CLF 2011 - 2012

Central Laser Facility Annual Report

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The front cover shows an optical photo of a full power laser shot onto target in the Vulcan TAP interaction chamber. The image is filtered for first and second harmonic laser and plasma emission.

Acknowledgements

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Celebrating 10 years of the Vulcan PW facility.

Foreword

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This annual report for the Central Laser Facility (CLF) at the STFC Rutherford Appleton Laboratory provides highlights of the scientific and technical research which has been carried out by users of the Facility and its staff over the financial year 2011-12.

Despite its ongoing operation within the constrained environment set by the Large Facilities Funding Model (LFFM), the CLF and its community have continued to deliver scientific output and technical development of the highest order. This period has again seen considerable change and improvement in the programme delivery:

- Vulcan - in response to the LFFM constraint, Vulcan has successfully switched its delivery basis to 5 week experimental periods rather than the traditional 6 weeks in an attempt to further optimize its experimental delivery across a user programme that is heavily oversubscribed. The five weeks experiments have enabled more experiments to be conducted within the same overall constrained envelope and have been welcomed by the Vulcan Community.
- Gemini - has seen enhancements to its pulse energy, pulse length and pulse contrast. The South compressor grating has been replaced, returning the on target energy of the South beam to its original specification of 15J. By installing a commercial phase measurement device (Wizzler) the system has been able to consistently deliver pulse durations below 40fs. Improvements in laser contrast have enabled user groups to successfully irradiate ultrathin foil targets (less than 10nm thickness), measuring ion beam parameters and transmission harmonics.
- Artemis - A significant development for the Artemis facility over this year has been the implementation of long-wavelength pumping (up to 4 micron) for time-resolved photoemission measurements on condensed matter, which enables one to tune the photon energy across band gaps, for example. This has been used in on-going series of experiments on charge density wave materials.
- Ultra - The Ultra facility has seen the commissioning of the Time Resolved Multiple Probe Spectroscopy (TRMPS) station. This new capability allows the measurement of processes across a very large time scale, ranging from femtoseconds to milliseconds, and is already being used by a number of groups to investigate chemical and biological processes.
- Octopus - Developments in Octopus include the decommissioning of a confocal microscopy station and its replacement with an Alternating Laser Excitation (ALEX) set-up, used for the measurement of dynamics and conformation of single biological molecules. The year has also seen the introduction of super-resolution imaging to Octopus with the commissioning of a Photoactivated Localization Microscopy (PALM) station, which offers 2D imaging with a resolution of better than 50 nm. The super-resolution imaging capabilities of Octopus will be extended further in the next few years

The CLF spin-out Cobalt Light Systems goes from strength to strength with an additional £2 million raised from investors to continue its development and exploitation of Spatially Offset Raman (SORS) technology. Trials are underway in a number of airports to explore the potential of using SORS for screening of liquids in bottles. Within the CLF, work is also underway to investigate the use of SORS for non-invasive diagnosis of breast cancer, and of bone diseases. This year has also seen the further growth of Scitech Precision Ltd., the CLF spinout supplying laser targets internationally.

The CLF has continued to work on essential technology for the 10 PW upgrade to Vulcan. Even though the availability of capital to enable this project to proceed remains elusive, the CLF is determined to remain in a position to be able to start construction immediately should it appear. Over the year, CLF developments have seen improvements in the performance of key components such as gratings, crystals and mirrors thereby enabling us to contemplate an expected performance that exceeds the 20 PW level when this project eventually proceeds.

The CLF's newly established Centre for Advanced Laser Technology and Applications (CALTA) concluded its first year of operation with the rapid development of the prototype of the DiPOLE laser technology and other important components that will be essential for high average power operation of high power lasers. Initial potential applications have been identified and CLF has attracted additional internal funding from STFC's Business and Innovations Directorate to support "innovations" use of Vulcan in the coming year, working closely with both industrial and academic partners. This imaginative approach also goes some way to filling the vacant "slots" on Vulcan left by the constrained funding from the LFFM.

The success of the EU funded Laserlab-Europe consortium is once again celebrated with the award of a third incarnation of this highly effective transnational programme. Building on the strengths of Laserlab-Europe I and II, and with participation from 19 countries, Laserlab-Europe III will bring together 28 of the largest European laser research infrastructures (including CLF), a diverse user base and pioneering technology development to strengthen the European leading role in advanced laser related research.

In the year the financing of the Czech node of the Extreme Light Infrastructure (ELI) was finally approved by the European Commission and work now begins in earnest in its construction. In developing the first truly international laser infrastructure, ELI presents many opportunities for CLF and its Community in the coming years as this exciting project takes shape. The HiPER project, which the CLF leads, also entered into its two year extension of its preparatory phase as we eagerly anticipate developments on the US's National Ignition Facility.

Outreach and the communication of our work and impact to non-scientific audiences continues to be vital. Again, I have been very pleased to see the number of high profile articles in the general media. This year we also started work on a dedicated visitor centre for the CLF to accommodate the growing number of people that visit the CLF each year.

Finally, the close partnership the CLF has with its User community has been central to our past success, and as we look forward, it is imperative that we collectively draw on that partnership to promote our collective success that is, in part, represented in this publication.

I hope that you enjoy reading it !

Professor John Collier
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Overview

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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 8 beam Nd:glass laser facility that operates to two independent target areas. The 8 beams can be configured in a number of combinations of long (>500ps) and short (<30ps) pulse arrangements. The maximum energy that can be delivered is 2.5KJ when all 8 beams are configured for long pulse operation. Temporal pulse shaping is available for long pulse operation and there are a number of focusing, beam smoothing, probe beam and harmonic conversion options. Target Area Petawatt is Vulcan's highest intensity area it is capable of 500J/500fs pulses focused to 10^{21} W/cm^2.

