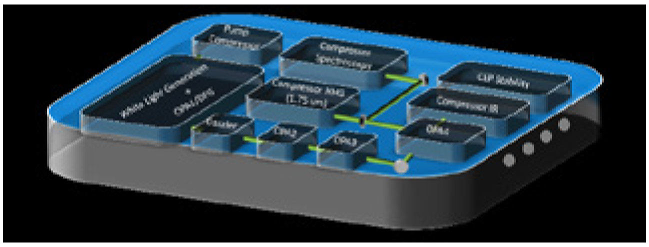
Laser Science & Development

Installation of the Mid-IR OPCPA Laser in the RCaH CLF Laboratories

G. Karras, G. Greetham, Y. Zhang, S. Conroy, A.S. Wyatt, A. Cox, P. Rice, S. Spurdle, P. Brummitt, E. Springate, M. Towrie (*Central Laser Facility, Research Complex at Harwell, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK*)

The Artemis / ULTRA upgrade continued this year with the relocation of the Artemis laboratory to the Research Complex at Harwell (RCaH). The relocation included the introduction of third generation ultrafast laser technology to these facilities. The installed system has passed the major milestone of factory acceptance, demonstrating its capability, and is now located in the RCaH for installation and site acceptance in January 2020. The system comprises a high average power pump laser, based on an Yb:YAG thin disk regenerative amplifier front end and an OPCPA. In this paper we present results of evaluation measurements regarding the expected efficiency of the laser in producing high harmonic generation photons, and simulations of super continuum generation in the mid-IR region.



Cartoon layout showing the different sections of the new OPCPA system

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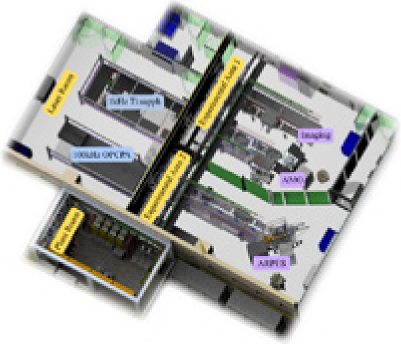
New laboratories for Artemis in the RCaH

A.S. Wyatt, R.T. Chapman, G. Karras, Y. Zhang, C. Sanders, G. Greetham, A. Cox, P. Rice, S. Spurdle, P. Brummitt, M.Towrie, E. Springate (*Central Laser Facility, Research Complex at Harwell, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK*)

The Artemis / ULTRA upgrade continued this year with the relocation of the Artemis laboratory to the Research Complex at Harwell (RCaH). Two adjacent laboratories totalling 120 m^2 have been fully refurbished for Artemis, doubling the floor space of the facility. In this article we report on the progress made and outline the laboratory configuration and future capabilities.



Schematic of the new Artemis facility in the Research Complex at Harwell

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Upgrades to the Artemis Material Science Station

Y. Zhang, C. Toolan, R.T. Chapman, A.S. Wyatt, C. Sanders, E. Springate (*Central Laser Facility, Research Complex at Harwell, STFC Rutherford Appleton Laboratory, Didcot UK*)

We have upgraded the material science station at Artemis by motorizing the sample manipulator, and installing a new two-dimensional photoelectron detector and high-speed camera. These upgrades will enable new experimental schemes and more efficient data collection.

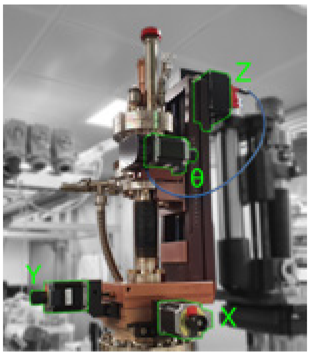

Photo of the manipulator on the motorized translation stage. The corresponding driving motors are highlighted.

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Acoustic signature of laser shock peening for a qualitative evaluation of residual stress

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Acoustic signals recorded from laser shock peening (LSP) of aluminium, titanium and stainless steel alloys were analysed for different laser pulse widths, energy and confinement conditions. In this paper, we report that different materials and conditions registered unique acoustic signatures. Further, the acoustic signatures in the time domain were transformed to the frequency domain and were fitted to a lognormal distribution, yielding a unique set of parameters for each material and set of conditions. These parameters were benchmarked using the measurements of residual stress by the incremental centre hole-drilling (ICHD) method. Detailed analysis of the acoustic signal reveals that this method once calibrated with few ICHD data, can identify successful peening of materials.

