Laser Science & Development

Artemis Upgrade, Relocation and the New 100 kHz OPCPA Laser for Ultra / Artemis

A.S. Wyatt, G. Karras, R.T. Chapman, Y. Zhang, C. Sanders, P. Pearcy, S. Spurdle, P. Brummitt, E. Springate *(Central Laser Facility, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)*

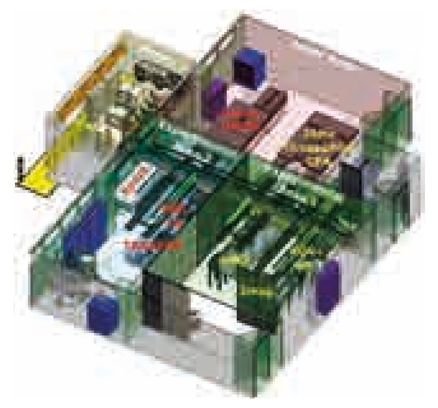
G.M. Greetham, B. Young, I.V. Sazanovich, P.M. Donaldson, M. Towrie *(Central Laser Facility, Research Complex at Harwell, STFC Rutherford Appleton Laboratory, Harwell Oxford, Didcot, UK)*

The Ultra and Artemis laboratories provide ultrafast dynamics and spectroscopy facilities for UK and international scientists, addressing problems across physics, chemistry and biology. Synergies in the technology and experimental approaches of these two CLF facilities will be exploited in the coming years by the relocation of Artemis to the Research Complex at Harwell, the home of Ultra.

The acquisition of a new 100 kHz optical parametric chirped pulse amplifier (OPCPA) laser system will upgrade the facilities and underpin future laser technology for both facilities, and the existing Artemis Ti:sapphire chirped pulse amplifier (CPA) will be upgraded with the addition of a third amplification stage. The separation of the laser and plant room from the experimental areas, and the introduction of additional beamlines with more specific end stations, will provide a more efficient user experience, whilst the laser upgrades will significantly enhance the experimental capabilities of both the Ultra and Artemis facilities.

We are actively engaging with the user community through our user meetings, conferences and scientific collaborations, and welcome suggestions from existing and potential new users to aid in shaping the future direction.

Contact: E. Springate (emma.springate@stfc.ac.uk)



Schematic of new Artemis laser facility. Top left: plant room containing vacuum pumps and laser chillers. Top: laser room containing upgraded 1 kHz Ti:sapphire CPA and new 100 kHz OPCPA. Bottom right: Experimental area 1 containing existing Artemis beamlines: atomic and molecular optics (AMO), XUV flat-field (FF) and imaging (Imag.). Bottom left: Experimental area 2 containing new Artemis beamlines: soft x-ray transient absorption (SXR TA) and time and angularly resolved photoelectron spectroscopy (TR-ARPES) and Ultra spectroscopy (Spect.) area.

Characterisation of the Carrier Envelope Phase of Few-Cycle Short-Wave Infrared Pulses

A.S. Wyatt, P. Majchrzak, R.T. Chapman, E. Springate *(Central Laser Facility, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)*

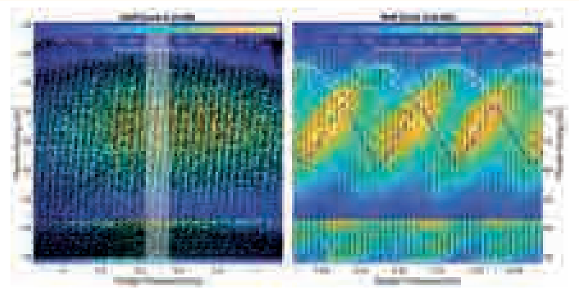
A. Pettipher, J.P. Marangos, J.W.G. Tisch *(Blackett Laboratory, Imperial College London, UK)*

Carrier envelope phase (CEP) stabilized few-cycle optical pulses in the short-wave infrared (SWIR) spectral region have many applications in strong-field physics, such as the generation of coherent femtosecond soft x-ray (SXR) pulses in the water window (~280—530eV) for transient absorption x-ray spectroscopy.