A replacement of the large aperture optics in the compressor has recently been completed restoring the area to its original energy specification. The ps OPCPA front end ensures that the ASE contrast of the PW system is better than 10^{10} at 1ns. To complement the short pulse beamline is an additional 250J long pulse beam line as well as a variety of possible probe beams that can be configured in the area.

Target Area West is Vulcan's most flexible target area offering up to 8 long pulse beams or 2 short and 6 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.

Astra Gemini

This high rep-rate Petawatt laser based on Ti:Sapphire technology has a unique capability to offer 2 synchronised beams, each with a power of 0.5 PW and a repetition rate of one shot every 20 seconds. The facility will enable interaction studies up to 10^{22} Wcm^{-2}. F/20 and F/2 beam focusing options are available, with a built-in plasma mirror set-up in one beam line for high contrast pulse delivery. This year the Gemini has continued to devote effort to improve the pulse contrast by implementing changes in the laser system. Gemini is now able to field several cutting-edge experiments – including laser interaction with a few nanometer-thick foils and high-harmonic generation from solid foils – that were not previously possible.

Artemis

Artemis is an ultrafast laser and XUV science facility, offering high repetition-rate, ultrashort pulses spanning the spectral range from the far-infrared to the XUV. The facility is configured flexibly for pump-probe experiments. Tuneable or few-cycle, carrier-envelope phase-stabilised pulses can be used to generate ultrafast, coherent XUV pulses through harmonic generation or used as pump and probe pulses. Two XUV beamlines, offering optimised time resolution or energy resolution lead to end-stations for gas-phase atomic and molecular physics or materials science.

The materials science station enables time-and angle-resolved photoemission spectroscopy with XUV pulses, and is equipped with hemispherical electron analyser, five-axis manipulator with cooling to 14K and a sample preparation chamber. The gas-phase end-station for atomic and molecular physics and chemistry contains a velocity-map imaging detector, capable of imaging ions and electrons with energies up to 200 eV, and a molecular beam source.

Lasers for Science Facility (LSF)

The LSF, located in the Research Complex at Harwell, develops and operates facilities in two areas: molecular structural dynamics (Ultra), and functional bio-systems imaging (Octopus).

In the molecular dynamics area Ultra offers a state-of-the-art high power 10 kilohertz fs/ps system combined with OPAs to generate pulses for a range of unique pump and probe spectroscopy techniques. It provides spectral coverage from 200-12000 nm and temporal resolution down to 50fs. This is used in the investigations of fast photodynamic processes in solids, solutions and gases. Its time resolved resonance Raman (TR^3) capability enables highly fluorescent samples to be studied using a 4ps optical Kerr shutter. The recently commissioned Time-Resolved Multiple-Probe Spectroscopy (TRMPS) facility links Ultra with the LSF's 1 kHz ultrafast laser spectroscopy system, giving a femtosecond to millisecond pump-multiple probe spectrometer in a singe experiment.

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)/single-molecule imaging, confocal microscopy (including multiphoton), fluorescence energy transfer (FRET) and fluorescence lifetime imaging (FLIM), and single molecule Alternating Laser Excitation (ALEX) in both confocal and TIRF modes . Super-resolution imaging techniques (2D Photoactivated Localization Microscopy "PALM") are currently being commissioned. In addition, a "laser tweezers" laboratory is available to study Raman spectra and pico-Newton forces between particles in solution for bioscience and environmental research. Laser tweezers can be combined with microscopes in the Octopus and Ultra clusters for combined manipulation/trapping and imaging.

Chemistry, biology, and spectroscopy laboratories support the laser facilities, and the LSF 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.

Laser Loan Pool

Commercial laser systems are available from the EPSRC Laser Loan Pool for periods of up to 6 months at the user's home laboratory. A wide range of ancillary and diagnostic equipment is also available to support user experiments.

Engineering Services

Mechanical, electrical and computing support is provided for the operation of the laser facilities at the CLF, for the experimental programmes on these facilities and for the CLF's research and development activities. Mechanical and electrical CAD tools and workshop facilities enable a rapid response.

Theory and Modelling

The CLF will offer to support scheduled experiments throughout the design, analysis and interpretation phases, if required and within the resources available. We offer hydrodynamic, particle-in-cell, hybrid and Vlasov-Fokker-Planck modelling capabilities and access to large-scale computing. New 1D and multi-dimensional radiation- hydrodynamic and atomic physics tools have also been acquired in the past year. Student training in computational methods and opportunities for networking with colleagues will be provided. Extended collaborative placements within the group are particularly encouraged.

Target Fabrication

A high quality target fabrication facility is operated within the CLF offering integrated microassembly, thin film coating and characterisation areas. A dedicated chemistry laboratory has recently been commissioned. The facility is equipped with a wide range of complementary target production and characterisation equipment including evaporation and sputter coating plants, interference microscopy, SEM, AFM and surface profiling. Many microcomponents are produced in collaboration with the STFC micromachining and MEMS facilities. Target Fabrication is ISO9001 accredited. Commercial access to target fabrication capabilities is available to external laboratories and experimentalists via the spin-out company Scitech Precision Ltd.

Centre for Advanced Laser Technology and Applications (CALTA).

CALTA is a new STFC/CLF Centre that is charged with driving forward next generation laser technology that is principally focussed on the industrial and commercial application of high power lasers and the by-products interactions (e.g super bright, high energy photons, electrons, ions etc). At its heart is a campaign to develop advanced, proprietary diode pumped laser technology (DiPOLE) and associated multi-PW component technology that has been pioneered within the CLF in recent years.

