EUV continuum from compressed multiple thin plate supercontinuum

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Abstract: A one-cycle (3.3fs) pulse compressed from multiple thin plates generated supercontinuum has been demonstrated and used to produce a bright EUV continuum covering from 43 to 65 eV with high up-conversion efficiency of 5×10^{-5}.
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1. Introduction

A promising approach for the production of bright, coherent, attosecond pulses is through high harmonic generation (HHG). One practical generation scheme for achieving isolated attosecond pulses requires using few-cycle pulses with high pulse energy to drive HHG [1]. These pulses are typically obtained by coupling femtosecond pulses at the mJ level into hallow core fibers (HCF). Recently we demonstrated an alternative approach to supercontinuum generation using an all-solid-state multiple thin plate system (MPContinuum) [2]. We have successfully compressed the MPContinuum pulse to 3 fs pulse duration, one-cycle pulse [3]. Here we report the application of these pulses for the first time to generate a continuum in the EUV region of the spectrum around 43-65 eV. The transform limit of the EUV spectrum supports an isolated 190 as pulse.

There are several advantages to using the MPContinuum as compared with HCF for producing isolated attosecond pulses. Firstly, MPContinuum only requires low pumping pulse energy, typically a few tens of µJ, in order to obtain a broad spectrum capable of supporting few-cycle pulses. The required initial pulse energy is a factor of ten less than the gaseous approach. Secondly, it has the advantage of being compact, simple, and reliable. Furthermore, we found the up-conversion efficiency of the total high-harmonic photon count per pulse driven by the one-cycle MPContinuum pulses is a factor of 1.6 times higher than that driven by multi-cycle pulses. All factors of MPContinuum HHG are very favorable for extending attosecond technology to very high repetition rate lasers and into many more laboratories in the future.

2. Experimental Result

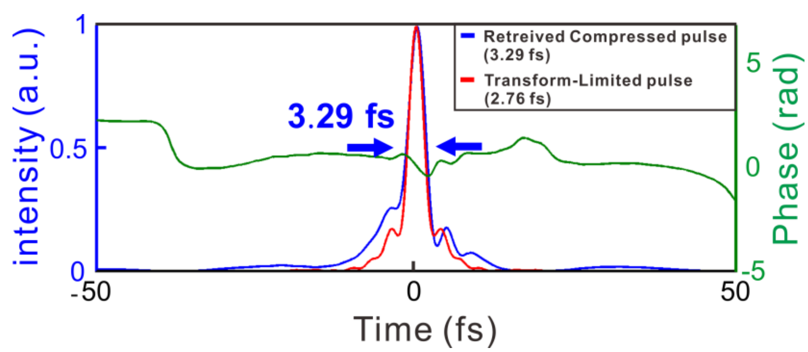

Fig. 1. Intensity profile of the one-cycle input pulse, generated from a compressed supercontinuum pulse, reconstructed from PG-XFROG measurement

The supercontinuum used in this experiment was obtained by converting 30 fs transform-limited pulses from a commercial carrier envelope phase (CEP)-stable Ti:Sapphier amplifier (Femtopower HE PRO CEP, Femtolasers) to a white-light source using multiple plates of thin fused silica. Details of this conversion process were previously reported [2]. We have improved the supercontinuum output from our first report and have achieved a broader octave-spanning spectrum (420 nm to 980 nm at the -20 dB intensity level) and nearly doubled the output pulse energy to 250 µJ per pulse with 56 % conversion efficiency. A shaper-assisted 4-f phase compensator consisting of a grating pair and a spatial light modulator (SLM, JenOptik SLM640d) cleans up high-order dispersion and the chirped phases that are inherent in supercontinuum generation. The compressed pulse demonstrates near-one-cycle oscillation with a duration of 3.3 fs as determined by PG-XFROG (Fig. 1). The pulse energy after compression is 50 μJ with an estimated peak power of 8.4 GW.