In attosecond pump-probe spectroscopy applications, a single probe pulse with a well-defined time-delay with respect to the pump pulse is desired. Since any measurement is averaged over an ensemble of pulses, it is therefore necessary to ensure that the CEP is controllable and held constant over the course of a single measurement. One method of generating CEP stable pulses is to use the idler wave from an optical parametric amplifier (OPA), followed by spectral broadening and temporal compression in a gas-filled hollow-core fibre succeeded by a pair of fused silica wedges.

We used high harmonic generation (HHG) in argon to generate extreme ultraviolet radiation up to 100eV, and demonstrated the passive CEP stabilisation via the measurement of half-cycle cut-off spectra. Thus, we have shown that it is possible to obtain CEP sensitive measurements from a passive stabilisation alone.

Contact: A.S. Wyatt (adam.wyatt@stfc.ac.uk)



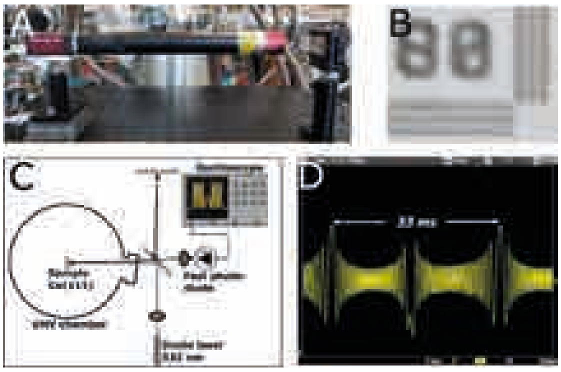
Averaged half-cycle cut-off spectra. Left: False colourmap of the harmonic spectra as a function of wedge thickness averaged over 25 repeat scans. The HCOs for each individual scan are marked by the black circles. The intensity of the lower energy harmonics has been scaled by a factor of x7. Right: Zoom in of the shaded white region marked on the left-hand plot. The individual HCOs are marked by the black dots. The white and blue dots/lines mark the theoretical primary (i.e. highest energy) and secondary HCOs calculated from the driving electric field.

Measurements of the sample vibration in the material science station of Artemis

Y. Zhang, P. Pearcy, G. Karras, R.T. Chapman, A.S. Wyatt, C. Sanders, E. Springate *(Central Laser Facility, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)*

The vibration of the sample stage on the manipulator of the material science station at Artemis is measured by two methods: a microscope, and a Michelson interferometer. The amplitude of sample vibration is found to be smaller than 3 µm with all four turbo pumps on, but two scroll pumps off. The running of scroll pumps introduces a sample vibration as large as 10 µm.

This work ensures the current manipulator is suitable for angle-resolved photoemission spectroscopy (ARPES) with small spot sizes ("micro-ARPES") down to 10 µm, and helps us to understand — so as to minimize — vibration transfer in the design of the new Artemis laboratory.



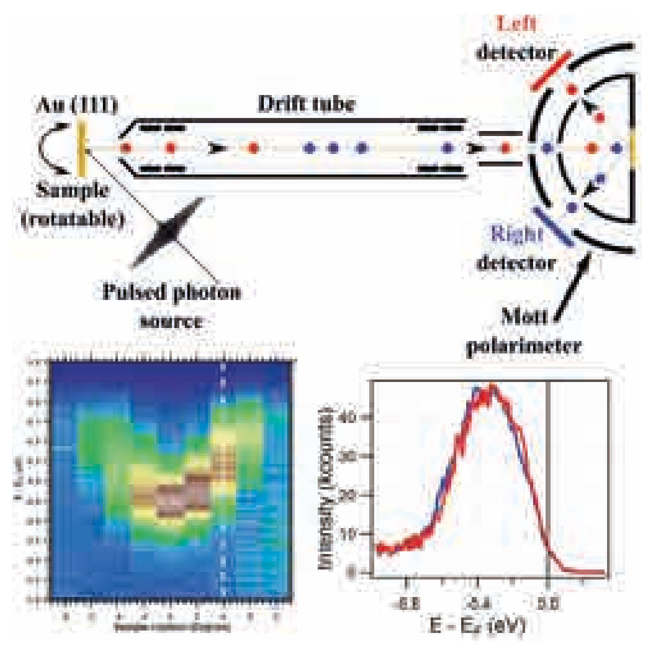
A. The microscope to monitor the vibration of samples.
B. An 80 line pairs/mm resolution test pattern is shown in the image. It is blurred due to the 10 µm vibration induced by the scroll pumps.
C. The schematic of Michelson interferometer setup.
D. The interference signal of the vibration induced by the scroll pump.