The main activity within DiPOLE is the development of a scalable diode pumped solid state laser (DPSSL) concept that is capable of delivering kJ-level pulses at a 10 Hz or above repetition rate. A conceptual design of a cryogenic Yb:YAG amplifier that can be scaled to kJ energy levels and beyond, owing to its geometry, unique laser design and cooling technique has been developed. To test this concept in the laboratory a lower-energy 10J prototype amplifier system has been built and is currently being tested. This year CALTA secured a euro 2.2M contract to supply a 10J DiPOLE to the ELI-beamlines project in the Czech Republic.
The CLF will continue to develop 10 PW technologies that are crucial to a future upgrade to the Vulcan high power laser to 10 Petawatt (PW). This includes developing a test component facility based on OPCPA, ultra broadband optics such as diffraction gratings and high damage threshold coatings, and the realisation of specialised large aperture crystals required in multi Petawatt facilities.

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.

Economic impact

The delivery of high Economic Impact (EI) forms an integral component of the CLF strategic objectives and the overall delivery plan.

The CLF has a long track record in intellectual property development and technology transfer. To deliver the most effective long term EI the CLF encourages, facilitates and actively promotes:

- The further enhancement of our core expertise in photonic sciences and technology
- Encourage inward investment to the UK through high profile collaborations and projects
- Formation and support of new spinouts
- Securing of new intellectual property and its licensing
- Addressing societal priorities
- Training of the next generation of scientists
- Actively seeking partnerships to enhance the Harwell and Daresbury Science and Innovation Campuses (HSIC and DSIC)
- Educational programmes – internally, externally and through active involvement of industry

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

Communication and outreach activities within the CLF

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Introduction

Once again, the Central Laser Facility (CLF) has had a great year of reaching out to the public and communicating the science and engineering work that is carried out here. In line with the Science and Technology Facilities Council (STFC) communications strategy, the CLF feel that public engagement (PE) is an important part of the facility's role. PE contributes towards inspiring the next generation, raises the profile of our world-class research and offers a platform on which to demonstrate the high-impact (and awesome) science that the CLF delivers.

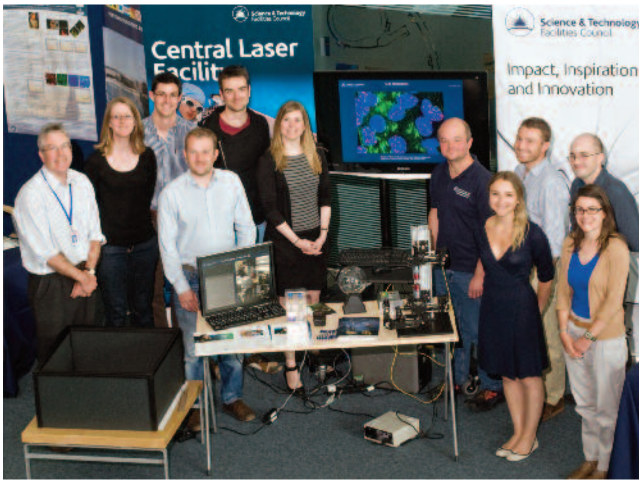

Figure 1: Some of the CLF communicators at the CLF stand for the Diamond open days. (L to R): Andy Ward, Emma Springate, Mark Pollard, Steve Hawkes, Stephen Webb, Peta Foster, Graham Wiggins, Ceri Brenner, Robbie Scott, Alex Robinson, Stephanie Jones.

CLF featured on the Backstage Science youtube channel and The Naked Scientists programme

The 2011 and 2012 STFC Science in Society large bursaries for public engagement were awarded to Brady Haran, for a video series called 'Backstage Science', and the Naked Scientists (http://thenakedscientists.com), for a series of podcasts featuring STFC science.

The CLF has played a large part in the content already produced as part of these projects. The Backstage Science videos are broadcast via a dedicated youtube channel (http://youtube.com/backstagescience) with the number of people subscribed to the channel already well in excess of 10,000. Featured on the channel is the Vulcan facility ('Super Intense Laser') and the OCTOPUS facility ('Octopus laser' and 'DNA and lasers').

The first Naked Scientists STFC podcast featured Emma Springate and facility user, Klaus von Haeften, on a tour of the Artemis facility. Another CLF mention came from an interview with Pavel Matousek about the imaging technology behind the CLF spin-out Cobalt Light Systems Ltd. The Naked Scientists bring with them a large and far-reaching audience, so the CLF is hoping to produce more content with them over the coming months.

Visits and work experience

The CLF continues to welcome visitors and host tours around the facility. Over the last year, almost 1000 people have visited the CLF, including many VIP guests, industry representatives, secondary school students and undergraduates.
The STFC communications team has worked hard this year to run the education access days, in which a whole day is dedicated to running tours for school groups around the RAL site. The CLF has been very accommodating to this new scheme by scheduling time to give talks to the students and opening up the areas to show the next generation what big facility science looks like. The impact of this is already showing in the positive feedback that we have received, comments include: "CLF Vulcan was mind-blowing" and "it was great being given access to the facility".
Work experience is another very effective way in which the CLF is able to reach out to students interested in a career in science.

Figure 2: CLF engineers and students of Downe House School taking part in the Engineering Education Scheme.

Normally occurring over the summer, sixth-form and undergraduate students are matched with a CLF supervisor to carry out a project lasting up to 6 weeks. Over the last year, the CLF has been able to host more than 30 students in the facility.

Engineering education scheme

The Engineering Education Scheme is run by the UK's Engineering Development Trust to promote engineering education to school students. It is part of the Royal Academy of Engineering's BEST (Better Engineering, Science and Technology) programme and introduces sixth formers to the world of engineering via a programme of joint projects between participating schools and sponsoring companies.

Two CLF engineers, Darren Neville and Steve Hook, mentored a group of year-12 students through an engineering project on the design and build of a prototype debris shield, for use on the Astra Gemini plasma mirror system (see figure 2). Peta Foster, the CLF scientist in charge of the plasma mirror system, also provided project and science guidance during the project. In addition to this another CLF engineer, Steph Tomlinson, was part of the judging panel for the scheme in April 2012.

