Generation of Sub 7-fs Pulses at 800 nm from a Degenerate Optical Parametric Amplifier

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Abstract: We generate 800-nm, sub-7-fs pulses from a degenerate Optical Parametric Amplifier pumped by the second harmonic of a Ti:sapphire system and seeded by supercontinuum generated by a near IR OPA pumped by the same source.

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Optical Parametric Amplifiers (OPAs), thanks to their broad phase matching bandwidths, allow for the dramatic shortening of the duration of the driving pulse. In particular, OPAs pumped by the fundamental frequency (FF) or the second harmonic (SH) of Ti:sapphire and seeded by white-light continuum (WLC) enable the generation of few-optical-cycle pulses in a wide spectral range, from the visible [1] to the near-IR [2]. However the important spectral range around 800 nm has not yet been covered. In fact the WLC produced from an 800-nm driving pulse presents a highly structured amplitude and phase profile around the pump frequency. Previous attempts of amplification at 800 nm of a supercontinuum generated in a photonic crystal fiber resulted in ultra-broadband spectra, which were however not compressed due to the strong chirp on the seed pulses [3]. In this work, we demonstrate a two-stage OPA scheme for the generation of few-optical-cycle pulses at 800nm starting from a 150-fs amplified Ti:sapphire laser system. First, a FF-pumped near-IR OPA is used to generate either a signal at 1.3 μm or an idler at 1.6 μm , which in turn produces a WLC with well-behaved spectral amplitude and phase around 800 nm. This WLC is then amplified in a broadband degenerate SH-pumped OPA and compressed by chirped mirrors to nearly transform-limited (TL) sub-7-fs duration. We achieve a pulse shortening by a factor of 20 with respect to the driving laser [4].

Figure 1. Setup of the broadband SH-pumped OPA at degeneracy BS, beam splitter; VA, variable attenuator; WLC, white light continuum generation; DCM, double chirped mirror; FS, fused silica wedge, BBO 1: second harmonic stage; BBO 2: OPA at 800 nm.

Figure 1 shows a scheme of the experimental setup. The system starts with an amplified Ti:sapphire laser system producing 150-fs pulses at 1 kHz. A fraction of the pulses is used to drive a two-stage FF-pumped near-IR OPA. The first OPA stage, pumped with 60 μJ , is seeded by the WLC generated in a 3-mm-thick sapphire plate and employs a 5-mm-thick β -barium borate (BBO) crystal in a type II configuration ($\theta=27^\circ$, $\phi=30^\circ$) providing pulses with 5 μJ of energy. The second stage is pumped with 100 μJ energy and uses a 3-mm-thick BBO crystal in the same type II configuration. This stage produces signal energies up to 15 μJ tunable from 1.2 to 1.6 μm (corresponding to an idler from 1.6 to 2.4 μm). To facilitate separation of the beams, a slightly non-collinear configuration is used for both OPAs; the non-collinear angle is however kept as small as possible to avoid angular dispersion in the idler beam when it is used for seeding. In principle, a single stage could be used for the near-IR OPA, however the two-stage design allows to achieve better stability, by driving into deeper saturation the second stage which had a conversion efficiency of pump into signal and idler of up to 30%.

Either the signal or the idler (in the latter case after rotating the polarization with a half-wave plate) of the near-IR OPA were used to generate the broadband WLC seed for the SH-pumped degenerate OPA. With the 1.3 μm signal, the WLC was generated in a 3-mm sapphire plate. The visible part of the optimized WLC spectrum provides

a rather spectrally flat and stable seed around 800 nm. The SH-pumped degenerate OPA employs a single pass in a 1-mm-thick type I BBO crystal ($\theta=29^\circ$, $\phi=0^\circ$), pumped by 70 μJ of the SH, to amplify the WLC up to 5 μJ . The resulting ultra-broadband spectrum spans from 670 to 950 nm. The phase-matching condition was slightly detuned from degeneracy, resulting in a slightly broader gain bandwidth allowing for the generation of a broad, double-humped spectrum.

Alternatively, we also generated the WLC from the idler of the OPA, tuned to 1.6 μm ; in this case, we used a 2-mm YAG plate instead of sapphire. YAG was chosen because we observed that it produces a WLC shifted to shorter wavelengths with respect to sapphire for the same drive wavelength. Since the idler of the near-IR OPA is at a longer wavelength, the use of YAG optimizes the WLC in the 800 nm range. Owing to the small pump-seed angle and the narrow amplification bandwidth in the near-IR OPA, the angular dispersion of the idler beam is smaller than 1 mrad and is negligible in comparison to its divergence. Thus, the WLC had minimal spatial chirp. The idler of our near-IR OPA is Carrier-Envelope Phase (CEP) stable since it arises from a difference-frequency generation process between a pump and WLC seed which are derived from the same 800-nm Ti:sapphire source, thus with the same CEP fluctuations. This CEP stability is expected to be transferred to the WLC and to the amplified pulses. The idler-driven WLC is amplified by the same broadband SH-pumped OPA as the signal-driven one, and gives very similar performance both in terms of output energy and spectrum. The spectrum is shown in Figure 2(a).

We designed a simple, high-throughput compressor consisting of two bounces on a pair of broadband double-chirped mirrors with compensating phase ripples, followed by fused silica wedges for fine dispersion tuning. The group delay introduced by the compressor compensates for that of the pulses over a broad bandwidth. The compressed pulses were characterized by Second Harmonic Generation Frequency Resolved Optical Gating (SHG-FROG) employing a 10- μm BBO crystal. Figure 2(c) shows the experimental SHG-FROG traces for the idler-derived case, while Figure 2(b) reports the retrieved temporal intensity. The measured 6.9 fs pulsewidth is very close to the 6.5 fs TL duration. For the signal-derived case, with a slightly larger wedge insertion, we obtained a similar result with a pulsewidth of 6.8 fs.

Figure 2. (a) OPA spectrum; (b) corresponding pulse profile and (c) measured FROG trace after compression.

In conclusion, we have demonstrated an ultrabroadband degenerate OPA generating nearly TL sub-7-fs pulses at 800 nm. This system fills a gap in few-optical-cycle pulse generation from OPAs and achieves a shortening by a factor of 20 of the 150-fs driving pulse. It can be synchronized with other few-optical-cycle OPAs and used for high time resolution two-colour pump-probe spectroscopy. In addition, the use of the idler pulses to produce the WLC opens the possibility to generate in a simple way few-optical-cycle CEP stable pulses at 800 nm starting from a conventional non CEP stabilized, long-pulse system. This simple front-end may also, by energy scaling with further OPA stages, become interesting for CEP-dependent high-field science.

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