Artemis: a sub 10-fs XUV source for ultrafast time-resolved science

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Introduction

Artemis is a multi-partner, multi-disciplinary project to develop a facility based on high repetition rate, few optical cycle tuneable laser sources – one of which will be used to produce ultra-fast XUV pulses through high harmonic generation. These synchronised sources will then be coupled to a number of beam-lines with end-stations for materials science, surface science and atomic and molecular physics and chemistry (Figure 1). The aim is to combine frontier femtosecond optical and synchrotron technologies and enable new science in the emerging field of ultrafast x-rays.

Laser beamlines

The Artemis facility will provide a variety of ultrafast, synchronised laser beamlines which can be configured flexibly either to generate XUV or as pump and probe pulses. The basis of the facility will be a 14 mJ, 25 fs, 1 kHz Ti:Sapphire CPA system operating at 780 nm. Part of the output energy will be split and spectrally broadened in a gas-filled hollow fibre and recompressed using chirped mirrors to give sub-10 fs pulses. This technology has already been successfully implemented in Astra TA1, where 0.3 mJ, 10 fs pulses are now routinely available. The laser system will be carrier-envelope phase controlled [1], providing few-cycle pulses with precisely defined optical electric fields. Part of the 14 mJ, 25 fs output will also be used to drive a widely tuneable OPA system, providing 30-100 fs pulses from 195 nm to 20 microns.

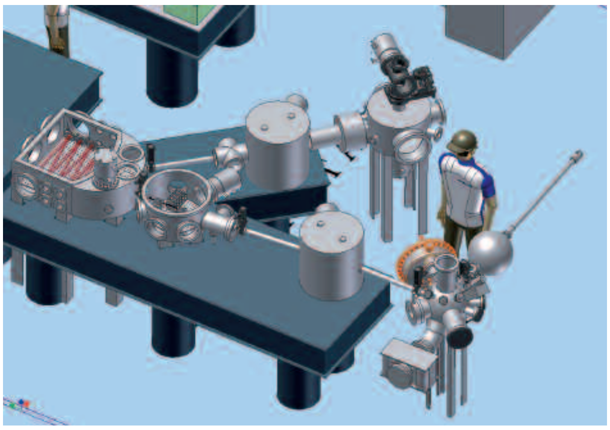

Figure 1. Layout of the Artemis XUV beamlines showing, from left to right, the harmonic generation chamber, monochromator, two relay imaging chambers, atomic and molecular physics station, materials science station.

XUV beamlines

XUV radiation in the wavelength range 10 – 100 nm (10 – 100 eV) will be produced through high harmonic generation (HHG) in a gas target. The resulting XUV radiation will have similar pulse-duration to the drive laser pulse, contain laser harmonics from 10eV to ~300eV and be synchronised to the drive laser pulse with sub-fs resolution. With conversion efficiencies up to 10^{-6} at 30 eV, we estimate a photon flux of up to 10^{11} photons s^{-1} per harmonic.

The XUV generated will be delivered to the interaction stations in two beamlines – one for broadband and one for monochromatised XUV pulses. Both of the beamlines will provide spectral filtering with a selection of thin metallic filters, focusing and recombination with pump or probe laser beams.

For experiments requiring wavelength and bandwidth selection, the harmonics will pass through a state of the art high resolution XUV monochromator for ultrashort pulses. This is being designed and built in collaboration with the LUXOR Laboratory of the Italian National Council of Research. The monochromator exploits the off-plane mounting of a plane grating and limits the time spread of the pulses, maintaining a good resolving power and high efficiency. The instrument is equipped with four interchangeable diffraction gratings to cover two spectral ranges with either high resolving power or short pulse duration, as shown in table 1.

Grating 1	20-40 eV (62-31 nm)	10fs	$\lambda/\Delta\lambda$ 26@46 nm (27 eV)
Grating 2	100-35 eV (12-31 nm)	10fs	$\lambda/\Delta\lambda$ 23@20 nm (62 eV)
Grating 3	20-40 eV (62-31 nm)	56fs	$\lambda/\Delta\lambda$ 100@46 nm (27 eV)
Grating 4	100-35 eV (12-31 nm)	40fs	$\lambda/\Delta\lambda$ 70@20 nm (62 eV)

Table 1. Calculated performance of the monochromator for each of the four interchangeable gratings.

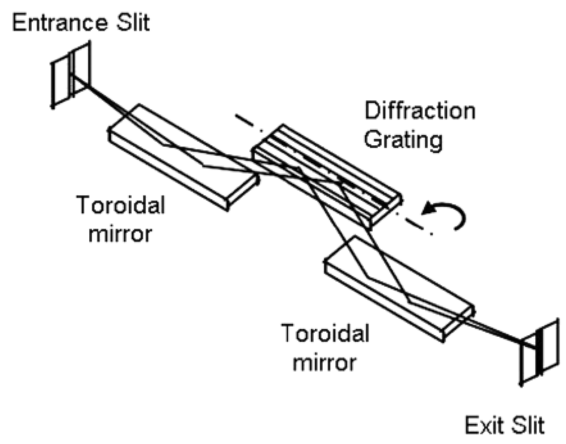

Figure 2. The pulse-length preserving monochromator.