'I'm a scientist and I'm an engineer, get me out of here' 2012

This two-week, high impact outreach event is an online competition in which five scientists/engineers interact with school students in short chat-room style sessions and answer hundreds of questions left by the students in the Q+A forums. The students then vote for their favourite and a winner is announced after daily evictions.

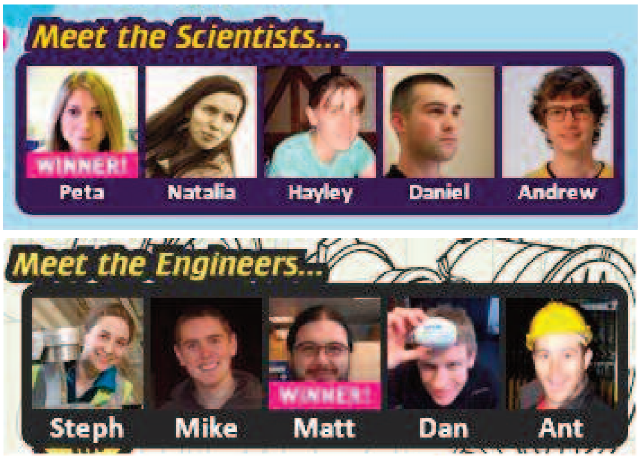

Figure 3: Steph and Peta take part in an online engagement event

The CLF's Peta Foster and Steph Tomlinson took part in the 'I'm a scientist' and 'I'm an engineer' rounds, respectively, of this popular outreach event, with Peta surviving four eviction rounds to be crowned winner of her zone.

Enthusing the public

An impressive effort has been made by many of the CLF staff in volunteering their time to carry out outreach and communication activities related to CLF science, both on-and off-site.

Figure 4: Peta Foster showing how lasers work at the Oxfordshire Science Festival 2012.

Andy Ward put together a CLF stand for the 'Diamond 10th anniversary open days' to demonstrate the collaborative work between the CLF and Diamond light source (see figure 1). On show was the optical manipulation, or 'laser trapping', kit developed at the Lasers for Science facility (LSF) along with information and demos that helped explain how lasers are used at the CLF for imaging and plasma production. Andy, along with Ceri Brenner, Stephanie Jones, Mark Pollard and Peta Foster, were also on hand to speak to the hundreds of general public and school visitors over the five open days.

Peta Foster and Jonathan Alston have designed and built a piece of hands-on demonstration kit to help the younger members of the public understand how laser and particle beams can be used to image small structures. Peta first trialed the kit as part of the STFC stand for the Oxfordshire Science Festival earlier this year (see figure 4) and then further developed it in time for use during the Diamond open days.

As part of the STFC 'Talking Science' series, Ceri Brenner presented an hour-long talk in the lecture theatre at RAL, entitled 'Super Intense Lasers: the bright approach', to the general public (see figure 5). Her lecture covered all aspects of CLF science, from advanced imaging at the LSF to laser fusion research using the Vulcan laser, and reached an audience of over 500 people by repeating the talk at the Swindon and Daresbury campuses.

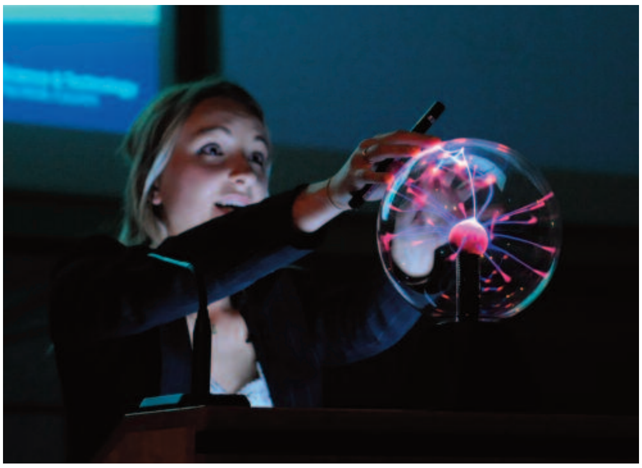

Figure 5: Ceri Brenner presenting a talk on CLF science at the RAL lecture theatre as part of STFC's Talking Science

A good number of CLF staff are signed up with the national STEM ambassadors scheme, STEMNET, which supports them in carrying out outreach activities in local schools, which include hosting laser-themed classroom workshops and attending 'Girls into Physics' events. John Collier recently earned his outreach medal by hosting a workshop for 60 young students during their school's science week, explaining how light and lasers work. Vicky Stowell and Emma Springate continue to work with the RAL press officer to coordinate and produce press releases on CLF research and related work. They have also been looking after the CLF website, keeping it up-to-date with departmental news and useful information for users.

Rutherford prize for the public understanding of plasma physics 2012

This annual prize of £500 seeks to recognize achievements made by PhD students in the communication of plasma physics to the general public. This year the prize was awarded during the Institute of Physics Plasma Physics conference to Arthur Turrell of Imperial College London, for the public lecture he gave at the British Science Festival 2011, entitled 'Plasma: The Mysterious Fourth State of Matter'.

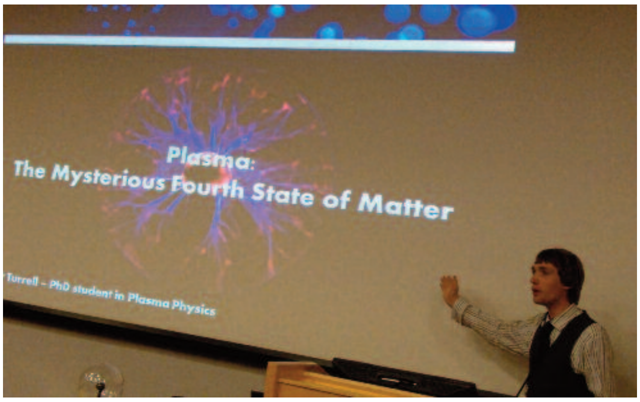

Figure 6: Arthur Turrell was recognized for the plasma talk that he presented at the British Science Festival 2011.

