Overview of the Central Laser Facility (CLF)

Cristina Hernandez-Gomez
Associate Director, Head of High Power Lasers

Introduction

The CLF is a world-leading centre for research using lasers in a wide range of scientific disciplines. This section provides an overview of the capabilities offered to our international academic and industrial community.

Vulcan

Vulcan is a versatile high power laser system composed of Nd:glass amplifier chains capable of delivering up to 2.6 kJ of laser energy in long pulses (nanosecond duration) and up to 1 PW peak power in a short pulse (500 fs duration) at 1053 nm. It can deliver up to eight beam lines. Two of these beam lines can operate in either short pulse mode or long pulse mode, while the remaining six normally operate in a long pulse mode. The short-pulse can be directed to two different target areas, enabling sophisticated interaction and probing experiments, with all eight beamlines available to one target area (TAW).

In this configuration, the facility delivered four full academic experiments and one commercial experiment.

Following these, the Vulcan facility was decommissioned in advance of the start of the demolition and building work needed for the Vulcan 20-20 project. Decommissioning work began in October 2023 and was completed in February 2024.

The upgrade agreed will see the power of Vulcan increased by a factor of 20, to 20 PW, and its focused intensity increased by a factor of 100.

Gemini

Gemini is a dual-beam petawatt-class Ti:Sapphire laser system that provides unique capabilities for relativistic laser-matter interactions and secondary source production. With 30 J on target in two beams, an intensity greater than 10^{21} Wcm^{-2} and a repetition rate of three shots per minute, the extreme concentration of energy possible with Gemini makes it one of the most intense lasers in the world.

Gemini Target Area 3 (TA3) is the main target area with access to both Gemini beams (15 J, 35 fs) that can be focussed using f/20 or f/2 parabolic mirrors at a rate of one shot per 20 seconds. Plasma mirrors are optional in one beamline. The maximum intensity is of order 2×10^{21} Wcm^{-2}.

During 2023/24, TA2 was closed for user operations to set it up for EPAC prototyping and testing. TA2 is being setup for a mock-up electron beamline at 5 Hz, which will de-risk much of the development for the EPAC laser wakefield area.

Target Fabrication

The Target Fabrication (TF) group works closely with the user community to provide delivery, characterisation and support of high specification micro-targets.

During 2023/24, the TF group made the majority of the solid targets shot on the CLF's high-power lasers, and also supported target design for the academic access on the Orion Facility at AWE.

The TF group has also supported the Lasers for Science Facility (LSF) with microfabrication capabilities to enable their experimental campaigns, and provided support for the wider STFC community with micro-fabrication. Commercial access to target fabrication capabilities was available to external laboratories and companies via the spinout company Scitech Precision Ltd.

In addition to this work, the Group has remained focused on delivery of target solutions for day one operations in EPAC. Further experiments were carried out on the tape drive system, further increasing confidence in the system ahead of EPAC installation. In collaboration with the SCAPA team at the University of Strathclyde, work continued to increase the shot rates and to add triggers to synchronise the system to the laser. The TF group is procuring a coating plant to integrate the tape roller system, which will enable the coating of tapes up to 50 m in length in one operation: this capability is key for high-repetition-rate (HRR) operations.

Liquid targets will also be essential for EPAC operations, and the TF group has designed and built a system to provide thin liquid sheets. A delivery system, nozzle and catcher system were installed in EPAC, and the target was run out of vacuum to test imaging and characterisation set ups.

The TF group continues to develop robotic target assembly. This capability is used as standard for HRR experiments.

Theory and Modelling

The Plasma Physics Group (PPG) supports scheduled experiments throughout the design, analysis and interpretation phases, as well as users who need theoretical support in matters relating to CLF science. In the 2023-24 period, the Group continued to base its support model around: direct collaborative support; code development; code hosting; and high performance computing (HPC) provision.

Direct collaborative support is greatly enhanced by the computational resources, externally sourced codes, and in-house codes available to the PPG. As well as maintaining a suite of in-house codes that are used by PhD students and in user support projects, PPG is working to expand the code portfolio.

The PPG continued to provide the PRISM computational suite to five different user groups, as well as access to the HYADES and h2D codes.

Alongside the core mission of the PPG, the group continues to engage with the academic community to contribute to Laser fusion research.

Artemis (Research Complex at Harwell)

Artemis is an ultrafast XUV science facility, using high harmonics to investigate electron dynamics in condensed matter and gas-phase molecules, and for lensless imaging.