Contact: Y. Zhang (yu.zhang@stfc.ac.uk)

Benchmarking the performance of the spin-resolved time-of-flight electron analyzer in Artemis

Y. Zhang, P. Pearcy, G. Karras, R.T. Chapman, A.S. Wyatt, C. Sanders, E. Springate *(Central Laser Facility, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)*

We have benchmarked the performance of the spin-resolved time-of-flight (Spin-TOF) electron energy analyzer at Artemis by measuring the spin-polarized surface state on an Au(111) crystal. To avoid space charge effect, an XUV flux of around 10^6 photons/pulse (10^9 photons/s) at around 15.5 eV was employed.
The parabolic dispersion of the Au(111) surface state was observed, with an energy resolution of around 130 meV. By using a Mott polarimeter, the spin-polarized states were successfully resolved at about 0.11 A^{-1}. The measurement took about 48 hours to reach a satisfactory signal-to-noise ratio, however, which indicates that a higher repetition rate source will be necessary for the study of electron dynamics using the spin-TOF analyzer.



(Top) Schematic of the Spin-TOF measurement. Spin-polarized electrons created from the surface of Au(111) fly into the analyzer and get distinguished at the Mott polarimeter.
(Bottom left) The parabolic surface state measured with spin-integration.
(Bottom right) The spin-resolved spectra (red for spin-up, blue for spin-down) measured at about 0.11 A^{-1}, which is indicated by the white dashed line on the left graph. The binding energy offset of the red peak relative to the blue peak is due to the Rashba splitting of the Au(111) surface state.

Contact: Y. Zhang (yu.zhang@stfc.ac.uk)

CARAVAGGIO: a new experimental station for characterising materials and optics over a wide range of temperatures

A.M. Wojtusiak, M. De Vido, K. Ertel, I. Cheshire, T.J. Butcher, P. Mason *(Central Laser Facility, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)*

CARAVAGGIO, a new experimental station to characterise optical components and materials and to perform proof-of-concept demonstrations, has been commissioned. CARAVAGGIO is an important tool to enable the scaling of DiPOLE technology, as it allows the optimisation of concepts and optics before they enter the system. The layout of CARAVAGGIO is highly flexible, which allows a variety of measurements to be taken.
It consists of two main beamlines: one operating at room temperature, which can be used for measuring reflectivity and transmission of optics over a wide range of angles, while the other allows to measure the optical properties of materials over a temperature range between 77K and 500K.

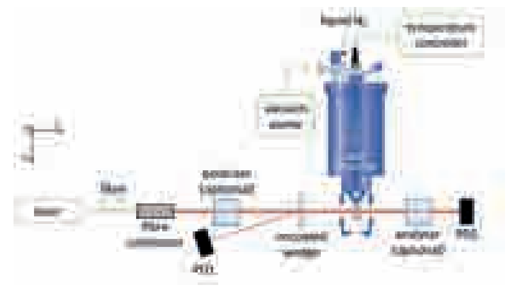


Figure 1: Experimental setup for the room temperature beamline of CARAVAGGIO.

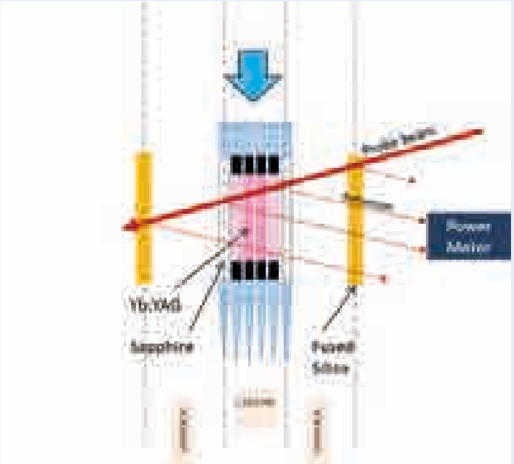
Figure 2: Experimental setup for the optical cryostat beamline of CARAVAGGIO.