For more information on submissions for next year's prize, please contact Alex Robinson (alex.robinson@stfc.ac.uk).

New CLF Visitor Centre

The CLF is proud to announce that work has started on a CLF Visitor Centre which will be used as an area to showcase the work of the CLF, explain some of the science behind the research and host groups during their visit to the CLF.

The idea of the Centre is to create an area where people can meet, refresh and educate visitors; ranging from school children and members of the public, to senior scientific and influential figures. The Centre will be built on the ground floor of the R1 building, at the entrance to the Central Laser Facility with completion expected towards the end of 2012.

Figure 7: Designer's impression of what the visitor centre will look like (Credit: Artejano).

Continuing the good work

We would like to thank all members of facility staff and the user community who participate in public engagement activities to help promote the laser science and engineering work of the CLF. If you would like to work with us to promote your research or any aspect of CLF work, then please get in touch with Ceri Brenner (ceri.brenner@stfc.ac.uk). Whether it be through outreach events and activities, or via press releases and website content, we welcome collaboration on communicating CLF science.

CALTA – The Centre for Advanced Laser Technology and Applications

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Introduction

STFC has established CALTA at the CLF both to develop one specific new area of technology, and to encourage applications of all our technology in wider society. CALTA is thus all about Technology and Applications.

Technology

Our next-generation technology development centres around a Diode-pumped solid-state laser called DiPOLE. Because diodes provide the power for the laser, such systems are much more efficient than the current competing technologies for ultra-high power (petawatt level) lasers. Using diodes as the laser pumping source brings excellent energy efficiency. That, together with their robust and compact nature, means that this technology could ultimately be made transportable for remote site operations. Another important feature of DiPOLE is that the basic principle is in principle scalable to very high energy (~kJ) pulses. DiPOLE is described more fully elsewhere in this report. It currently produces 10J pulses at 10Hz, and we are working on the next generation which will produce 100J pulses at the same repetition rate.

In addition to DiPOLE, CALTA can access all of the technologies developed at CLF over many years in pursuit of its core scientific mission.

Collaboration with ELI

CALTA were delighted to announce in June, the signing of a contract with the ELI Beamlines project in the Czech Republic. The contract, worth approximately £2.2M, involves the supply of a 10J DiPOLE amplifier head together with advice on how to configure it within an overall laser system. This is planned to be the first step in a larger collaborative endeavour in which CALTA and CLF will supply elements of technology including a 100J version of DiPOLE, to this important European project.

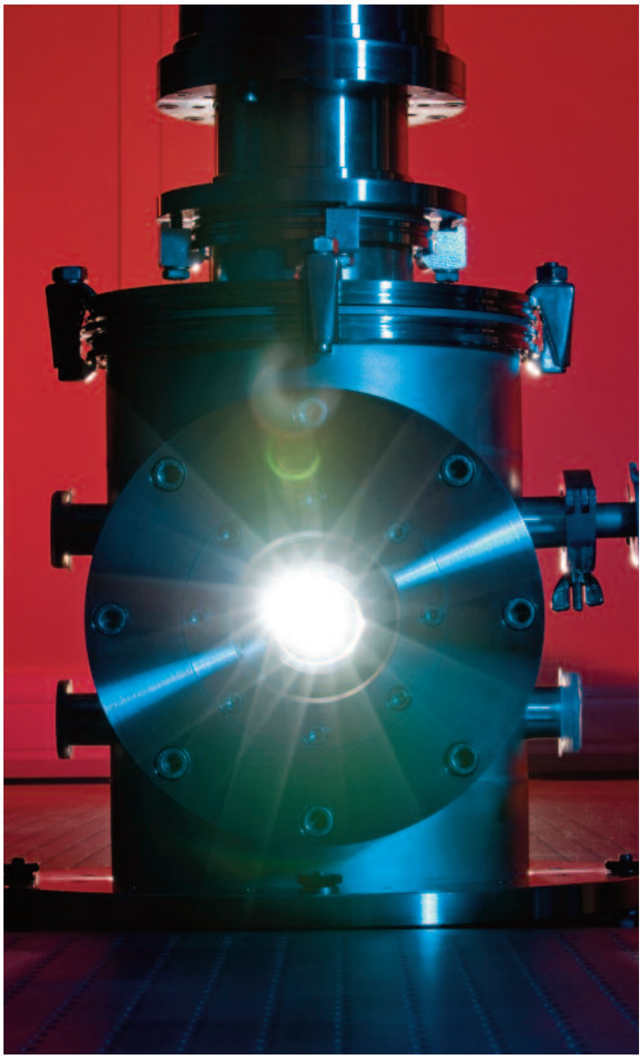

Figure 1: The DiPOLE amplifier head.

Application areas

With access to high-power lasers, including in due course DiPOLE, a raft of application areas opens up. The laser light can be applied directly, perhaps in areas such as laser materials processing. Or, with suitable targets and detectors, imaging techniques such as ultrafast X-ray imaging will become possible. CLF's background technology in areas such as simultaneous control of multiple motion systems, is also applicable in a range of settings.

Applying laser light

We expect that pulses of light at 100J with a repetition rate of 10Hz will find applications in traditional areas of laser materials processing such as shot peening, and also in new areas not currently accessible to lasers. Other possible applications include diverse fields such as communications, medical applications, and laser-driven fusion.

