Overview of the Central Laser Facility (CLF)

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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.

The installation of the new short-pulse OPCPA beamline (VOPPEL) has continued: this beamline aims to deliver a PW-level pulse (30 J in 30 fs) to the Vulcan Petawatt Area (TAP) in conjunction with the existing PW (500 J, 500 fs) and long pulse (250 J) capabilities. The new laser area (LA5) houses the VOPPEL Front End and initial I stages of amplification, and the commissioning of these systems in LA5 has started. In addition, building work in TAP enabled the floor to be strengthened for the new compressor chamber vessel, which has now been installed.

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. Gemini is one of the leading centres for laser-driven plasma accelerators and applications. In the reporting year, Gemini managed to recover from COVID-affected operations, running a full programme of experiments. Ventilation levels in Gemini target area were also improved, which allowed us to get back to the pre-COVID levels of occupancy in the experimental area.

The highlight from this period is the production of 10s of MeV carbon ions using radiation pressure acceleration. This experiment, led by the Queen's University Belfast optimised the mechanism to preferentially accelerate carbon ions over contaminant hydrogen – an important result for the use of heavy ions for radiobiology applications.

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 companies via the spinout company Scitech Precision Ltd. The group also supported the LSF with microfabrication capabilities to enable their experimental campaigns.

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 the development and experimental fielding of a high stability, high rep-rate (HRR) tape drive, which was used on experiments in Gemini and on external facilities. In 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, and exploratory work on liquid targetry for EPAC was started in collaboration with SLAC and QUB.

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.

PPG supports 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).

Strong support of users throughout this period has continued, including the provision of the PRISM suite. Alongside the core mission of the PPG, this year also commemorated the contributions of Professor Peter Norreys to the PPG in a symposium to mark his formal retirement from STFC.

ARTEMIS

(Research Complex at Harwell)

This was the first year of operations for Artemis in the Research Complex, following the lab move and completion of the upgrade project.

The first experiments on the 1 kHz beamline started in June, gradually increasing in complexity through the year. The much higher XUV flux obtained on the fully refurbished beamline was appreciated by the users.

Commissioning of the 100 kHz laser continued throughout the year. It has now fully met specifications and continues to work reliably. Engineering work on the 100 kHz beamline was completed by commissioning of the vacuum control system in the summer. The pump laser of the 100 kHz system was used in the autumn for its first experiments. These involved a collaboration with Ultra on Kerr-gated Raman spectroscopy, exploring the advantages of pumping at much higher average power. The team also generated high harmonics with the 100 kHz laser for the first time.

The Artemis and Ultra teams resubmittted their 'HiLUX' proposal for major transformation of the ultrafast spectroscopy and dynamics facilities in autumn 2021, and this has now been approved. For Artemis, this will include replacement of the unreliable 1 kHz system with a 100 kHz Yb-based laser, and upgrades of the materials science and molecular dynamics end-stations to capitalise on the higher repetition rate. The work done to move the facility to new labs and upgrade the infrastructure puts the CLF in an excellent position to implement these new technologies.

ULTRA

(Research Complex at Harwell)

The structural dynamics facilities at Ultra explore molecular structure during changes, such as chemical reactions, or in complex environments. Ultra's unique combinations of multiple laser amplifiers provide light across UV to IR, spectrally narrow and broad, measuring dynamics across femtoseconds to seconds, to address a diverse portfolio of scientific problems. The scientific themes span the dynamics of drug binding and protein folding to structural changes in battery charging and catalytic cycles. The available techniques provide highly sensitive time-resolved vibrational and electronic absorption spectroscopies or Kerr-gated Raman spectroscopy to observe weak signals obscured by strong emission from samples.

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) 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, the CLF Engineering and Technology centre (ETC) building was completed and is now fully operational on the ground floor. The ETC brings 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. All the mechanical teams are now co-located and the electrical teams will gradually join them in the coming year.

THE CENTRE FOR ADVANCED LASER TECHNOLOGY AND APPLICATIONS (CALTA)

CALTA aims to deliver societal, scientific and economic impact from developments in the CLF, and continues to support the EPAC Project and develop the next generation of 100 Hz DIPOLE lasers as part of a Widespread teaming project. Construction of this new 100 Hz DiPOLE system is almost complete and CALTA expects to break new ground in the coming year. The commissioning work of the D-100X system at the European XFEL continues, with the first two stages of the laser amplifier chain now commissioned and operating as expected. Completion of this system will be ready for user experiments in 2023. The in-house DiPOLE 10 J laser was used to demonstrate a new laser shock peening (LSP) technique that does not require a water confinement layer, opening up LSP to a wider range of applications, particularly in combination with CALTA's DiPOLE laser system, for which the beam behaviour can be controlled closely and adapted for optimal results.

THE EXTREME PHOTONICS APPLICATIONS CENTRE (EPAC)

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 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. A third experimental area is still to be specified.

The first and second floor will also have a large office space where staff and long-term visitors will be based. The building is expected to be handed over to the CLF in May 2022.

ECONOMIC IMPACT

This year, industry contract-access projects amounted to 19 facility access weeks, delivering experimental access to Gemini, Ultra and Octopus, along with access to CLF scientific expertise. The level of interaction with industry remained lower than that prior to COVID, as this year was focused on recovering the core funded academic access. This focus will remain for the coming year, and further impact on the industry user programme is anticipated.

The Industry Partnership and Innovation (IPI) Group has been pushing to ensure that the interactions delivered are strategically aligned to the CLF and of the highest economic and societal impact to the UK. Industry access with Rolls Royce was delivered, enabling them to non-destructively test their electric rotor for aerospace. This access not only helped them to gain a better understanding the structural changes, but will also help to drive forward the technological development of EPAC. Other access has also strengthened strategic industry partnerships with Johnson Matthey, UCB Pharma and the MOD's dstl.

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 as a project partner organisation on the European Horizon 2020 IMPULSE project.

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.