Facility upgrades for Artemis: new and upgraded XUV beamlines

The Artemis facility has recently moved into new labs in the Research Complex at Harwell and had a major upgrade of capability, with a new 100 kHz laser system and new beamlines. In 2020-21, we focused on developing the vacuum beamlines that allow us to generate ultrashort pulses in the extreme ultraviolet (XUV) through high harmonic generation (HHG), select the XUV wavelength, and re-focus them on target at the end-stations.

Artemis facility upgrade

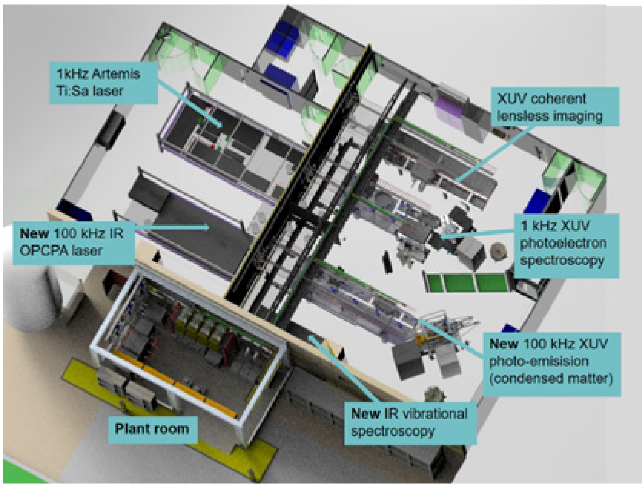

Figure 1: New Artemis labs in the Research Complex at Harwell

The new lab (Figure 1) contains four independent beamlines that support user experiments in time-resolved photoemission from the gas and solid states using HHG probes, XUV coherent imaging, and IR spectroscopy. The two laser systems are housed in a temperature- and humidity-controlled laser room, while the experimental stations are in the neighbouring room. A plant room segregates compressors and mechanical pumps from the lab, so as to reduce noise and vibrations in the measurement area.

Artemis has a new, 100 kHz laser system, based on optical parametric chirped pulse amplification of the output from a Yb:YAG thin-disc pump. The laser produces 50 fs pulses at 1750 nm wavelength with an average power of 20 W. It can also be tuned to produce 100 fs pulses across the wavelength regions from 1430-1850 nm and 2330-3680 nm. This laser currently serves our IR spectroscopy area and a new beamline that is being built for the material science program. This will ultimately support beam times for pump-probe photoemission spectroscopy with improved signal-to-noise characteristics, and will also be the basis for new capabilities in pump-probe transient absorption spectroscopy. The beamline will generate short pulses in the tens of fs regime, with photon energies of tens of eV through HHG.

The 1 kHz KLM Labs Red Dragon titanium-sapphire laser system that has served Artemis since 2008 has been refurbished with new Pockels cells, stretcher and compressor upgrades, and a third amplifier. This laser primarily serves beamlines for XUV coherent imaging, and for gas-phase time-resolved photoemission spectroscopy. The combination of laser upgrades and improvements to the XUV beamline has increased XUV flux on target by an order of magnitude.

New 100 kHz XUV beamline

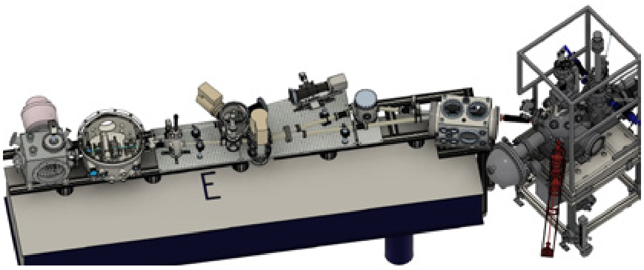

Figure 2: New 100 kHz XUV beamline for Artemis. The laser enters from the left and generates harmonics in the first chamber. This is followed by a time-preserving monochromator and focusing optics. The end-station for time-and-angle-resolved photoemission is shown on the right

As part of the upgrade and relocation of Artemis to the Research Complex at Harwell, we are installing a new beamline dedicated to materials science and transient absorption experiments with the tuneable 100 kHz laser (Figure 2). The beamline consists of a differentially pumped high harmonic generation (HHG) source for the production of extreme ultraviolet (XUV) radiation (optimised in the 20-50 eV photon energy range but with the potential capability to extend beyond the carbon K-edge); a time-preserving monochromator; flat-field XUV spectrometer; dual-magnification XUV relay imaging; and materials science end station.

The main objective for materials science at 100 kHz is to increase the data acquisition rate whilst maintaining the photon density per pulse, and thus maintaining the space-charge. The benefits of this are two-fold: (1) to reduce the data collection time and/or allow a wider parameter space to be studied; and (2) to enable a reduction of the XUV spot size to match the sample or domain sizes (down to the 10 µm level).

The objective for transient absorption spectroscopy is to allow high spectral resolution measurements to be performed at photon energies up to and potentially beyond the carbon K-edge. The higher repetition rate and stability of the laser should significantly improve the signal-to-noise and thus enable pump-probe measurements to be performed at these photon energies.