Lasers as radiation sources: X-ray imaging and more

The advent of petawatt (PW) class lasers brings with it the possibility to generate a variety of different types of radiation. For example, x-rays can be generated for use in imaging applications. The pulse of radiation is very short (of order of picoseconds, ps) which means that motion in the image is “frozen”. It is very small (sub-mm), which minimises the need for collimation. Finally it is bright enough that a single ~ps pulse can form an image of a large object. This raises the possibility of being able to image, for example, the blades of a gas turbine in an X-ray image taken while it is running. And the fact that DiPOLE runs at 10Hz raises the possibility of X-Ray movies.

Applying other high power laser technology

CALTA has access to a wealth of technology developed in CLF over the years.

A beam stabilization system has been developed to handle multiple interacting control demands. The most obvious application is to stabilising very large laser systems but other complex equipment with multiple controls can also benefit from this technology.

Our engineers have produced a simple, elegant safety interlock system with a unified interface which works across all our laser systems. While the most obvious application is to other major laser systems, any facility needing controlled access with multiple points of entry can benefit from this technology.
With many motorised systems to control for beam shutters and so on, we faced the problem of interfacing their multiple manufacturer’s interfaces to our own unified system. We have developed a “universal” motor controller card, and an intuitive user interface, to allow simple control of a large number of motorised functions across different platforms. This could readily be applied in other major facilities but also in any setting where multiple motorised systems need to be managed.

We have developed advanced adaptive optics systems to keep our various laser beams stable as thermal gradients in the optics and the air tend to distort them. In order to provide Chirped-Pulse Amplification (CPA) with high-power lasers, we have developed diffraction gratings capable of withstanding very high energy pulses. We are working to refine optical parametric amplifiers which use non-linear crystals to add pump energy to a seed laser, and we are working on beam combination to allow the beams from two lasers to be added coherently to act as a single laser of double the power.

CALTA securities

There are a host of potential applications of CALTA technologies to defence, such as the detection of land mines and screening of goods as part of border control. We are working with the security community to push forward these areas, exploiting the fact that we can trial applications using spare capacity on CLF’s laser suite. This allows us to establish strategic partnerships at an early stage and so guide other activities in order to ensure that CALTA’s effectiveness is as high as it can be.

Conclusions

All of CLF’s technology, and the development of DiPOLE, puts CALTA in a good position to generate real societal impact and the win on the Czech Republic contract has got us off to a flying start.

References

1. The CALTA website: http://stfc.ac.uk/calta/
2. The ELI Beamlines website: http://www.eli-beams.eu/

Figure 2: Members of the team assembling DiPOLE.

Celebrating 35 years of the Central Laser Facility and its World class delivery

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Introduction

2012 is a year of celebration for the United Kingdom. We have enjoyed the Queen's Diamond Jubilee in June, marking the 60th anniversary of her accession to the throne. The Olympic Games opened at the end of July and the country hosted the world in a friendly gathering of sporting competition. These special events allowed the nation to take pride in its history and its present-day contributions to peace and security.

In a much more modest way, 2012 is also a very special year for the Rutherford Appleton Laboratory's Central Laser Facility. It marks the 35th anniversary of its inauguration with the opening of the Vulcan Nd:glass laser. It also happens to be the 10th anniversary of the completion of the Vulcan PW and the 5th anniversary of the commencement of the Astra-Gemini Ti-S laser. These world-class high-power solid state lasers have been complemented by the provision of state-of-the-art ultra-fast systems in the Lasers for Science facility over the years for studies in chemistry, biology and ultra-fast physics.

The success of the Central Laser Facility is, without doubt, due to the strong partnership between its staff and its many academic users. The flexible and proactive support by the administrative staff, the engineering division, the target fabrication, laser and experiment support teams to fast-paced changes in delivery by the visiting academic teams is a reflection of its celebrated "can-do" attitude.

So perhaps this is also the right moment for us to take stock, reflect on the science achievements of the past thirty-five years, celebrate the strong leadership since its foundation and look forward to the future with renewed vigour.

Formation

In 1973, a committee of ten academics published a report, sponsored by the then Science Research Council (SRC) entitled: "Proposal for a S.R.C. Central Laser Facility for the production and study of high energy density plasma". The committee was chaired by D. J. Bradley (Imperial College London) and M. Haines (Imperial College London) acted as Secretary. The report was taken seriously and discussions on a suitable site for its construction began. In 1975, the SRC announced that the Central Laser Facility would be based at the Rutherford Laboratory, and funds were released to ensure delivery. In 1977, the first shot was fired by Sir Sam Edwards and the user programme commenced.

Early years

One of the defining features of the facility has been its ability to renew, change and adapt to new circumstances quickly and effectively. Successive upgrades to the performance of the machines have allowed them to keep pace with rapid advances in high energy density plasma science. The Vulcan laser, for example, started life as a two-beam 400 GW laser delivering modest laser energy to two target areas. Early studies included pioneering the technique of X-ray radiography of dense plasmas; developing the methodologies for laser-driven Rayleigh-Taylor instabilities and the first measurements of X-ray K-α emission by fast electrons.

On the back of these successes, the laser was soon upgraded to a six-beam + one backlighting-beam facility and the first studies of electro-thermal instabilities were made. Also, the role of B-fields in laser-plasmas was explored for the first time. New target areas were added soon after in 1983 (now known as Target Area East and West) and beam-splitters allowed the number of beams to be doubled and arranged in a dodecahedral arrangement to target in the latter configuration. Forefront studies of mass ablation rates as functions of intensity, laser colour and pulse duration were made, and the heat-flux limit puzzle was solved by a proper description of non-local thermal electron energy transport. Systematic studies of low aspect ratio plastic shell implosions using 2nd harmonic light and 0.5kJ to target confirmed that it was difficult to achieve densities much above 10 gcm^{-3}.

After careful investigation, it was shown that the modulational instability was a limitation to large amplitude plasma wave formation using the beat-wave scheme.