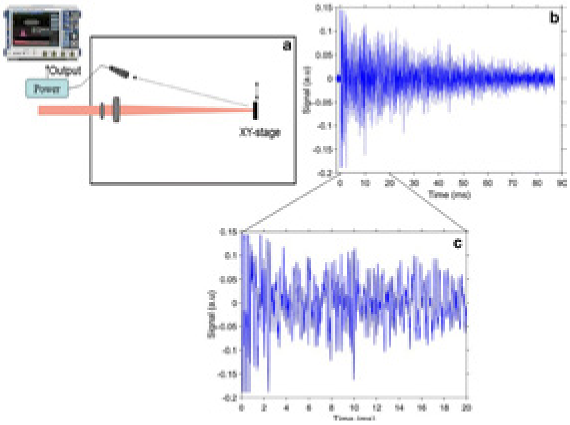

Figure 1: (a) layout of the LSP work station; (b) typical temporal evolution of the LSP acoustic signal; (c) expanded view of the temporal signal showing convolution of multiple signals

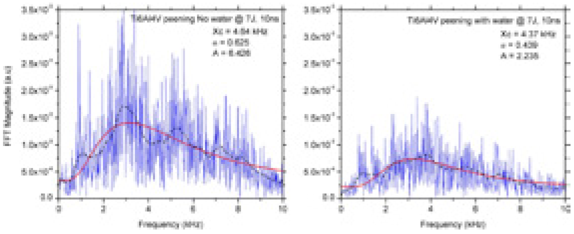

Figure 2: FFT obtained from the temporal acoustic signal for Ti6Al4V with and without a confinement medium (water) at 7 J, 10 ns. The red line shows a lognormal fit to the data. The dashed black line is the adjacent-averaged signal showing multiple peaks. Also given are the set of parameters obtained with the fit.

Reproduced from Banerjee, S., Phillips, P.J., Nygaard, J. et al. Appl. Phys. A 125, 571 (2019). https://doi.org/10.1007/s00339-019-2869-1, under the terms of the Creative Commons Attribution 4.0 International License.

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Optical rotatory power of quartz between 77K and 325K for 1030nm wavelength

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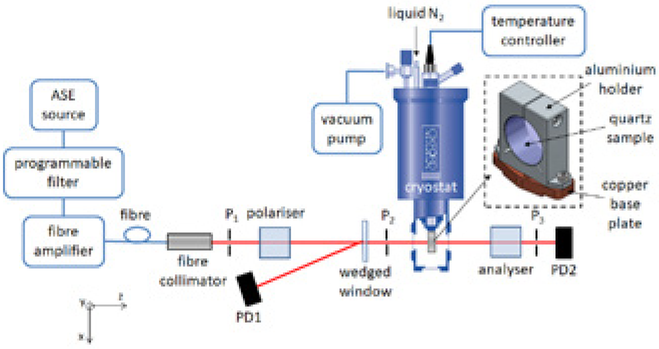
A. Wojtusiak *(Loughborough University, UK)*

We report on the experimental characterisation of the temperature dependence of the optical rotatory power of crystalline α-quartz at 1030 nm wavelength. The temperature range covered in this study is between 77 K and 325 K. For the measurement we propagated light through a 13.11 mm thick quartz plate collinearly with the optic axis. At room temperature, the plate rotates the polarisation plane of 1030 nm light by 89.3 deg, corresponding to a specific rotatory power of 6.8 deg/mm. When placed between parallel polarisers, the transmission through the system was 0.03% at room temperature and increased to 1% at 77 K, showing a measurable change in rotatory power. At 77 K, the angle of rotation imparted by the quartz plate is 85 deg, corresponding to a specific rotatory power of 6.5 deg/mm. To the best of our knowledge, this is the first time that the temperature dependence of optical activity of α-quartz is reported for cryogenic temperatures in the infrared. We expect that these results will assist in the design and characterisation of optical systems operating under cryogenic conditions.



Experimental setup used to characterise the temperature dependence of the rotatory power of quartz

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EPICS-based software for the Vulcan Target Alignment Rig

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New EPICS-based software was written to enable the alignment and inspection of targets in Vulcan Target Areas using the existing control hardware, with upgraded cameras.

The Vulcan Target Alignment Rig is used to inspect a component from various angles using three cameras and a rotary target stage, each of which can be controlled in x, y and z axes.

As the custom software written for the original system could not be upgraded to be compatible with Windows 10, it was decided to develop an EPICS-based software control system compatible with the existing motion controllers, while upgrading the cameras.

EPICS input/output controllers implement the required back-end functionality, such as communication with device drivers, inter-device communication and synchronization, parameter settings, etc. An intuitive graphical user interface has been developed with a similar appearance and features to the previous system.