Contact: M. De Vido (mariastefania.de-vido@stfc.ac.uk)

Suppression of reflected power in the DiPOLE cryogenically cooled amplifier head

J. Fullalove, J.M. Smith, K. Ertel, T. Butcher, J. Phillips, P. Mason, S. Banerjee, M. De Vido *(Central Laser Facility, STFC Rutherford Appleton Laboratory, Harwell campus, Didcot, UK)*

The DiPOLE prototype laser has been developed within CALTA at the CLF as a next generation, high energy, high average power, cryogenically cooled, diode pumped solid state laser (DPSSL). The amplifier head at the heart of DiPOLE houses a number of optics including multiple gain media disks, sapphire pressure windows and fused silica vacuum windows. In this report we detail a successful investigation and rectification of a phenomenon that resulted in a gradual decrease in the output energy of the amplifier during operation. The phenomenon was traced to an increase in the reflectivity of anti-reflection coated optics within the amplifier head, likely due to a condensation layer forming under cooling.



A cross-section of the CW beam which is propagated through and reflected by the DiPOLE amplifier head.

J.M. Smith (Jodie.smith@stfc.ac.uk)

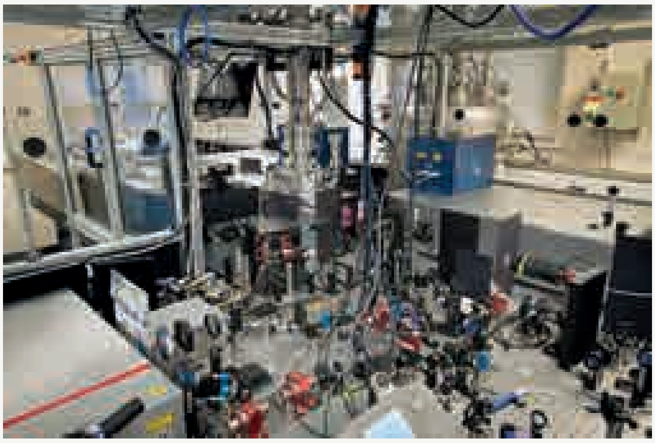
Increasing the productivity of the DiPOLE prototype laser

J.M. Smith, T.J. Butcher, K.Ertel, P. Mason. S. Banerjee, M. De Vido, P.J.P. Phillips, R. Allott, C.B. Edwards *(Central Laser Facility, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)*

The DiPOLE laser system was constructed as a proof of concept system, to establish a new architecture of scalable laser systems. The system has since become a test bed, enabling development of technologies and testing of optics.

The system started as a development space and therefore did not require, or indeed have, a long-term schedule for experiments and maintenance. Despite this approach, work carried out with the DiPOLE system had continued to deliver useful scientific output. While making changes to the DiPOLE system to accommodate laser shock peening experiments, however, the need for scheduling became more apparent.

Recently a new system that schedules experimental campaigns has been trialled, to allow more effective resource management and provide the necessary preparation time for a successful experiment. In 2017/18, a total of 27 experimental sessions of varying duration were scheduled and all successfully completed, including planned developments to the DiPOLE system itself.



The DiPOLE laser system.

Contact: J. Smith (jodie.smith@stfc.ac.uk)

Femtosecond Timing Monitor for Gemini Laser area

N. Bourgeois *(Central Laser Facility, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)*

M.J.V. Streeter *(The John Adams Institute for Accelerator Science, Imperial College London, UK)*

We present a diagnostic for monitoring the temporal overlap of the North and South beams of the Gemini laser.
The Femtosecond Timing Monitor (FTM) is installed in the Gemini laser area, and measures the pulse separation accurately over a 10 ps time window. This diagnostic also gives a direct indication of which pulse is ahead in time.

