Generation of High-Flux Attosecond Extreme Ultraviolet Continuum with a 20 Terawatt Laser

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Abstract: An XUV continuum is generated by high-order harmonic generation in argon with a 20 TW, sub-14-fs Ti:Sapphire laser using the generalized double optical gating technique. The XUV pulse energy is over 100 nJ at generation location.

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1. Introduction

Isolated attosecond pulses with high photon flux are required to perform attosecond pump – attosecond probe experiments or to stimulate ultrafast nonlinear phenomena in the XUV region. In order to scale up the isolated attosecond pulse energy, we developed a Ti:sapphire laser system optimized to provide both high-energy (350 mJ) and short-duration (13.9 fs) pulses for implementing Generalized Double Optical Gating (GDOG) [1].

2. Infrared Driving Laser

The optical layout of the driving laser and the setup for generating isolated attosecond pulses is shown schematically in Fig. 1. By distributing the high gain of the system ($\sim 10^9$) over two chirped-pulse amplifiers, the significant spectral narrowing in the first CPA, is recovered by spectral broadening in a neon gas-filled hollow-core fiber.

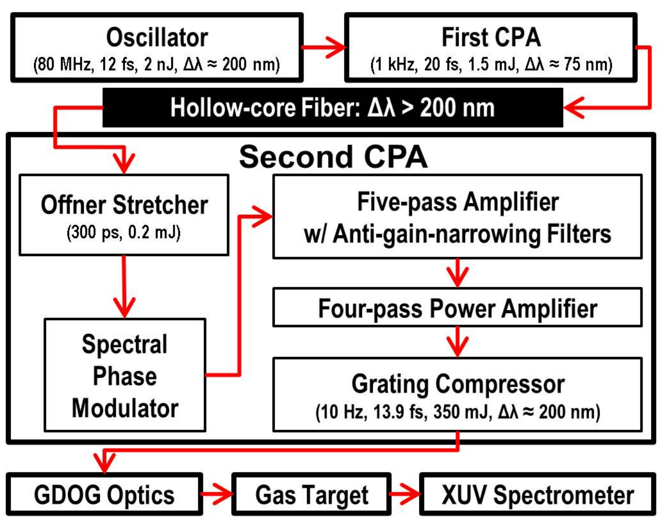

Fig. 1. Block diagram representing the 10 Hz, 20 TW, Ti:sapphire-based laser system with accompanying HHG and measurement setup.

The first CPA consists of a two-stage multi-pass Ti:sapphire amplifier seeded by a broadband Ti:sapphire oscillator. The output pulses (1 kHz, 20 fs, 1.5 mJ) are launched into a neon-filled hollow-core fiber (1.5 m length, 450 μm core diameter, 1.4 bar gas pressure) to generate a white-light continuum with spectrum from 550 nm to 950 nm. The center mode of the spectrally-broadened pulses is used to seed the second CPA.

The sub-mJ level pulses are stretched again to over 300 ps before amplified to 30 mJ in a five-pass amplifier operating at 10 Hz. The second four-pass amplifier stage boosts the pulse energy to 700 mJ. The spectrum of these pulses extends from 700 nm to 900 nm, which supports sub-13 fs transform-limited pulses. The long term stability, RMS/mean, is 1.6%, whereas the shot-to-shot fluctuation is $\pm$4.4% for 99% of all laser pulses over 6 hours.

The amplified pulses are compressed under vacuum by a pulse compressor with an overall throughput of 50%. The pulse compression was characterized by a single-shot second-harmonic FROG. The high-order phase distortions are further compensated by a low-loss, 4*f*-zero-dispersion adaptive phase modulator, which is located between the stretcher and the first amplification stage. Using FROG traces as the fitness function for an evolutionary algorithm, a pulse duration of 13.9 fs could be obtained after running the algorithm to convergence.

3. XUV Attosecond Laser

For isolated attosecond pulse generation, the sub-14-fs linearly-polarized laser field is transformed by a set of GDOG birefringent optics [1] placed after the 6.5 m focusing mirror to achieve a gate width less than one optical cycle. The attosecond pulses were generated in an argon gas cell held at 4 torr located at the laser focus. Two silicon mirrors set at the infrared Brewster angle are used to eliminate the residual driving laser.

The XUV spectra under various gating conditions were measured with an XUV grating spectrometer. Figure 2 shows single-shot HHG spectra of argon under various gating conditions. Well-resolved odd harmonics were generated when no gating was applied, and both odd and even harmonics appeared with the two-color laser field. These peaks merged to a continuum for every laser shot under the GDOG field. The energy of the XUV pulse was measured to be 0.5 nJ with an XUV photodiode placed behind two 300 nm-thick aluminum filters. This corresponds to an estimated XUV energy generated at the exit of the gas cell of 100 nJ.

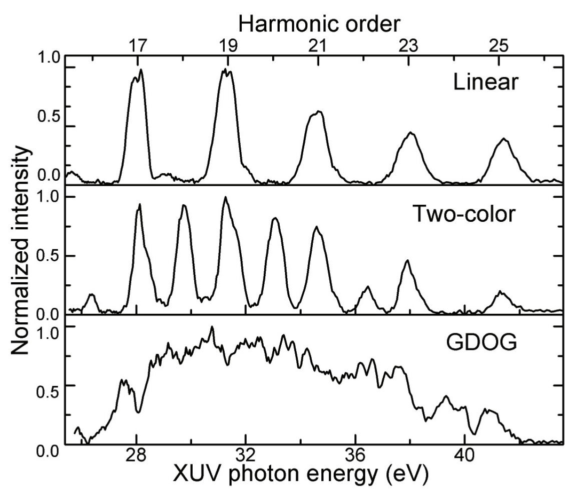

Fig. 2. Single-shot XUV spectra generated in argon under different gating conditions.

4. Conclusions

In conclusion, we have developed a 13.9 fs, 20 TW high-power laser system with a 10 Hz repetition rate for generating high-flux isolated attosecond pulses. This system represents the highest extent to which white-light from a hollow-core fiber has been amplified. This is also the first demonstration of using multi-cycle laser pulses at the 20 TW level with the GDOG technique to generate an XUV continuum. This material is based upon work supported by the U.S. Army Research Office and the National Science Foundation under Grant Number 1068604.

References

1. X. Feng, S. Gilbertson, H. Mashiko, H. Wang, S. D. Khan, M. Chini, Y. Wu, K. Zhao, and Z. Chang, Phys. Rev. Lett. **103**, 183901 (2009).