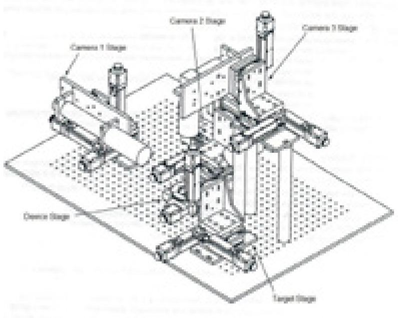

Figure 1: System layout

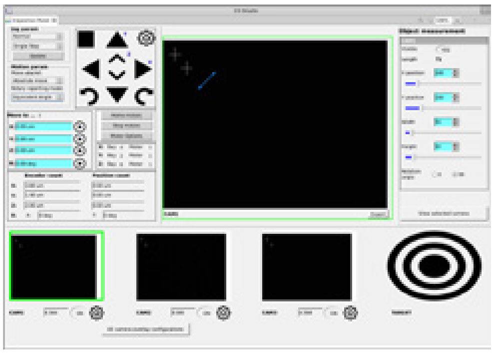

Figure 2: Inspection control panel

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Investigation of temporal properties of a cross-polarised wave generation temporal filter at the front–end of the Gemini laser system

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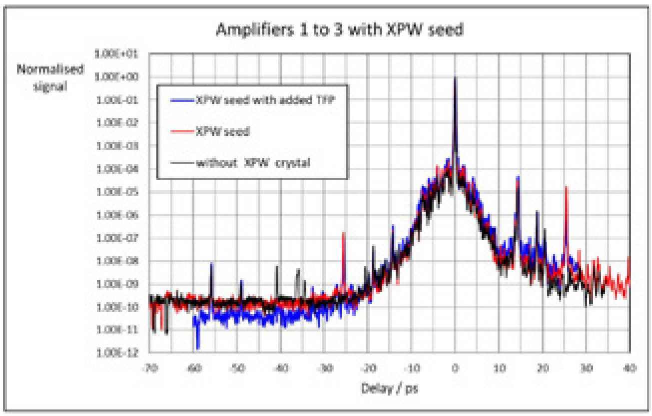
A temporal control unit (TCU) has been built at the front end of the Gemini system. The core of the TCU is a cross-polarized wave temporal filter (XPWTF). The device also includes a temporal stretcher with a programmable dispersion filter, and a booster amplifier that restores the energy of the pulses to ~ 0.9 mJ, compensating for the energy lost in the non-linear processes. The output of the TCU was recently coupled into the Gemini amplifier chain for the first time, and the energy, spectra and temporal contrast of the pulses were measured. The energy and spectrum were normal. The contrast traces, which are presented in the figure, were measured after the Gemini compressor with a third order cross correlator (Sequoia). Some pre-pulses have been eliminated, and the background level reduced. For a full description of the device and its operation, see the extended online version of this article.



Sequoia traces of the temporal contrast of the cleaned pulse after compression. Black: without XPW crystal in XPWTF; Red: with XPW crystal; Blue: with extra thin film polarizer before XPWTF.

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Beam Pointing Stabilisation on the Gemini Laser System

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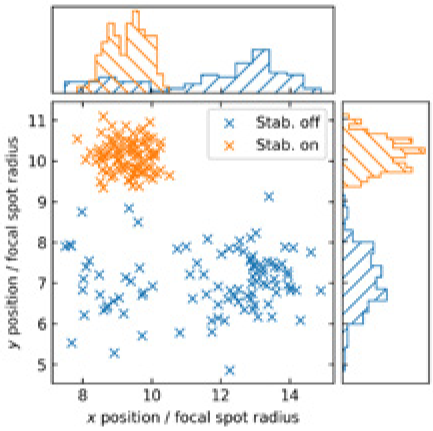
We describe a new system in the Gemini facility that uses a back-propagating pilot beam to detect changes in the beam direction. These changes are then corrected using a PID controller and a piezo-actuated mirror. This stabilises the pointing of the forward-propagating full power main beam, halving the observed variation in the target area. This could be used to lock the beam to a small target, or to stabilise one or (in the future) both beams at a collision point. Experiments requiring the best pointing stability, or in which a laser beam needs to interact with an electron beam or a second laser beam, will all benefit from this development.



The beam pointing during full power shots with stabilisation switched on and off, measured in multiples of the focal spot radius.