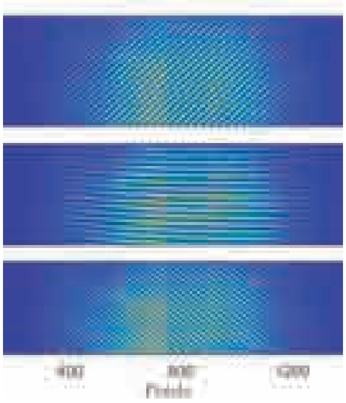


Figure 1: Timing fringes from the interference of the North and South beams. a) Δt = 1.26 ps South beam late, b) Δt = 74 fs, c) Δt = 1.40 ps South beam early.

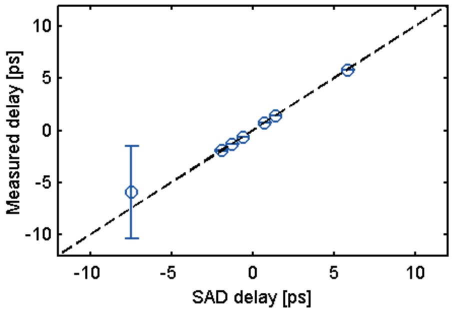


Figure 2: Measured pulse separation against delay introduced on the Split And Delay (SAD) table

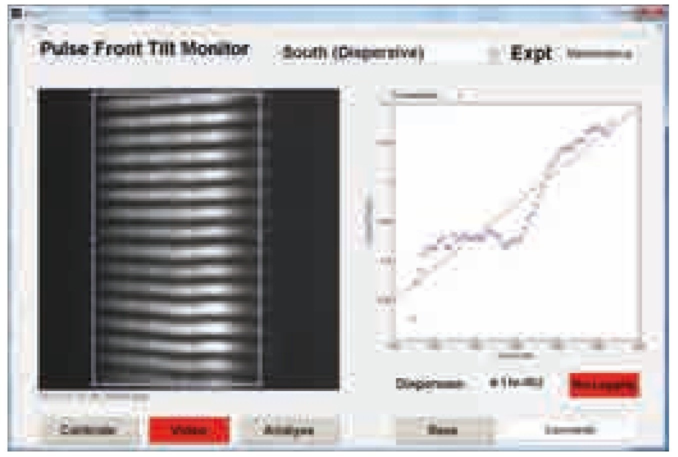
Contact: N. Bourgeois (nicolas.bourgeois@stfc.ac.uk)

Implementation of a spectrally-resolved inverted-field autocorrelator for angular dispersion measurements in Gemini

C.D. Gregory, Y. Tang, O. Chekhlov, S. Hawkes, C.J. Hooker, V.A. Marshall, B.T. Parry, D.R. Symes *(Central Laser Facility, Gemini Laser Group, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)*

Misalignment of the Gemini compressors can result in uncompensated angular dispersion of a laser beam, which increases the pulse duration, reduces the temporal contrast, and distorts the focal spot. After compressor alignment in the laser area, any residual minor misalignment is currently corrected for by making small changes to the compressor gratings while monitoring experimental observables in the target area (for example, focal spot shape or electron beam pointing).

A new diagnostic is being implemented to improve the accuracy of the laser area diagnostics, with the goal of eventually allowing a precise value of the angular dispersion to be measured on-shot. The system uses a spectrometer to analyse the output of an interferometer in a technique known as SRIFA (spectrally-resolved inverted-field autocorrelation). When commissioned, this diagnostic will provide a real-time measurement of the angular dispersion of the Gemini beam.



User interface for the new diagnostic, showing an example of raw data on the left, and the calculated dispersion on the right.

Contact: C.D. Gregory (christopher.gregory@stfc.ac.uk)

Software developments in Gemini

V.A. Marshall *(Central Laser Facility, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)*

The Gemini laser system software consists of a network of distributed applications, which are used to control elements of the laser and monitor a large number of parameters, both on-shot and continuously. There have been a number of changes and upgrades to the software this year.

At the request of the users, the interface with the Newport ESP300 slide has been upgraded to provide finer and easier-to-use control over the relative timing of the two beams. Other changes offer:

- improved temperature monitoring at multiple locations throughout Laser Area 3 to determine the effect (or otherwise) of temperature variations;
- better management of the 15 attenuating filter wheels used in front of cameras and diagnostics, so that failed wheels can be identified more easily;
- more detailed daily beam characterisation reports that can be emailed to laser operators and users.

