Overview of the Central Laser Facility (CLF)

Cristina Hernandez-Gomez
Central Laser Facility, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK
Email address: **cristina.hernandez-gomez@stfc.ac.uk** Website: **www.clf.stfc.ac.uk**

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 that is 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 currently has 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 and long-pulse systems operating jointly can be directed to two different target areas, enabling sophisticated interaction and probing experiments.

We have started to build the new short-pulse OPCPA beamline for the Vulcan TAP area, which will deliver a PW-level pulse (30 J in 30 fs) in addition to the existing PW (500 J, 500 fs) and long pulse (250 J) capabilities. The old Target Area East has now been refurbished as a new laser area (LA5) and will become the front-end for this beamline, housing the initial stages of amplification. The final stage of amplification will take place in laser area 4, which has been enlarged to accommodate this.

New ways of working were implemented during the COVID-19 pandemic to allow operations to continue with fewer people within the facility. These included the remote operation of diagnostics, switch-on of laser systems, and shot sign-off.

GEMINI

Gemini is a Titanium-Sapphire based dual-beam high power laser system with two synchronised Petawatt-class beams, enabling pump-probe studies at extreme light intensities (>10^{21} Wcm^{-2}). Many experiments in Gemini focus on the study and development of laser-driven plasma accelerators, with a view to employing these unique sources in a wide range of applications. Operations in Gemini this year were significantly affected by COVID-19 as it took over three-and-a-half months to get the facility back to being operational in mid-August 2020, following the initial nationwide lockdown in March 2020. Despite this interruption, the experiments in Gemini were quite successful. Highlights include using the x-rays from a laser-driven accelerator for study of extreme conditions through X-ray Near-Edge Spectroscopy, and testing out liquid-based targetry for laser-driven plasma accelerators, which will be invaluable for operations in EPAC.

TARGET FABRICATION

The Target Fabrication 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. Commercial access to target fabrication capabilities was available to external laboratories and experimentalists via the spinout company Scitech Precision Ltd.

A range of microtarget types were produced to enable the exploration of several experimental regimes. Fabrication techniques included thin film coating, precision micro-assembly, laser micromachining, and chemistry processes, all verified by sophisticated characterisation. STFC's advanced capabilities in both high precision micromachining and MEMS microfabrication were also utilised. The Group's processes and component tracking system provided a high level of traceability.

Further progress was made in developing a high stability, high rep-rate (HRR) tape drive, which was tested on Gemini. By collaboration with several Indian institutions through EPIC, advances were made in the production of complex tapes for novel HRR applications and experiments. Progress continued in the robotic assembly of target arrays. Work with Octopus on the assembly of advanced micro optics enabled a number of high profile publications.

THEORY AND MODELLING

The Plasma Physics Group supports scheduled experiments throughout the design, analysis and interpretation phases, as well as users who need theoretical support in matters relating to CLF science. We support principal investigators using radiation hydrodynamics, particle-in-cell, hybrid and Vlasov-Fokker-Planck codes, as well as by providing access to large-scale computing (SCARF).

Despite the on-going problems with the COVID-19 pandemic, the PPG staff endeavoured to continue to fulfil this mission, as the nature of the group's work is largely compatible with remote working.

The elements of support for users that involve students have all had to be carried out remotely, but this has largely been successful. The provision of the PRISM suite and other such resources have allowed us to continue strong support for users even in this difficult time.

ARTEMIS

(Research Complex at Harwell)
Artemis is the CLF's facility for ultrafast laser and XUV science. It offers ultrashort pulses at high repetition rate, tuneable over the spectral range from the XUV (10-100 eV) to the far-infrared, and with pulselengths down to a few optical cycles. Ultrafast, coherent XUV pulses are produced through high harmonic generation and delivered through vacuum beamlines to end-stations for gas-phase chemistry, materials science and imaging. Experiments in Artemis use XUV to investigate ultrafast dynamics in experiments on gas and solid materials, and for coherent lensless imaging.

Artemis has recently moved across campus to newly refurbished labs in the Research Complex at Harwell (RCaH), and undergone a major upgrade, adding a new laser system and a third XUV beamline. Over 2020-21, commissioning started on the new laser system, which produces 1700 nm and 3000 nm pulses at 100 kHz repetition rate, and is a joint purchase with Ultra. A new XUV beamline for this laser was designed and procured. The existing 1 kHz Ti:Sapphire system and XUV beamline have been upgraded and refurbished for higher XIV flux, and these were commissioned. The first user experiment in the new labs has also taken place.

OCTOPUS AND ULTRA

(Research Complex at Harwell)
The CLF operates two other facilities in the RCaH: Ultra, for ultrafast molecular dynamics measurements in chemistry and biology, and Octopus, a cluster of advanced laser microscopes for life science research.