On the bright side, studies of laser-driven soft X-ray lasers, particularly the hydrogen-like recombination schemes (which featured in the Central Laser Facility's programme from its foundation) were given much greater attention with the invention of collisionally excited Ne-like and Ni-like lasers in 1985. Academics using the Vulcan laser were instrumental in optimising all three lasing processes and reducing the energy required to drive them over the next 15-years.

Chirped Pulse Amplification

In 1990, the number of backlighting beams was doubled and the energy they could deliver to target was substantially enhanced, providing much greater flexibility to the range of experiments that could be investigated. Pioneering studies of X-ray diffraction in shock-driven materials, Rayleigh Taylor growth mitigation, shock propagation in foam targets and the first measurements using X-ray Thomson scattering were notable achievements.

The back-lighters were used to good effect when the first 20 TW laser pulse was added to the 12-beam implosion chamber in TAW in 1992. Immediate successes included the first measurements of ion acceleration from relativistic laser intensities, XUV harmonics from oscillating mirrors and the first demonstration of wave-breaking resulting in thermal electrons emerging from the self-modulated laser wakefields.

In 1997, the 100TW facility was completed, and a wealth of new physics followed, including the first demonstrations of MeV proton beams emerging from the rear surface of targets, photonuclear dissociation of ^{238}U, cone-guided fast ignition and proton deflectometry. At the same time, the US decided to close the NOVA laser facility in preparation for the construction of the National Ignition Facility and large components became available for academic institutions to bid for. The Central Laser Facility proposed to use these amplifiers, capacitors and large turning mirrors to construct the Vulcan PW facility. An exchange agreement was concluded between the Central Laser Facility and the US Department of Energy and the new petawatt facility was completed in 2002. Once the upgrade became available to the academic user community, the flow of world-class results started. These have included characterisation of the fast electron source for fast ignition inertial fusion (the latest being its control by two laser pulses), direct laser acceleration of electrons in gas targets, confirmation of the universal scaling law for harmonic radiation with the observation of the 3000th order, among many others.

Of course, one must not forget the humble beginnings of the Astra laser facility in the Lasers for Science Facility as a 50mJ laser. After the closure of the KrF laser programme in the late 1990's, it was decided to enhance the Astra laser and upgrade it to 15 TW and move it to the high power laser division. The new independent Astra laser emerged in 1999. Investments by Plasma Physics Groups at Imperial College London and the Central Laser Facility using their funding from the α-X Basic Technology grant allowed the demonstration of mono-energetic electron beams to be made for the first time in 2004. These remarkable observations then paved the way for the construction of the Astra-Gemini dual-beam petawatt laser which was opened in 2007.

Optical parametric chirped pulse amplification

It is the remarkable synergy between advances in plasma and laser science, with the flexibility of senior management to capitalise on them by making strategic investments in new laser capability (in consultation with its user community), that has kept the Central Laser Facility in the premier league of science provision over the past 35 years. This would not have been possible without the Central Laser Facility having within it a core capability of forefront laser scientists who have dedicated themselves to premier-league facility provision. For example, the technique of optical parametric chirped pulse amplification (OPCPA) that was invented here in 1997 was quickly adopted as the pre-amplifier of choice for high energy petawatt laser systems around the world for it remarkable stability and high contrast performance properties compared with the previous standard of regenerative amplification.

Building upon this success, OPCPA is at the cornerstone of the next stage in the evolution of Vulcan – its upgrade to 10PW peak power. The upgrade not only allows the community to explore high energy density plasma behaviour at the intensity frontier, but also brings along side it as a bonus an upgrade to its high energy laser capability. One can say without doubt that the academic community is looking forward to its completion with anticipation.

Student training

One of the hall-marks of facility provision in the Central Laser Facility has been the recognition that PhD students only become proficient in high energy density science by hands-on practical experience, learning "by doing" and not being afraid of making mistakes. The experience gained by students and post-doctoral fellows who set up their own experiments, run the target areas to their own specifications, and are aware of all aspects of the experimental environment, is invaluable. PhD students trained using Central Laser Facility machines are in high demand around the world and quickly find employment once they have completed their studies. Many have gone on rise to prominent leadership positions in academia, in the National Laboratories in the United States, in AWE Aldermaston, as well as in Japan and in China. The CLF can rightly be proud of its pre-eminent role in the training of next-generation scientists in high energy density science.

The Lasers for Science Facility (LSF)

The LSF was born in 1987 for multidisciplinary scientific applications of excimer and excimer pumped dye lasers and a picosecond system for photobiological applications. The Laser Loan Pool was also formed to lend lasers to support University based laser experiments. The mission was, as now, to work closely with the academic community providing a suite of versatile tunable lasers, for example developing time-resolved resonance Raman (TR^3) and working with the groups from The Royal Institution of Great Britain and University of York (Profs Phillips and Hester). In 1990 Under Bill Toner the LSF changed gear by purchasing several new laser systems and moving the nanosecond Raman capability into the picosecond domain using a copper vapour/dye laser system operating at 6kHz. Additional lasers also provided the beginnings of the laser VUV-X-ray station that was to be used for the first irradiation of cells in the CLF to study DNA damage/repair and fabrication of nm scale transistor gates. In 1990 the LSF scheduled 55 experiments and the Laser Loan Pool awarded 21 loans. Throughout the 1990s the scientific pace increased. The LSF revolutionised ultrafast vibrational spectroscopy taking advantage of tunable solid state titanium sapphire based laser technology in conjunction with optical parametric systems and "modern" detectors, in 1992 they introduced a 33MHz computer to control the transient absorption experiments. In'95 Tony Parker took the lead of the LSF and pushed the biological programme forward by developing a dedicated picosecond confocal laser imaging microscope, initially to develop drugs for photodynamic therapy. This brought the total number of active LSF laser labs to 5 bringing on line a femtosecond laboratory as well.