The oscillator for the 100 kHz laser system, which is now used for all condensed matter experiments, was replaced and is now working well. At 100 kHz, condensed matter experiments continue to benefit from the smaller XUV spot sizes and better energy and angular resolution achievable with this higher repetition rate. The gas-phase experiments on the 1 kHz system continue to work well, with increased XUV flux and a new effusive gas source, and the user community is expanding.

This was an intense year for Artemis, with the start of the HiLUX upgrade project managed alongside operations. The HiLUX project is set to transform the CLF's ultrafast spectroscopy capability and increase accessibility, with upgrades to both the Ultra and Artemis facilities that will increase in average laser power and repetition rate and data rate, unlocking new science applications and greatly reducing timescales to results.

The HiLUX project has completed its first year, and the design of the new laser system within Artemis is complete. It will consist of three synchronised 200 W Yb:KGW lasers operating at 100 kHz: the output of one laser will be compressed to 1.5 mJ in 50 fs and used for high harmonic generation; a second will drive OPAs, providing short pulses from the UV to the MIR; and a third will provide longer, 0.8 mJ pulses for molecular alignment experiments. The concept design for the new materials science end-station has also been completed and will provide a UHV chamber with a momentum microscope, a more advanced hemispherical analyser, and a six-axis manipulator.

Ultra (Research Complex at Harwell)

The structural dynamics facilities at Ultra explore molecular structure during changes, such as chemical reactions or dynamics in complex environments, such as heterogeneous catalysts. Ultra's unique combination of multiple laser amplifiers provides light across UV to IR for electronic and vibrational spectroscopies and measures dynamics across femtoseconds to seconds, to address a diverse portfolio of scientific challenges. The scientific themes span studies of drug binding and protein folding to observation of battery charging and structural changes through catalytic cycles. The available techniques provide sensitive time-resolved vibrational and electronic absorption spectroscopies and Kerr-gated Raman spectroscopy to observe weak signals obscured by strong sample emission.

The whole Ultra team has also been engaged in the HiLUX project. The Ultra A system has been decommissioned and the labs cleared ready for renovation. The design of the new facilities has been completed and will be able to accommodate the new laser systems consisting of five synchronised ytterbium amplifiers, which will pump an unprecedented array of optical parametric amplifiers to support five end-stations servicing time-resolved spectroscopy experiments from the few femtosecond to second, UV to IR.

Octopus (Research Complex at Harwell)

In the imaging area, the Octopus cluster offers a range of microscopy stations linked to a central core of pulsed and CW lasers, offering “tailor-made” illumination for imaging. Optical resolution techniques offered include total internal reflection (TIRF) and multi-wavelength single-molecule imaging, confocal microscopy (including multiphoton), fluorescence energy transfer (FRET), fluorescence lifetime imaging (FLIM), and Light Sheet Microscopy. Super-resolution techniques are also available: 2D and 3D Stochastic Optical Reconstruction Microscopy (STORM), Photo-activated Localization Microscopy (PALM), Structured Illumination Microscopy (SIM), gated 3D Stimulated Emission Depletion Microscopy (STED), 3D MINFLUX, and super-resolution cryo-microscopy. Laser tweezers are available for combined manipulation/trapping and imaging with other Octopus stations, and can also be used to study Raman spectra and pico-Newton forces between particles in solution for bioscience and environmental research. Two cryo focused ion beam scanning electron microscope (FIB-SEM) systems are also available. One is dedicated to 3D volume electron imaging, and the other, currently being commissioned, is dedicated to the preparation of lamellas and lift-out to prepare samples for cryo electron tomography. This latter system forms part of a correlative light and electron microscopy (CLEM) workflow currently under development.

Chemistry, biology, and spectroscopy laboratories support the laser facilities, and the CLF offers access to a multidisciplinary team providing advice to users on all aspects of imaging and spectroscopy, including specialised biological sample preparation, data acquisition, and advanced data analysis techniques. Access is also available to shared facilities in the Research Complex, including cell culture, scanning and transmission electron microscopy, NMR, and x-ray diffraction.

The portfolio of environmentally based research continues to advance, with studies in a wide range of areas including determining aerosol properties relevant to the atmosphere, super-resolution imaging of butterfly wings that relates colour and structure, and plant studies on ultra weak photoemission and endomembrane interaction with organelles. Materials imaging of catalyst structure has used the FIB-SEM technique, in collaboration the UK Catalysis Hub, to follow the compositional evolution of individual nanoparticles.

