Generation and control of single-cycle mid-infrared waveforms

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The generation of ultrashort laser pulses comprising a mere few or even a single electric-field oscillation, and the possibility to shape such electric-field waveforms are key technologies for investigating and controlling fundamental light-matter interactions on the sub-femtosecond time scale [1]. Extending the sub-cycle waveform control from the previously-demonstrated near-infrared (near-IR) to the mid-infrared (mid-IR) spectral range is crucial for several applications, including next-generation light-wave-driven electronic signal processing in low-bandgap highly-doped semiconductors [2] and field-resolved spectroscopy of biological systems [3].

Here, we present a novel approach for the generation and control of single-cycle mid-IR waveforms. Down-conversion of carrier-envelope-phase (CEP) stable single-cycle pulses from a Cr:ZnS laser (Fig. 1a) in a single $ZnGeP_2$ (ZGP) crystal provides a 3.7-octave supercontinuum, stretching from the near-IR to the mid-IR fingerprint region (Fig. 1b). By exploiting the CEP-dependence of the underlying cascaded intra-pulse difference-frequency-generation (IPDFG) we can continuously adjust the waveforms of the single-cycle mid-IR transients (Fig. 1c). The unprecedented CEP-stability of our Cr:ZnS driving laser results in highly reproducible control over the waveform generation [4].

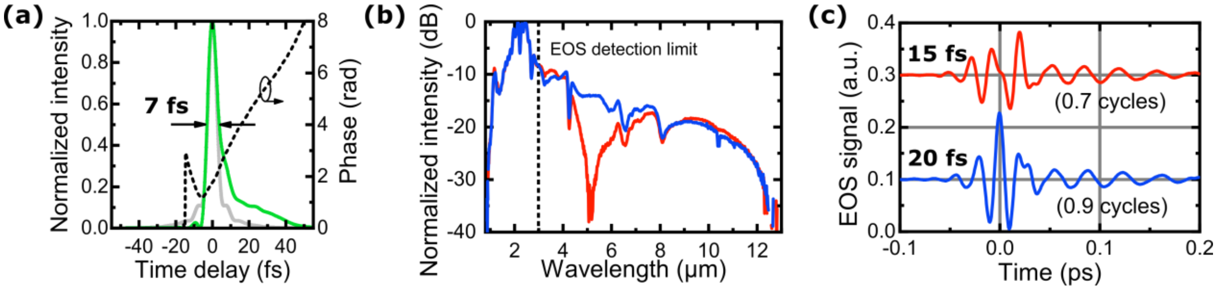

Fig. 1 (a) Single-cycle driving pulse as retrieved from SHG-FROG (green) compared with the Fourier-limited pulse (grey). (b) Supercontinuum from cascaded IPDFG for the extreme cases of CEP-dependent constructive (blue) and destructive (red) interference between the even and odd cascaded IPDFG orders. EOS measurement with 7-fs gating pulse allows to measure components with wavelengths longer than ~3µm. (c) EOS traces of the supercontinuum pulses in *b*; the FWHM pulse durations and the number of optical cycles at the spectral centroid are indicated.

The frontend of our setup is a diode-pumped Kerr-lens mode-locked Cr:ZnS laser oscillator producing 28 fs pulses at 2.3 µm. The repetition rate and the average output power amounted to 23 MHz and 480 mW, respectively. The laser output was focused into a 0.5-mm-thick TiO_2 plate, providing spectral broadening to a super-octave-spanning bandwidth (1.1 – 3.2 µm), with a corresponding Fourier-limit of 6 fs. The pulses were compressed with custom-designed multilayer dispersive mirrors down to 7 fs (Fig. 1a), constituting the first demonstration of single-cycle pulses generated with chromium-doped II-VI laser technology. These single-cycle pulses were CEP-stabilized with a residual phase noise of only 11 mrad (integrated from 1 mHz to 11.5 MHz). Subsequently, the beam was focused into a ZGP nonlinear crystal for cascaded IPDFG, resulting in an infrared supercontinnum covering 3.7 optical octaves (0.9 – 12 µm; Fig. 1b). The output power of the mid-IR ($\lambda > 3.6$ µm) amounted to 31 mW, corresponding to a high IPDFG conversion efficiency of 14%. We characterized the mid-IR transients with electro-optical sampling, using the 7-fs driver pulses for gating. Finally, we demonstrate that by tuning the CEP of the stabilized Cr:ZnS driver laser we can continuously shape the single-cycle mid-IR waveforms (Fig. 1c) and modify their spectral intensity (Fig. 1b).

References

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