The pulses were focused to an intensity of ~10^{15} W/cm^2 into argon at about 0.15 bar pressure. The generated EUV output was dispersed in a home-built vacuum spectrometer after passing through three 200nm Al filters and was detected by an x-ray CCD array camera (iKon-L, Andor). The resulting spectrum ranging from 43 eV to 65 eV is shown as the blue curve in Fig. 2(a). The measured spectrum is broad and continuous. The cutoff on the low-energy (left) side is due to EUV absorption by argon and the cutoff on the right side results from the limitation of phase matching in the high harmonic generation process [4]. The high-order harmonic spectrum is extremely sensitive to compressed pulse duration. Imperfect phase compensation within the 4-f system make the compressed pulse duration away from one-cycle regime, which reduces the cutoff energy and causes the EUV spectrum to become discontinuous as shown in Fig. 2(b). This result is robust evidence that we have successfully compressed the MPContinuum to a near one-cycle pulse.

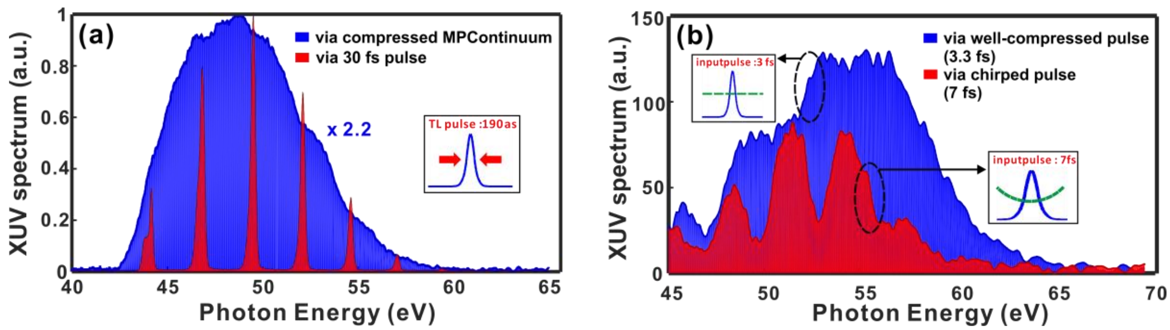

Fig. 2. (a) Normalized EUV spectrum (blue curve) driven by 50 μJ, 3.3 fs (near one-cycle) pulse, together with the red curve driven by 250 μJ, 30 fs (10-cycles) pulses directly from Ti:Sapphire amplifier. (b) EUV spectrum (blue curve) driven by 3.3 fs (near one-cycle) pulse, together with the red curve driven by 250 μJ, 7 fs (3 cycles) pulses, which is created by adding an additional 2nd order phase.

The bright continuous EUV spectrum we generated here can support an isolated attosecond pulse with a transform-limited pulse duration of ≈190 as. Interestingly, we found that the up-conversion efficiency of the total high-harmonic photons per pulse driven by the MPContinuum one-cycle pulses (blue area) is about 1.6 times higher than that driven by 30 fs pulses (red area). There is excellent agreement with our calculation that shorter pulses can drive high harmonic generation with less ionization level that hinders the phase matching conditions. Within a 0.1 s integration time, corresponding to 100 shots of our laser system, the EUV spectrum signal to noise ratio is greater than 200. The flux is 5×10^5 photons per pulse detected by CCD camera. After considering the transmission efficiencies of all the filters, reflection mirrors and dispersion grating in our system, we estimate that using MPContinuum (one-cycle pulses) as the driving laser the high harmonic generation up-conversion efficiency is more than 5×10^{-5}.

3. Conclusion

In this work, we have demonstrated the first continuous spectrum in EUV regime generated from a compressed all-solid-state supercontinuum light source, MPContinuum. The bright and continuous spectrum from 42eV to 65 eV is robust evidence that we have successfully compressed the MPContinuum to a near one-cycle pulse and that this pulse can be used in high harmonics generation with high up-conversion efficiency (> 5×10^{-5}). This novel scheme provides an accessible and reliable route for attosecond science.

4. References

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