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 highly versatile eight beam Nd: glass laser facility that operates to two independent target areas. The eight beams can be configured in a number of combinations of long (>500 ps) and short (<30 ps) pulse arrangements.

Target Area Petawatt is Vulcan's highest intensity area, capable of 500 J / 500 fs pulses focused to 10^{21} W/cm^2. The ps OPCPA front end ensures that the ASE contrast of the PW system is better than 10^{10} at 1 ns. To complement the short pulse beamline, an additional 250 J long pulse beam line, as well as a variety of possible probe beams, can be configured in the area. A compressor has been installed in the Vulcan front-end to help with characterising the contrast and for the development of new short-pulse diagnostics.

Target Area West is Vulcan's most flexible target area, offering up to eight long pulse beams or two short and six long pulse beams. The two short pulse beams operate independently and can be configured so that one operates at 80-100 J / 1 ps (10^{20} W/cm^2) and the other one at either at 80-100 J / 1 ps or at 300 J / 10 ps in flexible geometries. TAW can be also be configured with all eight beams in long pulse mode by using a compressor by-pass arrangement delivering a maximum of 2.5 kJ with all beams. Temporal pulse shaping is available for long pulse operation and there are a number of focusing, beam smoothing, probe beam and harmonic conversion options.

We have started on the design of a new short-pulse beamline for the Vulcan TAP area. It will be based on the technique of OPCPA which the CLF has pioneered and 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.

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^{22} W/cm^2). In recent years, Gemini has emerged as one of the preeminent centres in the world for laser-driven acceleration. Gemini offers a unique capability of generating high quality electron beams with GeV energies, and using them for interactions at extreme conditions generated by its second laser beam. This year, Gemini performed several experiments that utilised this capability, ranging from staged electron acceleration to QED experiments looking to generate electron-positron pairs from intense photon-photon interactions. Gemini also specialises in the application of laser-driven secondary sources. An experiment in Gemini used the betatron emission from a laser wakefield accelerator to image complex microstructures in alloys, and found that the image quality was better than those taken with synchrotrons in some cases. In collaboration with industrial and academic partners, Gemini also performed some proof-of-principle experiments to demonstrate the capability of laser-driven x-ray sources for non-destructive testing in industrial environments.

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. Two XUV beamlines lead to end-stations for time-resolved photoelectron spectroscopy (for both gas-phase and condensed matter experiments) and coherent lensless XUV imaging. This year, an additional amplifier has been added to the laser system to boost the energy available for high harmonic generation.

Artemis has received funding for a major upgrade, and is re-locating 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*. Over 2017-18, detailed planning of the project has taken place, for a re-opening of the upgraded facility in 2019.

Octopus and Ultra

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 a state-of-the-art high power high repetition rate fs / ps system to generate pulses for a range of highly sensitive pump and probe vibrational spectroscopy techniques.These techniques capture “movies” of the atomic and molecular dynamics, which can be 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 reaction 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.

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. Mechanical, electrical and computing 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. 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 and electrical CAD tools and workshop facilities enable a rapid response.

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 2017 the group successfully bid for £300k of capital funding. This will be used to acquire a new 1500 core cluster resource that will be hosted by SCD as part of the SCARF infrastructure.

Target Fabrication

The Target Fabrication Group makes almost all of the solid targets shot on the CLF's high power lasers. A wide variety of microtarget types are produced in collaboration with the user community to enable the exploration of many experimental regimes. The integrated range of fabrication techniques includes thin film coating, precision micro assembly, laser micromachining, and chemistry processes, all verified by sophisticated characterisation. Additionally the advanced capabilities within STFC in both high precision micro machining and MEMS microfabrication are utilised. The Target Fabrication Group is ISO9001 accredited and consequently provides a high level of traceability for all supplied microtargets. 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.

In the reporting year, the Diamond Point Turning machine was commissioned by the Precision Development Facility in RAL Space and began producing surfaces of a few nm roughness. The x-ray CT system was also commissioned, giving high precision of the internal structure of microtargets. The programme for high repetition rate solid targetry was extended by fielding the high accuracy tape target system on a Gemini experiment.

Centre for Advanced Laser Technology and Applications (CALTA)

The CLF's **C**entre for **A**dvanced **L**aser **T**echnology and **A**pplications **(CALTA)** was established in 2012 to develop a new class of lasers capable of delivering high energy, high peak power pulses at high repetition rate and high efficiency, to drive new applications in advanced imaging, materials processing, non-destructive testing and fundamental science. 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 100 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.

Hosting CALTA at the STFC's Central Laser Facility enables DiPOLE technology and associated applications to be developed in the shortest possible time. CALTA draws on 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. Rapid access to these resources is fundamental to CALTA's Business Model and central to its present and future success.

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, 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, developed specifically for the XFEL application, 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 system build is nearing completion and commissioning of the first stage of amplification is progressing. Final commissioning of the system will take place at RAL prior to packaging and delivery to Hamburg in 2019.

Further development of the DiPOLE technology is 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 is assisting in the establishment of the Centre and is playing a leading role in the development of advanced DPSSL technology. This 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

In summer 2017, the CLF/STFC spinout company Cobalt Light Systems Ltd, which develops and markets disruptive technology using Spatially Offset Raman Spectroscopy (SORS), was acquired by Agilent Technologies, a US company, for £40M. SORS is an exclusive CLF technique which differs from traditional Raman spectroscopy in that it can identify materials through opaque containers deeper beneath the surface than was achievable by previous methods. The SORS technique was originally developed using the CLF's cutting edge ultra-fast laser, Ultra. Cobalt was formed in 2008 and attracted numerous awards, including RAEng's prestigious MacRobert Award in 2014 and the Queen's Award for Enterprise in 2015. The company developed a number of SORS products including table-top devices to identify liquid explosives concealed within bottles, which are currently in operation at over 75 airports worldwide. Using the same technique, hand-held instruments were also developed by Cobalt to test the contents of bottles and jars for explosives, narcotics and hazardous substances quickly and efficiently. After the purchase by Agilent Technologies, the company will be moving from its previous base near Didcot, Oxfordshire, back to the Harwell Campus next to RAL. This will become Agilent's global centre for Raman spectroscopy.

Access to Facilities

Calls for access are made twice annually, 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.