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Femtosecond Lasers for the generation of Ultrafast XUV pulses

Reporting

Project Information

FLUX

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Final Report Summary - FLUX (Femtosecond Lasers for the generation of Ultrafast XUV pulses)

The FLUX IAPP project was conceived in 2007 in order to strengthen the collaboration of two industrial partners (Amplitude Technologies and Fastlite) and three academic partners (AMOLF, FORTH and CEA-Saclay) on the development of laser systems needed for the full-fledged exploitation of attosecond

science. For the industrial partners, participation in FLUX was important, because of its potential for the development of new products for the scientific market, while for the academic partners, FLUX offered the potential for the development of breakthrough scientific methods, that might lead – for the first time – to the possibility to be able to perform attosecond XUV pump-attosecond XUV probe experiments.
At the time that the FLUX project was proposed, attosecond laser pulses had been demonstrated and used in first proof-of-concept experiments, but prototypical attosecond XUV pump-attosecond XUV probe experiments, where a first attosecond “pump” pulse electronically excites a system, which is subsequently probed by a second attosecond “probe” pulse that generates a signal encoding the electronic time-evolution of the system, were still deemed impossible. The reason for this was that the attosecond pulses that were available at the time were very weak, leading to a situation where the probability for photo-absorption of both a pump ánd a probe photon (as opposed to photo-absorption by a pump ór probe-photon) was too small. FLUX sought to solve this, by developing laser systems and the related carrier envelope phase (CEP) and high-harmonic generation (HHG) technology that would allow the generation of attosecond pulses intense enough for performing attosecond XUV pump-attosecond XUV probe experiments. In the end, the collaborative work carried out within the FLUX project has led to a situation where the main targets of the original project have largely been met in all three work packages of the project, and where the first attosecond XUV pump-attosecond XUV probe experiment has been demonstrated.
FLUX was organized in terms of three workpackages, which will be briefly described in turn:

WP1) Generation of Terawatt-level CEP-stable many-cycle driver laser pulses for use in attosecond pulse generation experiments
In WP1 the objectives were two-fold, namely demonstration of the feasibility of CEP stabilization of (a) Terawatt-class low repetition rate laser amplifiers, and (b) that of high energy(> 10 mJ) high repetition rate (>1 kHz) laser amplifiers. In the former case, the main limitation is imposed by the shot-to-shot energy fluctuations of low repetition rate (25-50 Hz) pump lasers. Within FLUX, AMOLF and Amplitude developed the first-ever CEP-stable Terawatt-class (35mJ, 32 fs) laser amplifier. Furthermore, en route to being to offer CEP-stable laser amplifiers as a commercial product, Amplitude and CEA-Saclay collaborated on the development of a high energy high repetition rate CEP stable laser amplifier. This development was carried out in two steps: the first step was performed in CEA-Saclay with a 1 kHz system, whose output energy was increased from 3 mJ to 20 mJ (before compression), where different jitter issues were successfully addressed in collaboration with Fastlite. This work confirmed, among other things, that the CEP could be kept stable in the presence of the Fastlite Dazzler device. Stabilization of the CEP with 300mrad shot-to-shot noise on a 20W, 10kHz system was achieved, which led subsequently to the installation of a dual 1-10 kHz (2x20 W) system at MBI (the new affiliation of the AMOLF PI since 2010). In the future, as part of a new EID project (JMAP), MBI and Amplitude will continue collaborating on further CEP improvement of this system. In conclusion, all the main objectives of this task were achieved with the development of a new generation of high performance laser systems that are now a commercial product for Amplitude.

WP2) Generation of isolated attosecond XUV laser pulses and few-cycle UV pulses using many-cycle polarization gating
At FORTH, the goal of generating intense attosecond pulses from Terawatt-level many-cycle driver laser pulses for use in attosecond pulse generation experiments was achieved by application of the

interferometic polarization gating (IPG) method that was previously pioneered by FORTH. A compact Collinear Many-Cycle-Polarization-Gating (CMC-PG) device, which can be used within a high-power many-cycle laser system for the generation of intense isolated attosecond XUV and few-fs UV pulses, was developed and successfully implemented. Furthermore, a tool was developed for monitoring the absolute CEP of a high-power many-cycle driving pulse, measuring the variation of the XUV spectrum generated. Both results were reported in a number of publications (see overview).

The intense “isolated” attosecond XUV pulses were temporally characterized by using a 2nd-order autocorrelation measurement and were used in atomic experiments aimed at tracking time-dependent electron dynamics in an XUV attosecond pump-XUV attosecond probe configuration, which were published in a high-profile publication. The significance of these results is considerable, since it represents the first-ever attosecond pump-attosecond probe experiment, the main goals defined for the FLUX-IAPP project.

WP3) Compression of high energy CEP-stable laser pulses
The work in WP3 was devoted to the generation and characterization of sub-10fs pulses generated by post-compression. CEA-Saclay and Fastlite first designed diagnostics able to measure such short pulse durations. Next, work has been performed by CEA-Saclay on pulse spectral broadening of 1-mJ 40-fs laser pulse by filamentation, yielding spectra compatible with 6fs pulse duration. To improve the stability, the approach was changed to spectral broadening based on self-phase modulation in hollow core fibers filled with rare gas, where 9 fs pulses with 400µJ pulse energy were obtained. The successful development of a CEP-stable amplifier chain by CEA-Saclay and Amplitude led to the development of a device for CEP control by Faslite, using a “jitter-free” Dazzler and a new temporal characterization method based on self-referenced spectral interferometry. The resulting “Wizzler” technology is now a Fastlite product and is used by CEA-Saclay and Amplitude for the daily optimization of their systems, including those installed at partners like MBI.

In conclusion, the collaborative work in FLUX largely accomplished the goals put forward at the time that the proposal was written. The impact of this success is two-fold. On the one hand it leads to the realization of unique high intensity table-top XUV and UV attosecond and few-fs light sources which can be used by the academic community for studies in basic research, including now also for the first time the ability to perform attosecond XUV pump-attosecond XUV probe experiments. At the same time, the successes achieved in FLUX will allow the industrial partners to bring these new approaches to market, increasing their competiveness and expanding the size of their costumer base. At the moment that this report is being written, there is already ample evidence that, on the basis of the technological advances made in FLUX, Amplitude has been able to make a significant step forward in the market for high power CEP-stable laser systems, and several of the larger systems that have recently been acquired by teams in the attosecond community have been acquired from Amplitude. In addition, we note that within FLUX significant steps were taken towards the implementation of novel technologies, such as high repetition rate and high power OPCPA. These activities were not yet anticipated as activities of the FLUX partners at the time that the proposal was written, but became part of the FLUX research after the Midterm Review. Specifically, at AMOLF work was initiated on the development of a 400 kHz, CEP-stable Optical Parametric Chirped Pulse Amplifier (OPCPA), a system which is now being used in first experiments at MBI, where moreover the development of a multi-Terawatt OPCPA has been initiated that is expected to lead to the generation of more intense attosecond pulses than could be foreseen at the time that the FLUX project was conceived.

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