Ultra provides state-of-the-art structural dynamics facilities, to explore reactions in nature, energy capture and storage, catalysis and fundamental quantum level research on molecular and bio-molecular electronics, probes, therapeutics, enzymes and DNA. By utilising unique multiple laser amplifier combinations, the facility can address a wide range of problems, having the capability to access UV to IR or narrowband and broadband energy transitions, measuring dynamics across femtoseconds to seconds. A wide range of techniques are available, based on the ultrafast laser systems, providing highly sensitive time-resolved vibrational and electronic spectroscopies, as well as advanced steady-state vibrational spectroscopy techniques to observe specific interface species, with sum-frequency-generation, or weak signals obscured by strong emission from samples, with Kerr-gated

Raman. Recent developments have incorporated new high-speed spectrometers and data processing, and explored novel high average power Raman systems.

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) with adaptive optics, Photoactivated 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. A cryo focused ion beam scanning electron microscope (FIB-SEM) is also available for 3D volume electron imaging. This 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.

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), XFEL (Hamburg, Germany) and TIFR (Hyderabad, India).

This year, we have commissioned the design of a new building for Engineering, which will bring all the engineering lab spaces together into a central hub. Not only will this building provide increased space to build and test infrastructures, but it will also offer space to upskill the existing teams and support the training and development of apprentices. The ground floor of the new building will focus on manufacturing from raw materials, and the building of large structures and systems. This floor is expected to become operational in autumn 2022, once machinery has been relocated and recommissioned. The first floor will come online later, and will support the more delicate and intricate building and testing of components and sub-assemblies/sub-systems.

CENTRE FOR ADVANCED LASER TECHNOLOGY AND APPLICATIONS (CALTA)

The Centre for Advanced Laser Technology and Applications (CALTA) is developing a new class of laser, capable of delivering high energy, high peak power pulses at high repetition rate and high efficiency. Based on laser diode pumped Ytterbium-YAG in the form of a transparent ceramic, CALTA's DiPOLE Diode Pumped Solid State Laser (DPSSL) architecture has demonstrated stable 1 kW operation for extended periods in 150 J, 10 ns pulses delivered at 10 Hz. With an overall optical efficiency of >20%, DiPOLE systems have the potential to transform single shot demonstrations of effects into real world applications.

Following construction and commissioning at RAL in 2019, CALTA's most advanced 1 kW D-100X DiPOLE laser, was delivered to the HZDR laboratory in Hamburg as a UK contribution to the European XFEL facility. There it will be used to drive materials to high energy density states, to be diagnosed using the XFEL X-ray beam.

Commissioning of D-100X by CLF and HZDR staff has made progress, but COVID lockdowns and travel restrictions have inevitably delayed things. It is hoped that this phase of the project will be completed in the first few months of next year.

Access to CLF's development laboratories has been severely limited during the year, but the opportunity has been taken to continue the design work, computer modelling and simulations that underpin CALTA technology.

EXTREME PHOTONICS APPLICATIONS CENTRE (EPAC)

The Extreme Photonics Applications Centre (EPAC), which is under construction at the CLF, will enable the development of a transformational generation of laser-driven radiation sources and accelerators, and will maximise their scientific and economic exploitation through engagement of multiple end-user communities.

EPAC will initially deliver a PW laser operating at 10 Hz to three 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, with a third area still to be specified.

ECONOMIC IMPACT OVERVIEW 2020-2021

This year the facilities were significantly impacted by COVID-19. To ensure the safety of our staff, restrictions were put in place, but these directly affected our operational delivery. This year industry contract-access projects amounted to 14 facility access weeks, delivering experimental access to Gemini, Ultra and Octopus, and access to CLF scientific expertise.

New to this year, the Lasers for Science division introduced a COVID-10 Rapid Access mechanism to provide facility access for R&D related to the fight against COVID-19. This facility access 'rapid response' route was a particular success, with most projects led by or including an industry partner. The rapid nature of this unique call enabled the laser facilities to respond quickly to the needs of COVID-19 research, both diagnostic and R&D. The call delivered an additional six weeks of facility access with an industrial partner.

Internationally, the CLF is a project partner organisation on the European Horizon 2020 project IMPULSE (Integrated Management and Reliable Operations for User-based Laser Scientific Excellence) that kicked off this year. This year, a project team was also established with the Extreme Photonics Innovation Centre (EPIC), CLF's partner centre in India, and work has already begun on target fabrication design and developments to advance the capabilities of our facilities.

Despite the effects of COVID-19 on the facilities, CLF scientists continued to be creative and drive forward the innovation portfolio. An additional four proof-of-concept projects were introduced and the CLF filed two new patent families this year, giving a current total of 23 active patent families.

ACCESS TO FACILITIES

The CLF operates "free at the point of access", 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.

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