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Operational improvements to the Gemini Facility 2018-19

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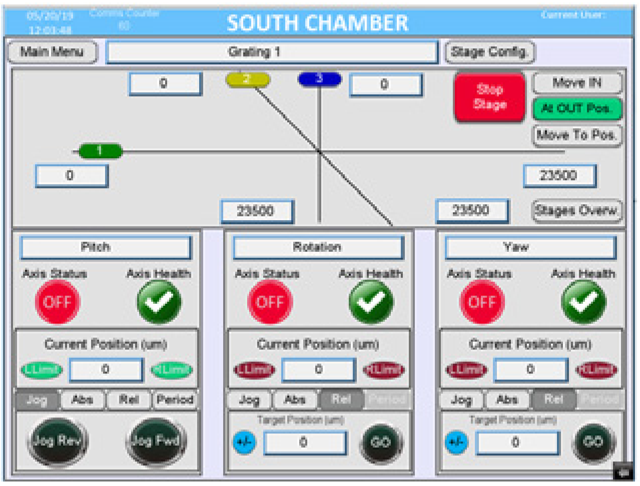
During the year there have been several modest improvements made to the Gemini facility, which individually do not merit separate articles. These include:

- The installation of a new drive system on the south compressor;
- The installation of new beam attenuators that allow the Gemini beams to be attenuated by 100x or 10,000x for setup purposes, without any change in relative timing;
- New lens pairs to enable adjustment of the focal length in the pump beam homogenization optics;
- Improved temperature monitoring in the Gemini laser area.

Each of these developments has led to either an improvement in the usability of the laser or a better understanding of a problem, which will in turn lead to further improvements once the problem has been solved.



Screenshot of the control interface of the new drive system for the Gemini south compressor.

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Operational improvements to the Gemini Facility 2018-19

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.

Over the last year, the most significant upgrade to this software has been the introduction of the Experimental Physics and Industrial Control System (EPICS), originally developed at Los Alamos National Laboratory. Software developed for Gemini using this system includes:

- The main control system, which exports around 80 EPICS Process Variables (PVs) detailing the state of the laser and the target areas;
- TA2 control system, the user interface of which has been upgraded and redesigned to display more clearly the state of the system;
- TA3 control system, the user interface of which has also been upgraded and redesigned, with a new in-window timeline facilitating visualisation of the sequence of events in the system (see Figure).

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In addition, two carefully configured servers have been introduced to act as Gateways between multiple networks (user institute, camera, laser and main site). These allow users to manage their own data acquisition systems, whilst also permitting visibility of Gemini PVs and diagnostic data.

Part of the TA3 Control System main window

Development of thin bond lines for high power laser experiment targets

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C. Spindloe, A. Hughes *(Central Laser Facility, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)*

This article gives a brief introduction to a micro-assembly project commissioned by the Atomic Weapons Establishment (AWE), to develop targets with ≤1 µm adhesion layers in between two of the components. Scitech Precision was successful in achieving the specification, with an average adhesion layer thickness of 1.07 µm ± 0.28 µm.

The assembled target consisted of a single crystal diamond (SCD) attached to a tungsten washer. Polymethylmethacrylate (PMMA) was spin-coated on to the SCD, to be used as the adhesion layer on which a copper foil was placed in a particular orientation, as instructed in the target specification.

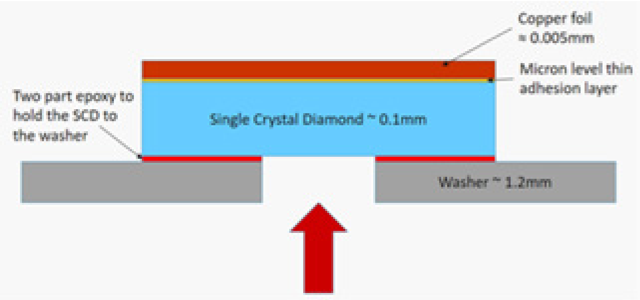

Figure 1: Schematic of the assembled multilayer target

Development work focused in particular on the spin-coated PMMA thin film, which was used as a micron-thick adhesion layer. The average thickness was measured using a touch probe (Tencor Alpha Step IQ). Spin speed and spin time, the main parameters of the spin coater that determine film thickness, were investigated to determine the optimum settings to achieve the required thickness, whilst maintaining a wet film on the SCD that would adhere sufficiently to the copper foil.