Regarding facility development, 3D MINFLUX is now established and attracting users, and the development of cryoCLEM facilities has continued. This has extended the CLF’s EPIC collaboration with India into biomedical imaging and will accelerate cryoCLEM developments in Octopus. A novel super-resolution technique based on radial fluctuation microscopy has also undergone preliminary development.

Engineering Services

Engineering is fundamental to all the operations and developments in the CLF. The engineering division operates across all of the CLF's facilities. Mechanical, electrical and software support is provided to deliver the experimental programmes, and the research and development activities. Support can range from making small-scale modifications to existing equipment to improve its performance, through to carrying out larger scale projects, such as the design and development of commercial projects. In addition, there are active engineering collaborations with regional and international partners such as, HiLASE (Prague, Czech Republic), the European XFEL (Hamburg, Germany) and TIFR (Hyderabad, India).

The CLF Engineering and Technology Centre (ETC) is now fully operational and has allowed the Engineering Division to develop capability not previously possible due to space constraints.

The CLF's Mechanical Workshop has taken custodianship of a diamond turn lathe, previously owned by RAL Space PDF department who used it to support the CLF's Target Fabrication Facility. This new capability, in addition to the CNC and wire eroding machines purchased last year, continues to expand the capabilities of the division. The focus has been to develop and upskill staff on this new technology and push the boundaries of target fabrication.

In 2023/24, the Engineering Team took the novel decision to install equipment that would enable production of nitrogen gas from air. The nitrogen generating plant has been successfully commissioned and is now providing the majority of the CLF's nitrogen gas supply.

The Centre for Advanced Laser Technology and Applications (CALTA)

CALTA aims to deliver societal, scientific and economic impact from developments in the CLF.

CALTA continues to support the EPAC Project, which will be driven by a 10 Hz petawatt-class laser enabled by STFC's proprietary DiPOLE laser technology. The next generation of 100 Hz DiPOLE lasers was developed as part of a Widespread teaming project, and was shipped to the ELI Beamlines Facility in autumn 2023.

Commissioning of the D-100X laser system at the European XFEL has been completed, and it exceeded all expectations on its first experiment in spring 2023. While not operating at its full energy and repetition rate quite yet, the D-100X laser delivered up to 40 J of energy per pulse at up to 1 Hz in the green, generating highly reproducible data at a rate not previously possible.

The Extreme Photonics Applications Centre (EPAC)

EPAC, a new facility at the CLF, has been designed to further the development and application of laser-driven accelerators in academic, industrial, medical and defence spheres.

EPAC will initially deliver a petawatt laser operating at 10 Hz to two dedicated experimental areas housed in a stand-alone building. In order to achieve this high peak power and repetition rate, DiPOLE technology will be used to pump a high energy titanium sapphire amplifier operating at 10 Hz.

The first experimental area (EA1) will be especially designed for laser wakefield acceleration (LWFA), where multi-GeV electron beams and synchrotron-like x-ray beams can be generated. The second experimental area (EA2) will be a very versatile area for fundamental science and applications with flexible focusing geometries.

The EPAC project continues to make good progress, with installation, design work and commissioning all now running in parallel.

Access to Facilities

The CLF operates “free at the point of access” and is available to any UK academic or industrial group engaged in open scientific research, subject to external peer review. European collaboration is fully open for the high power lasers, whilst European and international collaborations are also encouraged across the CLF suite for significant fractions of the time. Dedicated access to CLF facilities is awarded to European researchers via the Laserlab-Europe initiative (www.laserlab-europe.net) funded by the European Commission.

Hiring of the facilities and access to CLF expertise is also available on a commercial basis for proprietary or urgent industrial research and development.

Industrial access and partnerships

The Impact, Partnerships and Innovation (IPI) Group has been responsible for the delivery of the industrial access and establishing new collaborations with industry. The IPI group ensures that the interactions delivered are strategically aligned to the CLF and of the highest economic and societal impact to the UK. This year, industry contract-access projects has continued across all CLF facilities.

The CLF remains a strong department for innovation. Internationally, the CLF has driven forward its innovation policy and the growth of industry liaison offices, through shared learning and knowledge exchange across EU laser facilities. The CLF was a project partner organisation on the European Horizon 2020 IMPULSE project (completed January 2024).

Please visit **clf.stfc.ac.uk** for more details on all aspects of the CLF.