# 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**

**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 (>$10^{21}$ $Wcm^{-2}$). Many experiments 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. This year, control of a plasma accelerator using active feedback optimisation strategies was demonstrated in Target Area 2. These methods are critical to producing reliable and flexible secondary source facilities in the future. Progress continued towards using x-rays generated with Gemini for imaging applications. Control of the Target Area 3 pulses for x-ray scanning was automated, allowing several tomographic datasets to be acquired. The betatron x-ray source generated within the laser wakefield accelerator was also used to conduct single-shot x-ray absorption spectroscopy. This important result proves that these laser-driven x-ray sources are suitable for advanced imaging techniques that provide a wealth of information for scientific studies and industrial inspection.

The performance of Gemini was enhanced by the replacement of the pump laser for the kHz front-end. This resulted in a significant improvement in both energy and stability, and has proved reliable over the past year of operations. The transmission grating in the pulse stretcher was also replaced, improving the picosecond timescale contrast by a factor of 10. In Target Area 3 an independent probe beam has been installed, greatly simplifying experimental layouts inside the target vacuum chamber. The beam has a compressor separate to the main beams allowing variations in the pump beam properties while maintaining a short pulse probe. Manual and motorised delay stages enable time resolved optical imaging of the plasma.

## 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 just had a major upgrade, and has re-located across campus to newly refurbished labs in the Research Complex at Harwell (RCaH), adding a new laser system and a third XUV beamline. The new laser system produces 1700 nm and 3000 nm pulses at 100 kHz repetition rate, 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 2019-20, the laboratory infrastructure has been completed and all equipment installed in the new labs.

## 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, providing a high level of traceability for all supplied microtargets.

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 other HRR facilities at up to 10Hz. Through the EPIC project there has been a rapidly developing collaboration with several institutions across India to produce complex tapes which will enable new applications and experiments. Work has continued to implement robotic assembly for simple target geometries facilitating the production of array targets for HRR experiments.

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, as endorsed by the CLF User Forum. This is part of a rolling 3 year agreement with PRISM CS, which comes up for renewal after 2021. 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 2019, SCARF-Magnete has become operational.

## ULTRA AND OCTOPUS

### (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.

### ULTRA

In the molecular and materials dynamics area Ultra offers a 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.

### OCTOPUS

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. A cryo focused ion beam scanning electron microscope (FIB-SEM) is also available for volume imaging. This will form 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 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)

The mission of CLF's Centre for Advanced Laser Technology and Applications (CALTA) is to develop a new class of efficient, high power laser capable of operating for extended periods at 10Hz. Such a laser is essential in order to transform single shot, proof of principle demonstrations of effects into real world applications.

The technology pursued within CALTA is based on the DiPOLE architecture, first demonstrated at the CLF some years before the establishment of CALTA. Initially, DiPOLE was developed as a potential driver of inertial fusion energy schemes. This has now broadened to include advanced imaging, materials processing, non-destructive testing, medical diagnostics, security and defence, and fundamental science.

The DiPOLE architecture is based on laser diode pumped Ytterbium-YAG in the form of a transparent ceramic slabs, cooled by a high speed flow of cryogenic Helium. DiPOLE has demonstrated stable, 1 kW operation for extended periods (>12 hours) in 100 J, 10 ns pulses delivered at 10 Hz. With an overall optical efficiency of >20%.

In the period covered by this report, DiPOLE systems have demonstrated >70% energy conversion to the second harmonic, making it well suited to pumping of a Titanium Sapphire amplification stage for the generation of ultra-short pulses. Recent results also include preliminary operation at 150 J per pulse at 1 Hz for a period of 30 minutes; no damage was observed.

The first 1 kW DiPOLE system, developed under a commercial contract for the HiLASE facility in the Czech Republic, has been in operation since December 2016. To date it has delivered ~50 Million pulses to a number of applications laboratories including laser induced damage threshold (LIDT) measurements and aerospace component surface treatment studies.

DiPOLE technology will be used at the heart of the new EPAC facility to pump a PW/10 Hz Titanium Sapphire amplifier for the generation of secondary radiation. This will be used by a diverse user community for industrial, scientific and defence applications.

## Economic impact

This year's industrial contract-access projects amount to 22 facility access weeks delivering experimental access to Gemini, Ultra and Octopus, and access to CLF scientific expertise.

Internationally, the CLF's commissioning of the D-100X laser for the European X-FEL exceeded expectations; extending the world-leading reputation of the DiPOLE systems. Extreme Photonics Innovation Centre (EPIC) in India was inaugurated as a jointly funded hub for innovation and CLF IPI industrial scientists collaborated with HiLASE on an international aerospace and laser shock peening workshop.

Ongoing and new innovation proof-of-concept projects include exploitation of microwave plasma produced VUV, successful automation of proprietary FLImP single molecule imaging and award-winning publications on Shifted Excitation Raman Difference Spectroscopy (SERDS). The CLF filed two new patent families this year, giving a current total of 21 active patent families.

## 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.