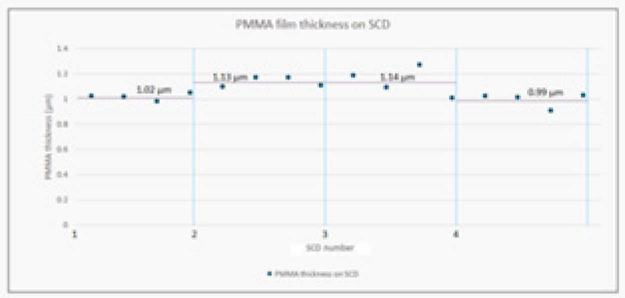

Figure 2: Graph showing the average PMMA film thickness across four different SCDs

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Progression of a tape-drive targetry solution for high rep-rate HPL experiments within the CLF

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L. Harman, P. Sykes *(Scitech Precision Ltd, Rutherford Appleton Laboratory, Harwell Science & Innovation Campus, Didcot, UK)*
W. Robins *(Precision Development Facility, RAL Space, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)*
R. Sarasola, K. Rodgers *(Electrical and Control Group, Central Laser Facility, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)*

This annual report focuses on the work undertaken by the Target Fabrication Group and the Electrical and Control Group on developing a novel tape-target technology, as well as a system for driving these tapes at a high stability.

The report includes interferometric and chromatic confocal scans of the flatness and stability of the tape, both while stationary and driving at high repetition rate velocities.

The tape drive is shown to have a stability in the laser axis to within ±5 µm and supports the use of the system and target technology on future high power laser experiments, without having to refocus between shots.

Future upgrades to the target fabrication methods are discussed, including manufacture of a coating plant compatible tape drive system for coating directly onto long rolls of tape. Improvements to the drive system are also suggested, namely being able to be ran in both directions to allow for even higher shot rates.

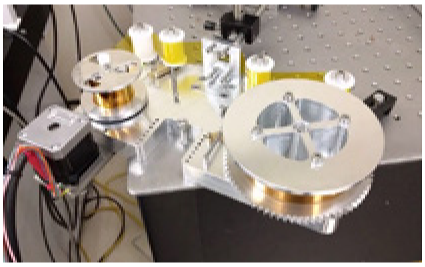

Figure 1. Design of CLF's high-stability tape drive system

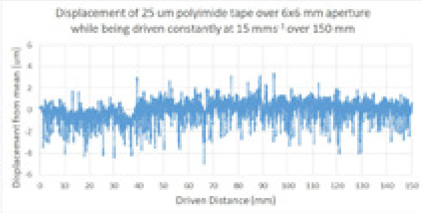

Figure 2. Chromatic confocal displacement scan of tape driving at 15 mms^{-1}

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Micro computed tomography for characterisation of high-power laser targets

S. Irving, C. Spindloe, A. Hughes *(Target Fabrication Group, Central Laser Facility, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)*

Precise characterisation of targets is a necessity in the field of high power laser experiments, to allow accurate analysis of experimental data, as well as to confirm that the targets produced conform to the agreed specifications.

For targets where features are embedded within other solid regions, standard imaging techniques (e.g. SEM, AFM) are inadequate. Micro-computed X-ray tomography (µCT) provides a means of imaging the interior of solid targets, thus overcoming this limitation. Using µCT it is possible to detect regions with different densities to the surrounding material within objects.

This report presents two case-studies in the use of µCT for imaging foam targets with embedded components, and the method of characterisation for these samples.

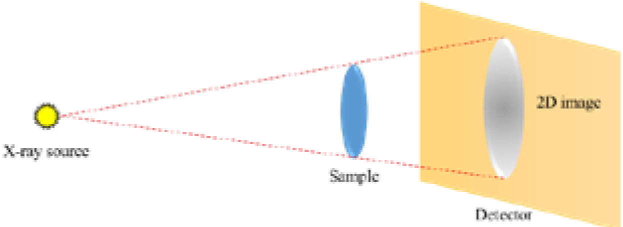

Figure 1: Schematic of the µCT imaging process; X-rays pass through the object, and are rendered on the detector, with denser regions producing darker images

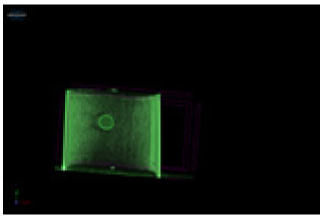

Figure 2: µCT scan of PS bead embedded in a foam target

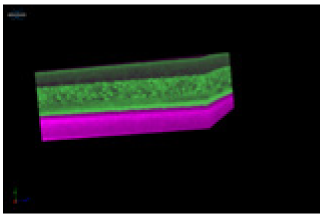

Figure 3: µCT scan of a multilayer target showing four distinctive layers: from bottom to top - Si wafer; 100 mg/cc foam; foam doped with 9 µm particles; foam doped with 80 µm particles

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Development of Automated Fabrication Processes for High Repetition Rate Micro-target

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P. Amos *(Electrical Engineering Group, Central Laser Facility, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)*
M. Williams *(Diamond Light Source, Diamond House, Harwell Science & Innovation Campus, Didcot, UK)*

As laser repetition rates increase, there is more demand for micro-targetry to support experiments.

