coherent pulse synthesis of two optical parametric chirped-pulse amplifiers [2] and of two optical parametric amplifiers (OPAs) on the few-μJ level [3].

Here we present the ongoing development of a novel 3-channel parametric synthesizer for generating a 2-octave-wide spectrum, which can easily be upscaled to the mJ-level. We start from a cryogenically cooled Ti:sapphire chirped-pulse amplifier (150 fs, 22 mJ, 0.8 μm, 1 kHz) and generate a CEP-stable continuum (0.5-2.3 μm) [5], by white-light generation in a YAG crystal pumped by the second harmonic (1.06 μm) of the CEP-stable idler of a NIR OPA. The continuum is split with custom-designed dichroic beam splitters (which will also be used for the final beam recombination) and seeds three OPAs, a VIS noncollinear OPA (NOPA), a NIR and an IR degenerate OPA (DOPA), each composed of 2 (later 3) amplification stages, and pumped by the pulses at 0.8 μm (IR DOPA), and by its second harmonic at 0.4 μm (VIS NOPA, NIR DOPA). To synthesize a coherent ultrashort pulse from these three OPAs, the relative timing of the pulses will be tightly locked using feedback loops with balanced optical cross-correlators, that can achieve sub-cycle synchronization with <30-as RMS timing jitter [2,3].

Figure 1(a) shows the measured output spectra and the energies from the second amplification stages operating in parallel. The transform-limited (TL) pulse duration from the synthesis of these spectra is 1.9 fs FWHM, corresponding to 0.7 optical cycles at 785 nm center wavelength, as shown in Fig. 1(b).

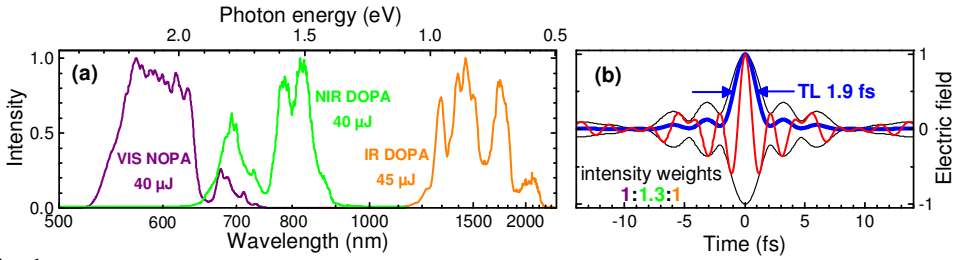


**Fig. 1** (a) Output spectra and energies from the second OPA stages. (b) The transform-limited pulse synthesized from the weighted spectra in (a) (red: electric field, thin black: field envelope, blue: intensity).

Our current work aims to scale up the energies (by a third amplification stage) to ~0.5 mJ for the VIS NOPA/NIR DOPA and ~2 mJ for the IR DOPA using the 18.5 mJ of pump remaining after the first two amplification stages. State-of-the-art double-chirped mirror pairs (at present in fabrication) will allow for the final pulse compression with ultralow residual ripple in the resulting total group-delay dispersion over the full bandwidth (0.52-2.3μm). Temporal characterization of the synthesized two-octave-spanning optical waveforms will be performed by two-dimensional spectral shearing interferometry (2DSI) [2,3].

We foresee that our 3-channel synthesizer, when further scaled in energy to the mJ level, will become a versatile tool for controlling strong-field interactions in atoms, molecules and solids and for attosecond pump-probe spectroscopy employing ultrashort pulses in the VIS/IR and XUV/soft-X-ray regions.

## References

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