Ten femtosecond 1kHz Laser Facility for Astra Target Area 1

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Introduction

The vibrant field of ultrafast laser – matter interactions continues to attract considerable international experimental and theoretical attention, as it allows the observation and control of rotational, nuclear and electronic degrees of freedom on a time-scale comparable to the characteristic period. The involvement of Astra Target Area 1 (ATA1) in the experimental realization of such research continues, hosting a number of research groups from a number of UK-based universities, along with European collaborators. Researchers from University College London, Queen's University Belfast, Imperial College London (with co-investigators from Madrid and Napoli), The Open University and the University of Strathclyde (with co-investigators from Ioannina, Greece) have all conducted successful experimental campaigns in ATA1, as reported elsewhere in this volume.

Installation of 1 kHz System

A considerable enhancement in the performance of the Astra Laser Facility was possible through the recent upgrade of the laser front-end, as discussed by Langley *et al.* [1] in this report. Two operational modes have been employed this year: the 35fs, 15mJ, 10Hz configuration [2] continues to allow world-leading experiments, where the high pulse energy allows moderate focused intensities in large focal volumes [3]. However, a second configuration, better suited to ultrafast laser – matter interactions, is now operational, generating ~10fs, 0.4mJ pulses at repetition rate of 1kHz.

The laser source consists of an oscillator (FemtoSource Pro, FemtoLasers GmbH) pumped by a solid state laser (Verdi, Coherent Inc), delivering sub-10 fs pulses of a few nJ in energy. This pulse is dispersively stretched to ~20 ps and amplified to ~2 mJ in a multi-pass amplifier, pumped with a second diode-pumped solid state laser (Jade, Thales Laser S.A.). The FemtoLasers system has operated very reliably [4] since installation in September 2005, and will form the front-end to the Astra Gemini Project [5].

Following this first stage of amplification, a Pockels cell switches one pulse from every 100 into the second and third amplifier stages. The residual pulse train (nominally at a repetition rate of 1kHz) is then sent into ATA1 for two-stage pulse compression, as shown in Figure 1.

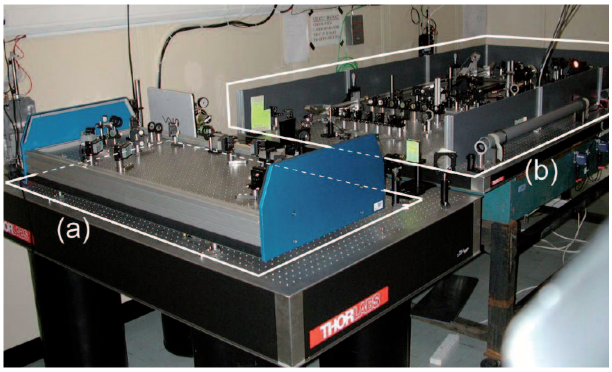

Figure 1. Annotated image of the 10fs 1kHz compressors installed in Astra TA1. (a) Prism compressor (input 1mJ, 2ps, output < 30fs, 0.8mJ). (b) Hollow fibre compressor (input <30fs, 0.7mJ, output <10fs, 0.4mJ).

Compressing to < 30 fs

Following transmission into the target area, the amplified pulses are compressed by two pairs of Brewster-angled fused silica prisms: by changing the prism pair separation, the dispersion of the compressor can be accurately controlled, fully reversing the influence of the chirp introduced in the stretcher. This allows a transform-limited optimal pulse duration of <30 fs to be generated. The prism compressor is illustrated in Figure 2.