This paper details a Target Fabrication Group project to enhance automated fabrication processes for micro-targetry. Array targets for use on the Gemini laser system are fabricated using two robots running independently: one to pick and place target foils, and the other to glue lines/dots upon which the target foils are to be placed.

Finding rapid and repeatable ways to fabricate these targets will reduce the strain placed on staff who carry out the fabrication and quality assurance processes. This, in turn, will allow staff more time to develop new capabilities within our laboratories, aiding experiments in the near future through improvements in the quality and rate of micro-targetry fabrication.

Future work is focused on developing more defined processes, with capabilities and reliabilities far beyond what is currently available. Use of data collection equipment, such as a camera and other sensors, will help to define and optimise the automated system, delivering improved manufacturing times, higher repeatability and greater precision without compromising flexibility.

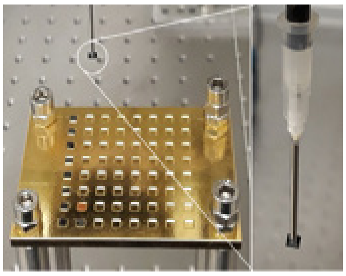

Figure 1: Gold coated, 3D-printed target foil tray. Shown is a pallet of 8x8 indents used to locate targets along with some test targets such as silicon or copper targets. Adjacent to that is a needle tip picking up a silicon target to transport over to a target array.

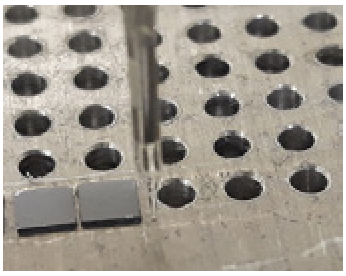

Figure 2: Target array with two targets adhered using glue dispensed from the needle tip shown.

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A compact micro-bolometer array for mid-infrared laser beam alignment, diagnostics and spot-size measurement

I.P. Clark, M. Towrie *(Central Laser Facility, Research Complex at Harwell, STFC Rutherford Appleton Laboratory, Harwell, Didcot, UK)*

Knowledge of a laser beam's profile throughout a laser system and experiment can help immensely in diagnosing laser problems, and assisting in beam alignment and focusing at a sample. Obtaining such profiles is a trivial task in the ultraviolet-visible wavelength range, but more challenging with near-infrared to infrared beams. High cost scientific grade bolometer arrays, suitable for such a task, do exist but are relatively big, and have a large pixel size, of the order of 80 µm, which is adequate for profiling larger beams but poses an issue when trying to profile sub 100 µm beams, for example, at a focal point.

We have identified a micro-bolometer array for near- to mid-infrared laser beam profiling, based on an inexpensive Seek Thermal Android camera. The device is very compact, enabling use in confined spaces, and has a small, 12 µm, pixel size permitting the profiling of focused laser beams. This compares to 17 µm for the nearest scientific grade device. This device is a powerful tool for infrared laser spectroscopists, reducing the time required to measure the spot size of beams and to achieve spatial overlap of multiple infrared beams, for example as used in two-dimensional infrared spectroscopy. This has proven to save many hours of setup time. The use of the bolometer array as a spectrographic detector and probe of long-term beam drifts have also been demonstrated.

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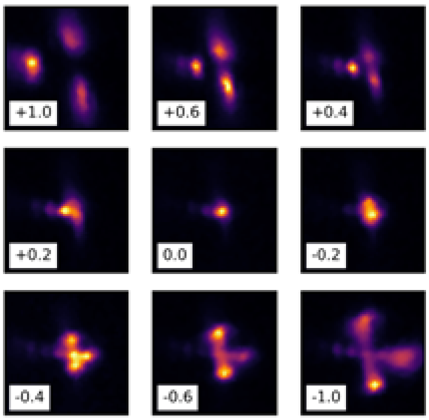

Images demonstrating the spatial overlapping of three infrared beams at the focal point of an off-axis parabolic mirror, f = 75 mm, centre image. One of the beams has satellite beams, clearly visible in the last image. Each image shows the bolometer output at a particular point along the experimental optical axis. The bolometer was translated along this axis between images, with the distance, in millimetres from the focal point indicated in each image. Each image, which displays a 50 × 50 pixel section of the bolometer array, is auto-scaled to use the full colour range for clearer display.

Optimizing the Temperature Recovery Rate in Temperature-Jump IR Spectroscopy

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C.P. Howe, B. Procacci, N.T. Hunt *(Department of Chemistry, University of York, UK)*

The new temperature-jump facility at ULTRA is briefly described, showing how rapid temperature rise and subsequent cooling can be used to follow temperature-triggered reactions, from nanoseconds to millisecond timescales. Control of the temperature-jump kinetics is discussed, showing how one can control the rate of cooling of the sample and so, experiment timescales.

