Overview of the Central Laser Facility (CLF)

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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 continued the design of a new short-pulse beamline for the Vulcan TAP area based on the technique of OPCPA which the CLF has pioneered. The upgrade 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. This will enable new areas of imaging and combined proton/electron interactions to take place. Designs for the main compressor and turning chambers are complete and in the process of procurement. At the same time, the refurbishment of the old Target Area East is nearing completion – transforming the area into a new laser bay for the new beamline front end and main amplifiers.

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}). In recent years, Gemini has emerged as one of the preeminent centres in the world for laser-driven acceleration. This year, Gemini performed some highly complicated experiments ranging from medical applications of laser-driven ion beams to implementing new techniques for laser-plasma electron accelerators. Experiments studied the biological effectiveness of laser-accelerated ions for cancer therapy, and ultrafast pulsed ion radiolysis with much better time resolution than previously possible. Progress towards operating laser-driven sources at higher repetition rates has included using a train of pulses in Target Area 3 to excite wakefields, thus lowering the demand on laser energy in the future. Operating Target Area 2 at 5 Hz allowed the implementation of feedback techniques that directly optimised secondary sources generated in the plasma. These developments, including machine learning methods, will be crucial to fully exploit upcoming high repetition rate petawatt laser facilities.

An important facility development has been progress towards active stabilisation of the laser beam onto target – for a consistent interaction between the laser pulse and the plasma, fluctuations in beam pointing must be minimised. This is particularly the case in dual beam experiments when the pulses need to be well overlapped both spatially and temporally. A beam stabilisation system was trialled consisting of a fibre-coupled pilot laser back-propagated from a gas cell target. Measurements of the position of this beam fed into a piezo-electrically driven mirror in the laser system that corrected pointing fluctuations at high frequency. This improved laser pointing jitter by a factor of 2.5 and in initial tests reduced electron beam jitter by 20%.

Artemis

Artemis is the CLF's facility for ultrafast laser and XUV science. It offers ultrashort pulses at high repetition-rate, spanning the spectral range from the XUV to the far-infrared. The facility is configured flexibly for pump-probe experiments. Tuneable or few-cycle pulses can be used as pump and probe pulses, or to generate ultrafast, coherent XUV pulses through high harmonic generation. XUV beamlines lead to end-stations for time-resolved photoelectron spectroscopy (for both gas-phase and condensed matter experiments) and coherent lensless XUV imaging.

Artemis has received funding for a major upgrade, and has re-located across campus to the Research Complex at Harwell (RCaH), adding a new laser system and a third XUV beamline. The new 100 kHz laser system operates at 1700 nm and 3000 nm, and is a joint purchase with Ultra. It will complement the existing 1 kHz Ti:Sapphire system, which has been updated with a new amplifier to increase the energy available for XUV generation. Over 2018-19, building work to upgrade the labs has been carried out, for re-opening of the upgraded facility in 2020.

Target Fabrication

The Target Fabrication Group makes the majority of the solid targets shot on the CLF's high-power lasers and also supports micro-assembly and characterisation in the wider CLF. The Group is also responsible for the production of targets for academic access shots on the Orion Facility at AWE. Commercial access to target fabrication capabilities is available to external laboratories and experimentalists via the spin-out company Scitech Precision Ltd.

A wide variety of microtarget types are produced to enable the exploration of many experimental regimes. Fabrication techniques include thin film coating, precision micro assembly, laser micromachining, and chemistry processes, all verified by sophisticated characterisation. STFC's advanced capabilities in both high precision micro machining and MEMS microfabrication are also utilised. The Group is ISO9001 accredited and has been awarded the latest ISO9001:2015 standard for its process management, providing a high level of traceability for all supplied microtargets.

This year, work has continued to implement robotic assembly for simple target geometries, to facilitate the production of array targets for high rep rate experiments. In collaboration with Scitech Precision, a high stability, high rep-rate (HRR) tape drive has been tested, to deliver targets to the Gemini laser and to other HRR facilities at up to 10 Hz. This work to produce complex tapes will open up new experimental regimes for the user community.

The Group remains at the leading edge of target fabrication technology, collaborating with universities in areas such as nanowire growth, thin diamond production, and advanced micro machining. Work with the LSF on the assembly of advanced micro optics has 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. Access to the PRISM suite has been renewed for a further year, as endorsed by the CLF User Forum. Support for student training in plasma physics, computational methods and opportunities for networking with colleagues will continue to be provided. Extended collaborative placements within the group are particularly encouraged.

In 2018 the group started replacing the SCARF-Lexicon-2 cluster with an up-to-date replacement, SCARF-DeMagnete which we hope will be operational in 2019.

Octopus and Ultra (Research Complex at Harwell)

The CLF operates two 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.