Table 1 below lists estimated expected parameters for initial materials science experiments on the beamline, based on modelling and benchmark experiments performed on our 1 kHz beamline.

Photon parameter	Expected performance of 100 kHz XUV beamline
Probe energy range	15 – 45 eV initially. Higher photon energies will be offered later.
Pump energy range	λ = 850 – 900 nm, 1700 – 1800 nm, and 2650 – 2950 nm initially.
Energy resolution (limited by short-pulse characteristics and by space charge)	~100 meV expected (Photon-energy and pulse-length dependent)
Time resolution (limited by pulse lengths of pump and probe)	~50 fs expected
Beam spot size at normal emission	<100 μm expected; smaller spot sizes to be pursued over the course of subsequent development
Probe flux	Expected: ~10^5 photons/pulse (~10^{10} photons/second) at about 25 eV
Pump fluence	Expected: several mJ/cm^2/pulse. Under development.
Probe polarization	Linear polarization, *s* or *p*
Pump polarization	Fully controllable

Table 1: Expected performance parameters of the 100 kHz XUV beamline

XUV radiation is produced via HHG in a purposely-designed differentially-pumped vacuum chamber. A gas cell/jet is inserted into a small conically shaped chamber, attached to a high-throughput pump and isolated from the main chamber using pinholes matched to the size of the optical beam. This should allow gas pressures in the generation region to reach above 1 bar whilst maintaining a vacuum level better than 10^{-4} mbar. The backing gas pressure can be controlled digitally. Three motorised stages allow the gas target to be positioned with micrometre accuracy, with a longitudinal travel of 50 mm. This should allow the optimal and repeatable phase matching conditions to be achieved reliably for the given optical source. A second pinhole is used to isolate the subsequent mono-chromator chamber.

After generation, a single harmonic can be selected using a time-preserving monochromator that uses gratings in conical diffraction geometry at grazing incidence to maximise throughput with minimal temporal and spatial aberration.[1] This has been specifically designed for the highly divergent beams expected from the required focusing geometry. It consists of three interchangeable gratings with maximum efficiency in the 20-45 eV and 60-100 eV photon energy ranges. The performance specification of the harmonics will depend on the grating and the mode of operation of the laser. The spectral resolution will be limited by the bandwidth of the harmonics (~1 eV in short pulse mode and >100 meV in long pulse mode), with a high temporal resolution (tens of femtoseconds in short pulse mode and hundreds of femtoseconds in long pulse mode). In addition, the monochromator can be by-passed to allow the HHG source to be relay imaged onto the exit slit of the monochromator, providing access to the full harmonic spectrum or the use of fixed transmission filters.

Two fully automated beam paths are available to relay-image the exit slit plane of the monochromator onto the sample in the end station. A single grazing incidence toroidal mirror will allow 1:1 imaging, yielding a spot size of ~100 μm and providing maximum flux on the sample.

Alternatively, a double toroid arrangement[2] specifically designed for this beamline can be used to give better than 3:1 demagnification, compensating the elongated beam from the monochromator, and giving a spot size on the order of 20 μm with monochromatisation and <10 μm using the grating by-pass (e.g. with fixed transmission filters). High precision six-axis stages allow spatial aberrations to be fully minimised and enable switching between the XUV beam paths without the need to realign the optical pump.

Upgrades to 1 kHz XUV beamline

Figure 3: Upgraded 1 kHz XUV beamline with monochromator.

The Artemis 1 kHz XUV beamline has also been overhauled and improved as part of the upgrade project (Figure 3). Improvements include a new, more compact chamber for high harmonic generation, similar to that on the new 100 kHz beamline, and upgrades to the differential pumping and positioning of the gas-jet. The geometry of the beamline has been changed, with the path lengths between the XUV focus and the first toroidal mirror in the monochromator, and from the second toroidal mirror to the grating exit slit, increased to 600 mm. This reduces the rate of damage to the optics, which always deteriorate over time due to the gas-jet being slightly ablated and metal being deposited on the mirrors. The toroidal mirrors in the beamline have been replaced, and this has increased the throughput of the beamline by about a factor of 10. The measured XUV flux after the monochromator is now ~2 x 10^{10} photons/sec at 30 eV. We are carefully monitoring the mirror surfaces and quality of the exit slit in order to maintain this performance. The flux can be increased further by generating harmonics of the second harmonic of the laser at 400 nm.

After the monochromator, the XUV pulses are refocused into the end-stations with a gold-coated mirror used at grazing incidence. The XUV can be recombined inside the end-station, with laser pulses at wavelengths from the ultraviolet to the far-infrared for pump-probe experiments. The high XUV flux and UV pump makes this beamline particularly well-suited for gas-phase chemistry.

Conclusions

Artemis is now installed in its new lab in the Research Complex at Harwell, and has carried out major upgrades to its capabilities. With a new laser, upgrades to the existing laser, new beamlines, and a new lab layout, users can expect major improvements in measurement capabilities and in the user experience. More details of the current status are posted on our website.[3]

References

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