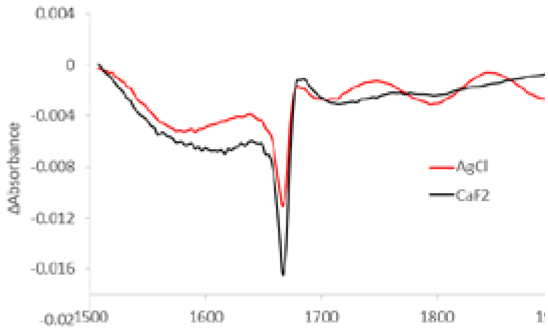

Figure 1: Normalised IR difference spectra of TFA in solution, immediately following the T-jump pulse. Two window materials, AgCl and CaF_2 are shown for comparison.

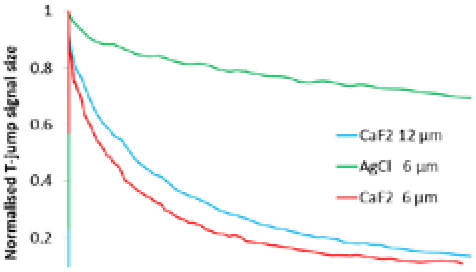

Figure 2: Kinetics of TFA T-jump signal change for different cell windows and sample path-lengths.

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Progress on the Coherent Beam Recombination project

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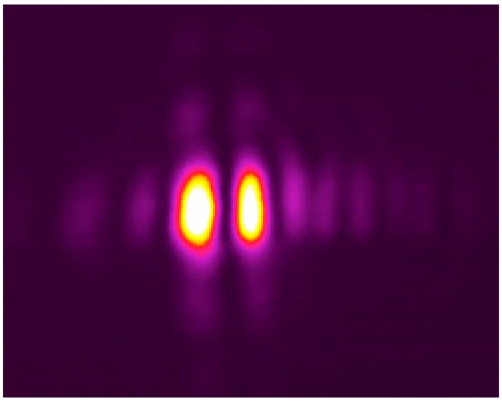
The HAPPIE lab project is devoted to investigate coherent beam recombination, a possible solution to overcome the current limitation on the maximum achievable power of the high power laser system. To achieve recombination, all the beams must be spatially and temporally locked to each other, and must also be of the same path length to within a fraction of a micrometre.

Building on previous work to achieve coherent combination, work this year focused on optimising the system. In particular, three main areas were explored:

- Changing the mounting method of the piezo mirror that stabilises the beam spatially and temporally. The current setup caused aberrations to the far field, most notably astigmatism.
- Developing a low cost PID control system for spatial stabilisation using field-programmable gate arrays, offering an alternative to the expensive analogue SIM modules.
- Developing an easy method to ensure the difference in path length traversed by the two lasers is within the coherence length so that constructive interference can occur with non-CW lasers

This report details progress of the work to achieve this, along with the preliminary results.



Combined FF of two spatially and temporally overlapping beams

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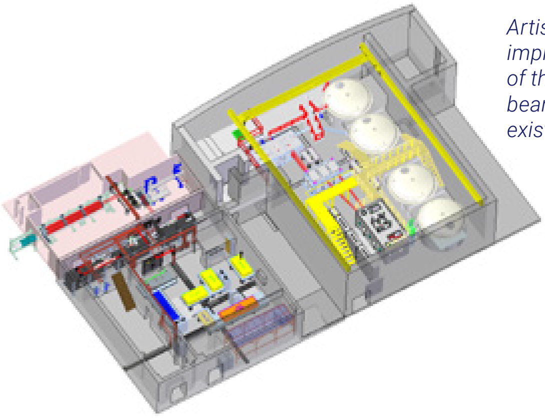
Overview of a new OPCPA beamline in Vulcan TAP

I. Musgrave, G. Archipovaite, S. Blake, N. Booth, D.C. Carroll, R.J. Clarke, R. Heathcote, C. Hernandez-Gomez, M. Galletti , M. Galimberti, P. Johnson, D. Neely, D. Pepler, P. Oliveira, J. Saa, A. Scott, A. Stallwood, T. Winstone, B. Wyborn *(Central Laser Facility, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)*

In this report, we outline our plans for an auxiliary beamline into Vulcan Target Area Petawatt (TAP). The new beamline will be based on Optical Parametric Chirped Pulse Amplification (OPCPA), and it will ultimately deliver 30 J in 30 fs onto target with a centre wavelength of 880 nm. The new beamline will be able to be operated both in conjunction with, and independently of, the existing petawatt beamline.