Contact: V.A. Marshall (victoria.marshall@stfc.ac.uk)

ESP300 control application user window.

Manufacture and assembly of shell-and-cone targets for plasma collision experiments

P. Ariyathilaka *(Scitech Precision Ltd, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)*
C. Spindloe *(Central Laser Facility, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)*
M. Harris *(RAL Space, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)*

This article gives a brief introduction to complex shell-and-cone targets Scitech Precision Ltd assembled for an experimental campaign involving the collision of plasmas. The main purpose of the experiment was to drive the target from two sides using two nanosecond lasers. The plasma that is ejected from the cones collides in the middle, which is observed. Diagnostics used were proton radiography and hard x-ray measurements.

The target consists of two gold micro cones, which had a wall thickness of ~20 μm and a height of ~380 μm. A 60 μm thick plastic hemisphere was glued inside the gold micro cone. Subsequently two such cones were attached to an aluminum bridge with a 100 μm ±5 μm gap to complete the target.
The small size and delicacy of the micro components made handling the target very difficult. Many different processes were used in the fabrication of the targets, including diamond point turning, PVD, CVD and laser micro machining, as well as complex manual assembly.

The article describes the target, its components and the different assembly processes in more detail.

Figure 1: Image showing a completed target. The aluminum bridge holds the whole assembly together and facilitates the mounting process.

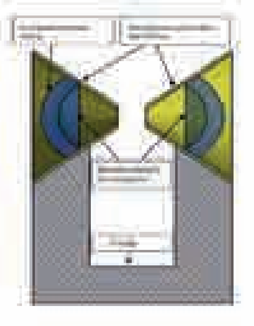


Figure 2: Drawing showing the full target.

Contact: P. Ariyathilaka (pawala.ariyathilaka@scitechprecision.com)

Development of patterned tape-drive targets for high rep-rate HPL experiments

S. Astbury, C. Spindloe, M. Tolley *(Target Fabrication Group, Central Laser Facility, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)*
L. Harman, P. Sykes *(Scitech Precision Ltd, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)*
W. Robins *(Precision Development Facility, RAL Space, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)*
B. Kettle, S. Mangles *(Faculty of Natural Sciences, Department of Physics, Imperial College London, UK)*

As high power lasers offer increasingly high repetition rates, delivery of solid targets for experiments is becoming a pressing issue. A tape substrate mounted on a driving mechanism aligned to the focal position of the beam can provide a constant 'stream' of targets for laser interaction. While this is a practical method for target delivery and thin CH tapes can be readily procured, the target material and coating thickness is very limited, and any coatings/patterns must be post-processed which is extremely time consuming and difficult.

A method for manufacturing custom-coated targets on a substrate material to specific thicknesses is presented. The fabrication process employs various technologies, including thin-film coating, chemical etching and laser-machining. The process theoretically allows the delivery of several thousands of targets in a single cycle. The benefits and challenges in producing such target tapes are discussed, as well as the methods for improving the technology for the future.

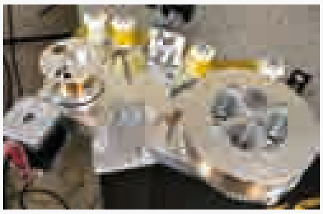


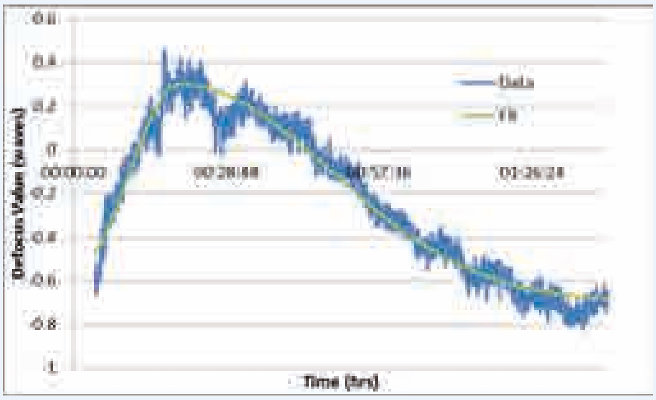
Figure 1: Completed sections of 100 nm Ge target tape. The black vertical markings indicate the joint location of each strip.
Figure 2: Prototype of high-stability tape drive system.

