Few Cycle EUV Continuum Generation via Thin Film Compression

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Abstract: Generation of an extreme ultraviolet continuum (33 eV to 72 eV) by a multi-millijoule, few-cycle (7 fs) laser pulse produced by the Thin Film Compression technique.

1. Introduction

High intensity pulses with kilohertz repetition rates can be achieved by using millijoule level pulses with single or few cycle pulse durations. Generation of such laser pulses directly from a laser cavity is difficult and expensive due to large bandwidth requirements for supporting such a pulse, and techniques to compress after exiting the laser cavity are typically limited to a maximum energy that is sub millijoule.

Thin film compression (TFC) is a pulse compression technique which can easily scale to Joules of energy. A propagating pulse undergoes self-phase modulation inside a thin dielectric material, which spectrally broadens the pulse. TFC can be staged such that further compression can be achieved, and it scales easily to beams with larger diameter and thus higher energies. In this first practical demonstration of TFC, we demonstrate that it is both an affordable and robust method of few cycle pulse generation [1].

Extreme ultraviolet light (EUV) generated via high harmonic generation (HHG) from multicycle pulses will have a discrete spectrum of odd harmonics of the fundamental frequency with a spectral width that is inversely proportional to the number of cycles in the driving laser. In contrast, a few cycle laser pulse produces harmonics broad enough to generate an quasi-continuum, useful for spectroscopy of sharp spectral features such as absorption edges. Driving HHG with a multi-millijoule few cycle laser pulse enables for a EUV continuum to be generated beyond the normal ionization cutoff due to a multiple ionization process, increasing the range where a continuum could be supported [2], in addition to enabling higher overall brightness beams. The use of TFC for HHG enables a new regime of attosecond technology capable of very high single pulse energies at kilohertz repetition rates. Here, we demonstrate a multistaged TFC setup with a commercial laser system producing millijoule level pulses with durations of sub-3 cycles to produce an EUV continuum.

2. Results

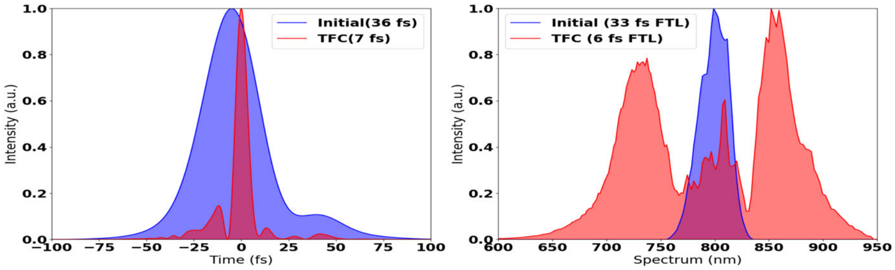

Fig. 1: Temporal profile and spectra of the initial(blue) and TFC(red) pulses.

To generate the spectrum required to support a few cycle laser pulse, two stages of TFC were used. A stage consists of a telescope to adjust the beam diameter, a dielectric medium for bandwidth generation, and dispersion correcting optics. The dielectric is fused silica with thickness 0.5 mm oriented at Brewster's angle, positioned to maintain an intensity of ~ 4.5 TW/cm^2. After spectral broadening, the pulse is recompressed through the combination of chirp mirrors and material dispersion. The initial pulse is generated from a multimillijoule, single-stage Ti:Sapphire regenerative amplifier system (Spectra Physics, Solstice Ace), which outputs a 36 fs (33 fs FTL)

Gaussian beam at a wavelength of 800 nm . A single stage is found to decrease the pulse duration by a factor of ~ 2.5 with losses of $< 8\%$. After two stages of TFC, the temporal profile was measured to be quasi-gaussian via TG-FROG, and had a measured pulse duration of 7 fs FWHM. This demonstrates an experimentally measured compression factor of 5. Initial pulse energies up to 7 mJ were used with a diameter of 24 mm. Larger energies could be supported if the beam diameter was increased.

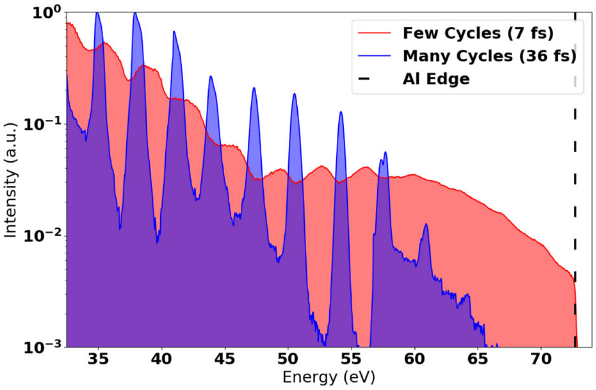

Fig. 2: Normalized EUV Spectrum driven by many cycle (36 fs, blue) and few cycle (7 fs, red) pulse. The aluminum absorption edge is clearly visible at 72.7 eV.

For the HHG experiment, we used the two stage TFC system with 1.3 mJ of laser energy and a diameter of 12 mm. The use of metallic mirrors caused reflectivity losses, reducing the energy throughput to 0.95 mJ. EUV spectra were taken for both the initial pulse(36 fs) and the TFC pulse(7 fs) in the same geometry. The pulse was then focused with a 500 mm focal length curved mirror onto a Argon gas jet with 256 um diameter capillary with 25 PSI of backing pressure. An iris after the TFC stages reduced the focused intensity $\sim 5\times10^{14}\mathrm{Wcm}^{-2}$ on the gas jet. When driven by the initial pulse, discrete harmonics are observed as expected. When driving the interaction with the TFC few cycle pulse we see a quasi-continuum spectra appear capable of supporting pulses with duration on the order of $\sim$ 100's of attoseconds. The continuum reaches out to the strong absorption edge at 72 eV from the 1.4 microns of aluminum used as x-ray filters. Significant photon flux was generated, within the energy range of 38 eV and 43 eV, a minimum of 10^5 photons where generated per shot, or $> 10^8$ photons per second. Due to constraints of the experimental setup, the entire HHG experiment was in a vacuum chamber making phase matching optimization difficult. With proper phase matching occurring a significant increase in total photon flux should be observed.

3. Conclusion

We have shown one of the first demonstrations of TFC to be used in an experiment, generating a HHG EUV quasi-continuum. We have shown millijoule level TFC in a staged geometry is capable of producing few cycle laser pulses with limited losses. The technique is both affordable and robust, the entire experiment was produced with commercially available components with a net cost of less than three thousand USD. With this, we were able to produce a broad EUV continuum with a high single shot flux ideal for EUV spectroscopic techniques such as near edge x-ray absorption spectroscopy. Since this technique is easily scalable to higher energies, it is ideally suited for future systems where tens to hundreds of millijoules are produced at kilohertz repetition rates, or for systems being deployed at facilities such as the Extreme Light Infrastructure.

Acknowledgements

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