In the molecular and materials dynamics area, Ultra offers state-of-the-art high power high repetition rate fs / ps systems to generate pulses for a range of highly sensitive pump and probe vibrational spectroscopy techniques. These capture "movies" of the atomic and molecular dynamics used to study processes ranging from reactions in nature, energy capture and storage, catalysis and fundamental quantum level research on molecular and bio-molecular electronics, probes, therapeutics, enzymes and DNA. Kerr gated time resolved resonance Raman (TR^3) is unique in enabling highly fluorescent samples to be studied. Time-Resolved Multiple-Probe Spectroscopy (TR^MPS) captures reactions from their earliest beginning on femtosecond timescales to completion on milliseconds timescales. Fast scanning ultrafast 2DIR spectroscopies capture intra- and inter-molecular vibrational coupling and energy transport applied in fundamental molecular dynamics research and in pharmaceutical analytical research. Broad spectral band surface sum frequency generation provides insights into the chemical changes that occur at interfaces and surfaces where many reactions in nature and industry occur.

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. Microscopy techniques offered include total internal reflection (TIRF) and multi-wavelength single-molecule imaging, confocal microscopy (including multiphoton), fluorescence energy transfer (FRET) and fluorescence lifetime imaging (FLIM). Super-resolution techniques available are Stochastic Optical Reconstruction Microscopy (STORM) with adaptive optics, Photoactivated Localization Microscopy (PALM), Structured Illumination Microscopy (SIM) and Stimulated Emission Depletion Microscopy (STED), Light Sheet Microscopy, 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. Current developments include 3D super-resolution microscopy using point spread function engineering, and a cryo focussed ion beam scanning electron microscope (FIB-SEM) has recently been commissioned with the aim of developing a workflow for correlative light and electron microscopy (CLEM).

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 team operates across all of the CLF's facilities, and endeavours to continually improve and expand the capabilities and reliability of the CLF. Mechanical, electrical and software support is provided for the operation of the laser facilities, for the experimental programmes on these facilities, and for the CLF's research and development activities. These developments can range from small-scale modifications to existing equipment to improve its performance, through to larger scale projects, such as the design and development of commercial projects. In addition, we have active engineering collaborations with regional and international partners such as, HiLASE (Prague, Czech Republic), XFEL (Hamburg, Germany) and TIFR (Hyderabad, India).

Over the last year the Mechanical Engineering Section has seen significant growth. The mechanical workshop is now fully staffed, and new machinery is in place to expand its capabilities. The workshop and storage area for the Experimental Support Technicians has also been regenerated to provide a purpose-built assembly area.

Centre for Advanced Laser Technology and Applications (CALTA)

CALTA's mission is to deliver societal, scientific and economic impact from developments in the CLF. Hosting CALTA at the CLF enables novel technology and associated applications to be developed in the shortest possible time. Access to the CLF infrastructure and expertise (cleanrooms, optical metrology and advanced diagnostics, etc.), STFC's capability in cryogenics and high performance computing, and commercial connections within the Business and Innovation Department is key to its present and future success.

CALTA has successfully developed a new class of lasers capable of delivering high energy, high peak power pulses at high repetition rate and high efficiency. This DiPOLE Diode Pumped Solid State Laser (DPSSL) architecture is driving new applications in advanced imaging, materials processing, non-destructive testing and fundamental science.

The first 1 kW DiPOLE system was developed under a commercial contract for the HiLASE Centre in the Czech Republic. Following delivery and installation, a joint CLF/HiLASE team commissioned the laser to its full design specification in December 2016, producing 100 J in 10 ns pulses at 10 Hz. This performance gives DiPOLE an enduring world lead in this area of laser technology.

Construction of a second 1 kW laser, destined for the European XFEL in Hamburg in late 2019, is well underway. Funded through a joint STFC / EPSRC research grant, the "DiPOLE 100" will be used to drive materials to high energy density states to be diagnosed using the XFEL x-ray beam. A unique temporal pulse shaping capability will enable precise control of the material energetic states produced while the high repetition rate will enable rapid accumulation of data for improved measurement accuracy.

The development of advanced DPSSL technology forms an essential element of a Widespread Teaming collaboration between STFC and the HiLASE Centre. The €50M project to establish HiLASE as a Centre of Excellence is jointly funded by the EC and the Czech Ministry of Science. STFC input includes the design and construction of a 100 Hz version of the DiPOLE 10 J laser, increasing the output power of the DiPOLE architecture and developing efficient second and third harmonic generation at 10 Hz. This work will extend STFC's lead at the forefront of DPSSL technology.

Economic impact

The CLF completed eight contract-access projects with industrial users, delivering experimental access to Gemini, Ultra, and Octopus, and access to expertise in target fabrication and CALTA.

The CLF-Johnson Matthey partnership continues, led by Dr Kathryn Welsby as the CLF-JM industry research fellow, with a series of access projects and iCASE studentships. Other ongoing CLF-industry partnerships include Dstl, Sellafield and AstraZeneca.

Three new proof-of-concept projects were funded and started, while four were completed. From target fabrication techniques, to microscopy optics, to detector readout solutions, the range of innovations coming from CLF expertise has the potential to impact on many sectors. The CLF filed two new patent families this year, giving a current total of 19 active patent families.

Access to Facilities

Calls for access are made twice a year, with applications peer reviewed by external Facility Access Panels.

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.