Contact: S. Astbury (sam.astbury@stfc.ac.uk)

Study of the prompt aberrations of the Vulcan TAP Beamline

I.O. Musgrave, M. Galimberti, P. Oliveira, D. Pepler, R. Clarke, D. Carroll *(Central Laser Facility, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)*

In this paper we discuss the progress that we have made in addressing the on-shot aberrations that occur when the Vulcan laser is fired, primarily addressing the amount of defocus. We see that there is evidence that the time since the last laser shot plays a significant role in the variability of this parameter and we report our investigation into its temporal evolution. Results shows that it is crucial for there to be a minimal amount of time between running the adaptive optic and then firing the laser.



Typical decay of the defocus term after a full disk shot showing exponential fits to determine some temporal constants of the system.

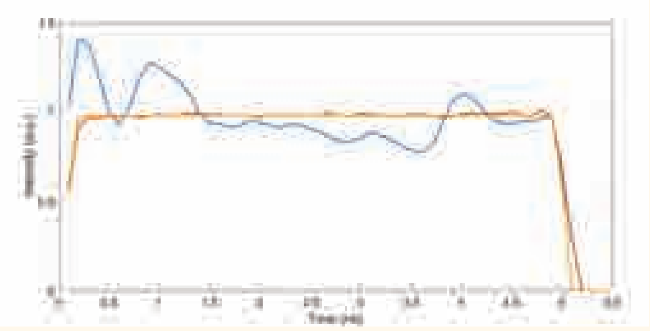
Contact: I.O. Musgrave (ian.musgrave@stfc.ac.uk)

Control of the temporal shape of nanosecond long lasers using feedback loops

P. Oliveira, S. Addis, J. Gay, K. Ertel, M. Galimberti, I. Musgrave *(Central Laser Facility, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)*

We present developments in the control of the temporal pulse shape of nanosecond long pulsed lasers. An active feedback loop between the output of a regenerative amplifier and its input to obtain the desired pulse shape is demonstrated. We compare several algorithms to achieve this, and the differences due to the targeted pulse shape and duration, in this paper. It is found that the algorithm that is based on the ratio of the target and measured pulse profiles provides the most robust solution. The method proposed here can be used to obtain any pulse shape with minimal knowledge of the laser amplification system.

Deformation of the pulse temporal profile due to our regenerative amplifier system. We input a 5 ns top hat temporal profile in into our system (yellow) and get the blue waveform at the output. After the described corrections we obtain the waveform in red.



Contact: P. Oliveira (pedro.oliveira@stfc.ac.uk)

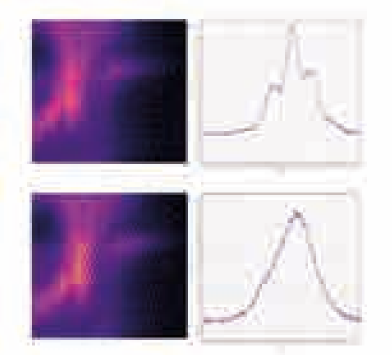
Progress Towards Coherent Combination of Free-Space Femtosecond Laser Pulses

W.H. Fraser, V.C. Lindsay, B. Parry, M. Galimberti *(Central Laser Facility, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)*

We have successfully achieved spatial and temporal locking of two ~100 fs duration laser pulses in the far field. The work is another step towards realising full coherent combination of multiple large aperture beams as part of the HAPPIE project.

Mirrors mounted on piezo tip/tilt and tip/tilt/piston platforms act to stabilise two 10 mm square beams to an external spatial set-point, and maintain them in phase at frequencies up to ~200 Hz.

This report focuses on developments required to accomplish reliable temporal stabilisation. A piezo phase-shifter and additional PID loop were introduced to permit robust correction in the presence of fast phase noise.



The top images show the focal spots and spectra of the short pulses with a path difference of ~100 μm between the two arms. The bottom images are with the path difference minimised, and spatial and temporal stabilisation enabled. Static interference fringes are observed in the far-field, with no interference in the spectral domain.

Contact: M. Galimberti (marco.galimberti@stfc.ac.uk)