The turn of the century saw many golden moments, PIRATE was turned on to perform ultrafast time-resolved infrared (working with Nottingham, George) and Kerr gated TR^3 began operations. Together this provided a unique combination of vibrational spectroscopy capability and ultimately removed the “wavelength” restriction for experimenters providing a laser system tunable from 200 nm to 1000 cm^{-1}. The TR^3 providing the seeds for the invention of Spatially Offset Raman Spectroscopy and the spin out Cobalt. An ICI grant also provided funds to develop laser tweezers, initially experiments looking at the particulates in solution but rapidly developed to look at more biological problems and aerosols, providing technology right across the Harwell site. By 2006-8 the LSF was running c. 125 weeks per year, and at one point publishing a reviewed paper every week, the Loan Pool had increased operation to 8 lasers producing some 20 papers annually. In 2006 the development of ultrafast spectroscopy continued with the BBSRC/STFC jointly funded project to develop the Ultra dual ps/fs 10 kHz, 10 W laser system. The LSF welcomed the arrival of the Advanced Single Molecule Imaging and Dynamics (ASMID) group from Daresbury that began operation in May 2009 and enormously strengthened the capability to LSF’s biological science programmes bringing single molecule fluorescence methods, computational imaging and biological labelling technology, funded in part by the award in 2009 of a “Longer Larger” (LoLa) grant from BBSRC, in collaboration with King’s College London. From 2009 the LSF began major restructuring as it prepared to move into the Research Complex at Harwell (RCaH) that ultimately took place in 2010-11 forming both Functional Biological Imaging (FBI) and the Molecular Structural Dynamics (MSD) sections. The multidisciplinary capability of the LSF provides a strong foundation for the Research Complex and fits in well with the latest developments across the Harwell Campus where it acts as a hub for cross facility programmes. In 2010-11 David Clarke took the helm as Ultra moved to RCaH, to join a new imaging facility, Octopus, which brought together the single molecule capabilities from ASMID and the multiphoton confocal microscopy facilities developed at Harwell. Developments of the facilities have continued, with the introduction of Time Resolved Multiple Probe Spectroscopy ($TR^M PS$) on Ultra, allowing the measurement of an unprecedented range of time scales in a single experiment, and with the addition of a 2D super-resolution imaging station to Octopus, with spatial resolution better than 50 nm, an order of magnitude improvement over conventional optical imaging. At the beginning of 2013, Octopus was given a major boost with the announcement of an award of £1.5M from MRC to establish 3D super-resolution capability on the facility.

With these developments, the LSF continues to go from strength to strength, and is well-placed to be at the heart of an internationally-leading spectroscopy and imaging centre at Harwell, linking laser techniques with x-ray methods on Diamond, neutron capabilities on ISIS, and whole organism imaging and genomics at the MRC Harwell unit. This combination is extremely powerful and will impact across a wide range of societally important areas such as health, energy, climate, and security.

Spin-off companies

Investment in basic science naturally leads to the emergence of spin-off companies, as new ideas and concepts find new applications to society. Prominent successes include: Exitech (founded by former Deputy Director Phil Rumsby and Malcolm Gower) for precision micromachining; Scitech Precision (founded by Martin Tolley) for target provision; Cobalt Light Sources (founded by Pavel Matousek) for exploitation of Raman spectroscopy; Laser Tweezers for ICI’s colloidal studies (led by Tony Parker); Colsi Coat Ltd (founded by Ian Ross) for random phase plate and anti-reflection coatings.

The Central Laser Facility has always had close ties with its large area optics manufacturing suppliers. This was reflected in the large business attendance of the September 2011 meeting at the Royal Society where commercial opportunities for inertial fusion associated with HiPER were discussed. Keeping industry abreast of latest developments is a key part of the Centrlal Laser Facility’s mission. In that spirit, the recent investments in diode-pumped solid state lasers via the Centre for Laser Technology and Applications is placing the UK in a leading position to take commercial advantage of new developments in solid state lasers via the Extreme Light Infrastructure projects in the EU and the HiPER/LIFE projects in the EU/US.

Leadership

The laser facility has had a number of distinguished Directors, drawn from academia, since its foundation. They have guided and steered the facility to its current-day success. They include:

1977 – 1983 Prof. Alan Gibson FRS
1983 – 1994 Prof. Mike Key
1994 – 1995 Dr. Bill Toner
1995 – 1996 Prof. Mike Key
1996 – 2006 Prof. Henry Hutchinson
2006 – 2010 Prof. Mike Dunne
2010 – Prof. John Collier

The Central Laser Facility has benefited immensely from their leadership. It is their selfless devotion to public service that has inspired the staff to emulate them, to “go beyond the call of duty” on many occasions and ensure the success of the high power laser programme as a whole.

Open to the world

One of the enduring features of experiments carried out at the Central Laser Facility is the wide participation of scientists from the United States, the European Union and Japan. The high power lasers are open directly to European researchers via the half-yearly call for proposals. Academics from the United States and Japan participate as collaborators of British principal investigators. Over a five year period, 70% of experiments have participants from overseas, a true reflection of the high regard with which it is held internationally.

Summary

And so, in conclusion of this year full of reflection and celebration, it is very pleasing to hold up the mirror and confirm that yes, the past thirty-five years are ones in which the United Kingdom can rightfully take great pride in the accomplishments of its Central Laser Facility. The welcoming atmosphere of the staff and the Laboratory to overseas guests is a reflection of the openness to new influences and cultures that is so characteristic of modern Britain. It is true to say that today the Science and Technology Facilities Council, through is Rutherford Appleton Laboratory, is equipped with the right skills, the right talent and the boundless energy to respond to the new challenges and the new opportunities as they emerge in the coming years.