Artist's impression of the new beamline in the existing facility

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Development of Air-cooled Disc Amplifiers for Vulcan

I. Musgrave, M. Ahmad, S. Chapman, T. Davenne, B. Fischer-Harrison, A. Frackiewicz, M. Harman, C. Hernandez-Gomez, N. O'Donoghue, M. Pitts, D. Robinson, P. Trimble, T. Winstone
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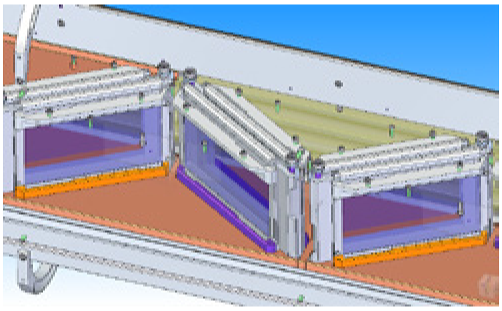
In this report, we detail the work undertaken at the STFC towards the development of an air-cooled flash-lamp pumped disk amplifier, to increase the repetition rate of high energy flash-lamp pumped lasers. The overall aim is to improve the current repetition rate from one shot every 20 minutes, to one shot every five minutes.



Artist's impression of the prototype air-cooled amplifier

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Progress on pulse shaping by compensating for temporal deformation in the Vulcan Nd:glass amplification chain

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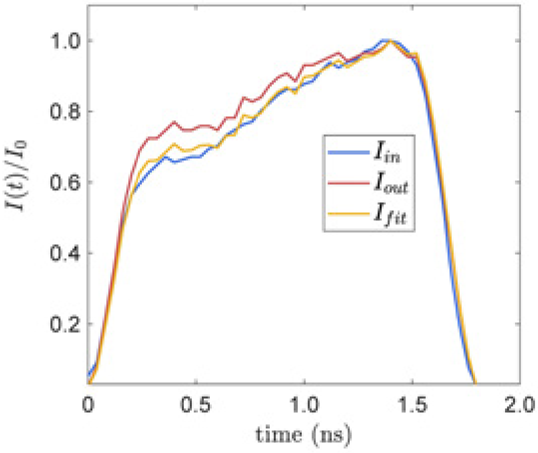
The evolution of the temporal shape of a pulse as it passes through a Nd:glass amplifier chain is difficult to predict and depends on the gain and losses throughout the complete chain. We demonstrate that a time-dependent Frantz-Nodvik model can be employed to get a target output pulse shape. This allows us to calculate the ideal input pulse shape that will compensate for gain saturation from the Vulcan amplifier chain. In the future, we plan on developing this model so that it simulates the deformation from the double-pass and single-pass 108 mm disk amplifiers.



Observation of temporal deformation in the pulse at three stages of the amplifier chain

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Modification of Regenerative Amplifier Resonating Cavity for New TAP Beam Line OPCPA Pump

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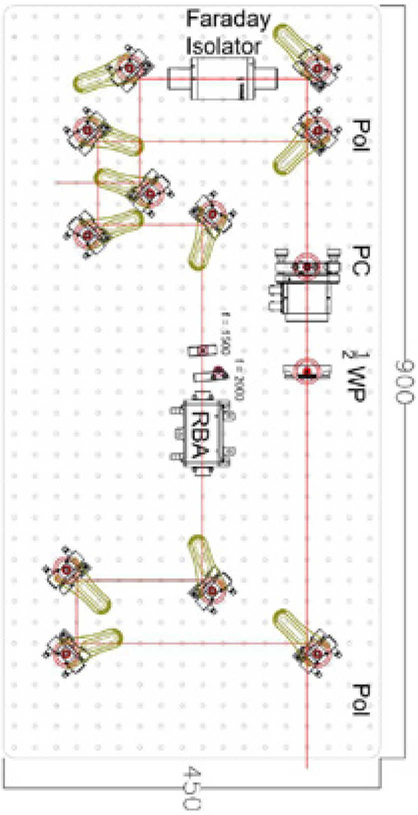
The new shaped long pulse laser, which is pumping the OPCPA stage of the new Vulcan beam line, features regenerative amplifier, that is currently laid out as a standing wave resonating cavity. It will be moved on the same optical table as the rest of the laser, due to space limitations. This paper discusses improvements that will be made to the cavity to increase its stability and to reduce its size. Ultimately, the cavity will be laid out as a ring cavity, and it will be built on a 450 x 900 mm breadboard.



Arrangement of the ring cavity on a 450 x 900 mm breadboard

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