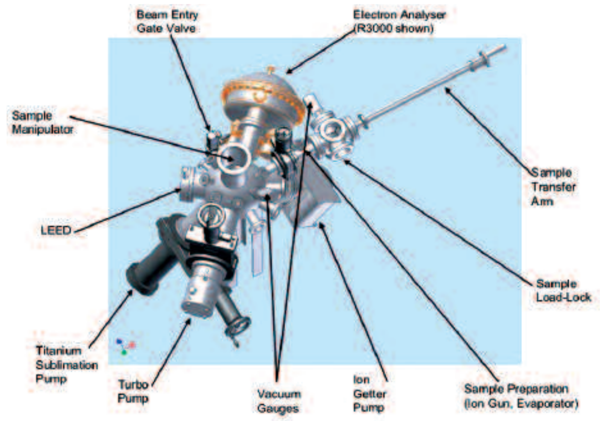

Figure 3. Schematic of the Materials Science Station.

The optical design is compact and is formed by three elements: two toroidal mirrors, one at the entrance to collimate the input radiation and one at the exit to focus it on the exit slit, and one plane grating (Figure 2). The whole instrument can be mounted in a vacuum chamber of 50cm diameter.

The output of the monochromator will be imaged onto the interaction region with 1:1 magnification using a gold, toroidal mirror at grazing incidence. In the broadband XUV beamline, a similar mirror images the high harmonic source. As grazing incidence toroidal mirrors can introduce large amounts of coma, the spot-size of the XUV pulses will be measured by imaging the fluorescence induced by the XUV pulses on a crystal such as Cerium-doped YAG that fluoresces in the visible [2]. Recombination of the XUV pulses with a pump or probe laser beam can be achieved through several techniques. The XUV can be passed through a gold mirror with a small central hole, while reflecting the much larger laser beam off it. Alternatively, the laser beam can be transmitted through a thin silicon flat at Brewster's angle and XUV wavelengths >25 nm reflected.

The XUV radiation will be spectrally characterised using a flat-field spectrometer. This instrument is formed by a spherical diffraction grating mounted at grazing incidence. The instrument will detect radiation from 10nm to 45nm with a theoretical resolution of about 200. The detector consists of a 40mm double stage MCP with a phosphor screen attached and a fast CMOS camera to allow single shot operation at 1kHz. This instrument will also enable measurement of the carrier-envelope phase of the drive laser pulses [3].

The Materials Science Station

The materials science station consists of a UHV ($< 2\times10^{-10}$ mbar) chamber, a five-axis manipulator with helium 'cold finger' offering sample temperature <10K and a hemispherical analyser equipped with a 2-dimensional detector for energy- and angle-resolved photoemission experiments (Figure 3).

Monochromatic XUV pulses can be combined on the sample, with variable time-delay, with 10 fs IR pulses and the broadly tuneable output from the OPAs. The availability of short pulses and multiple wavelengths extends the station's capabilities by offering pump-probe techniques for time-resolved photoemission experiments to investigate coherent control and Fermi surface dynamics in complex oxides, non-adiabatic melting of charge order and Mott-gap dynamics as well as ultra-fast core-level photoemission.

The station consists of a spherical main chamber constructed from mu-metal, to reduce the effect of stray magnetic fields. Attached to the main chamber is a separate load-lock system which greatly increases sample turn-around time, reducing the down-time that is associated with vacuum pumping and bake-out. A magnetic transfer arm allows the sample to be easily transferred from the separate load-lock chamber to the sample manipulator. The high-resolution manipulator offers the opportunity for spatial and angular mapping of samples.

The chamber will include facilities for cleaving bulk samples and a LEED for characterisation of the surface. A helium discharge lamp will be available for off-line alignment of the analyser and calibration of the energy resolution. In the future, provision for a wide-range of sample preparation techniques will be included, such as an ion gun for sample cleaning and evaporators and sputterers.

Surface Science Station

A surface science chamber has been built as collaboration between the University of Nottingham and the Lasers for Science Facility [4] and we aim to use this on the Artemis beamlines. The chamber includes an argon ion sputter gun for surface cleaning, Auger electron spectroscopy and LEED for checking sample surface contamination and reconstruction, sample manipulator with helium 'cold finger' and a mass spectrometer for line-of-sight temperature programmed desorption. The interaction station will be fitted with dry vacuum pumps before installation on the Artemis beamlines. The surface science station will allow investigations of time-resolved ultraviolet photo-electron spectroscopy from adsorbate-substrate systems such as nuclear dynamics of photo-initiated processes on metal surfaces, studies of negative ion resonances in molecular adsorbates on metals, surface photodissociation processes and vibrationally promoted surface reactions.

Atomic and Molecular Physics Station

The atomic and molecular physics chamber will be designed for strong-field experiments on gas and cluster targets. The differentially pumped, skimmed gas-jet source will enable experiments on cooled molecules and clusters.

This interaction station will permit experiments such as studies of the dynamics of aligned molecules, control of electron recollisions, tomographic imaging of 3D molecular orbitals, intramolecular Coulomb decay in clusters and dynamics of biological processes. The interaction station will initially be set up with a photoelectron time-of-flight detectors to enable XUV pulse-length measurements though XUV-IR cross-correlation.

Project Progress

The Artemis project is funded through a £1.5M Facility Development grant awarded for a 2.5 year project that started in October 2006. Few-cycle, carrier-phase controlled pulses will become available in early 2008 and the XUV beamlines will come on-line throughout the year.

References

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