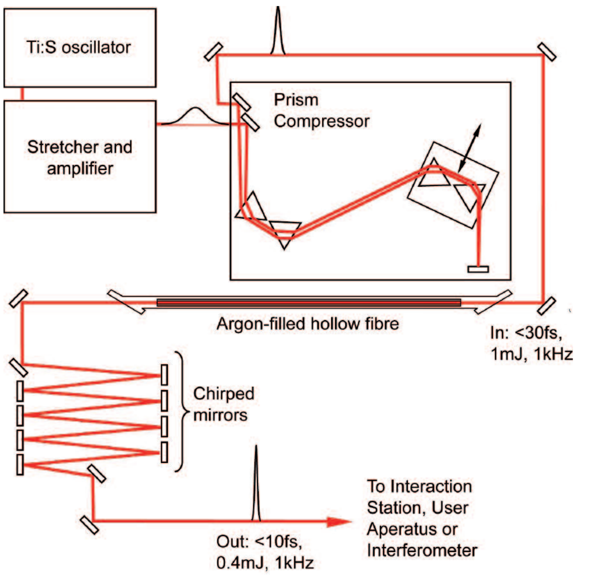

Figure 2. Schematic of the two-stage pulse compression technique employed in ATA1 to generate a <10fs, 0.4mJ pulse at repetition rate of 1kHz. The prism compressor reduces the pulse duration to <30fs. The noble-gas filled hollow fibre spectrally broadens the pulse, which is then compressed to <10fs on reflection from a series of multilayer chirped mirrors.

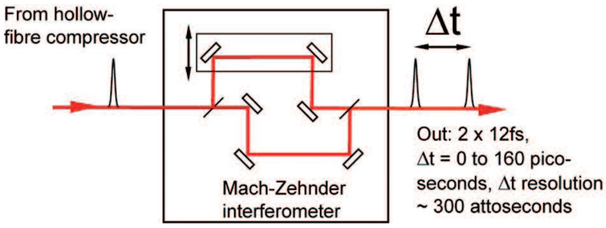

Figure 3. Schematic of Mach-Zehnder interferometer. The incoming few-cycle laser pulse is split and recombined using two pellicle beamsplitters. A computer-controlled Newport M-MFN25CC translation stage is used to move two mirrors in the upper arm parallel to the propagation direction.

A major advantage of employing prisms to compress chirped ultrafast laser pulses is the efficiency with which the pulses are transmitted through the system as a whole. Typically, a grating compressor has losses of at least 30% due to high-order diffraction and absorption losses in the grating coatings. However, a prism compressor with AR-coatings demonstrates the same performance (also for a lower cost) with losses of less than 5%.

Compressing to < 10 fs

We introduce additional bandwidth to support a pulse duration shorter than 30fs by self-phase modulation in a noble-gas filled hollow fibre, as discussed by the authors in reference (2). The pulse bandwidth is increased from 30nm to ~100 nm FWHM, allowing recompressed to a near-transform limited duration of 10 fs by a series of ultrabroadband multi-layer chirped mirrors, as illustrated in Figure 2. Each mirror reflection introduces a group-delay dispersion of $-30fs^2$, thus after five to eight reflections, the additional dispersion introduced on transmission through the hollow fibre is corrected. The pulse duration of our few-cycle pulse (FCP) is characterized using both SHG-autocorrelation and Frequency-Resolved Optical Gating (FROG) techniques.

Pump-probe configuration

Ultrafast laser - matter interactions are naturally suited to time-resolved measurement: such a measurement mode requires a pump-probe configuration. The FCP is split into two pulse replicas in a Mach-Zehnder interferometer, as illustrated in Figure 3. To minimize stretching of the pulses, 4-micron thick pellicle beamsplitters are employed to split and recombine the beams. The delay between the two replicas (Δt) is controlled using a high-resolution translation stage, with a repeatable resolution of ~ 150 nm, equivalent to ~300 attoseconds double-pass. The delay can be scanned over the range $0 < \Delta t < 160$ picoseconds. The temporal stability and reproducibility of our interferometer is tested by measuring the ionization yields from xenon, see Bryan *et al.* [6], and is used to create rotational and vibrational wavepackets in hydrogenic molecules, see references [7-9].

A similar experimental configuration has been employed by a team from Imperial College London, in which 10fs pulses generated from the 10Hz output from Astra produce high-harmonic emission from molecules aligned by a 30fs pump pulse - see Kajumba *et al.* [10].

Future directions

Carrier envelope phase stabilization will be installed in the Astra front-end, allowing the absolute phase of the electric field to be controlled. This will open new avenues for investigation, particularly the motion of electrons within atoms and molecules on the attosecond timescale. Such technology is an essential part of the funded Astra-Artemis Project [11], an upgrade of ATA1 that will provide three ultrafast synchronized beams for time-resolved science, bringing ATA1 right to the state of the art.

References

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