Laser Science & Development

ULTRA/ARTEMIS - 100 kHz High Power OPCPA Progress Report

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This report provides the technical specification of the Fastlite 100 kHz high power optical parametric chirped-pulse amplifiers (OPCPA) system to be delivered to the CLF in June 2018. The CLF will use and develop the laser and OPCPA to generate light from the XUV to mid IR in the first phase in the bringing together of ULTRA and Artemis, and the provision of world leading pump probe facilities into the future.

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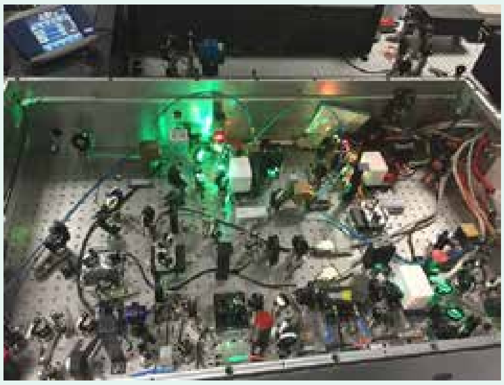

The OPCPA

Short-Wave Infrared Few Cycle Pulse Generation and Characterization for High Harmonic Generation in the Water Window

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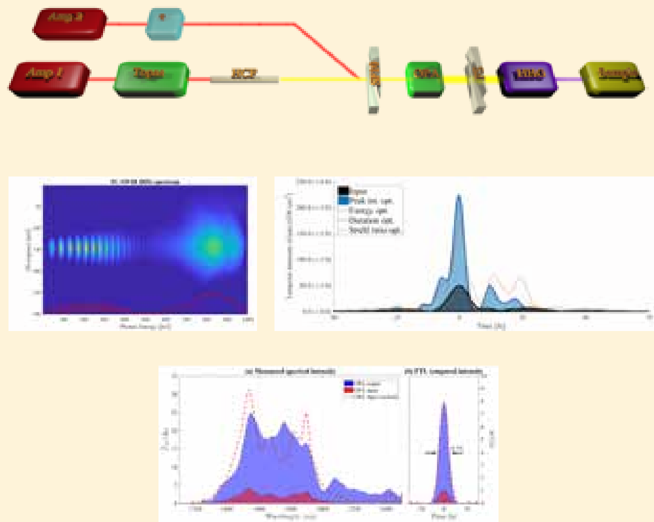
We present developments of carrier envelope phase (CEP) stabilized short-wave infrared (SWIR) few-cycle pulses for driving high harmonic generation (HHG) for the production of extreme ultraviolet pulses in the water window (280-530eV). This spectral region has a wide range of applications in spectroscopy and element specific imaging due to the relatively high transmission in water, the presence of biologically important elements such as carbon (284eV), nitrogen (410eV) and oxygen (543eV) and the potential for nanometre spatial and attosecond temporal resolutions.

We present complete temporal characterization of the few-cycle pulses using a newly developed version of the dispersion scan technique utilizing third harmonic generation, allowing the source to be optimized and providing valuable information for the users. Initial experimental results show HHG of a continuous spectrum spanning up to ~150eV, with characteristic signatures of CEP effects. We also present a simple broadband amplification scheme to increase the few-cycle pulse energy to multiple millijoules to increase the harmonic flux.



Top: schematic of high-flux table-top source of water window harmonics. Middle left: high harmonic spectrum from few-cycle SWIR source; middle right: numerical modelling showing amplified temporal intensity from OPA; bottom: measured amplified SWIR pulse spectrum.

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A new long pulse beamline for the Gemini facility

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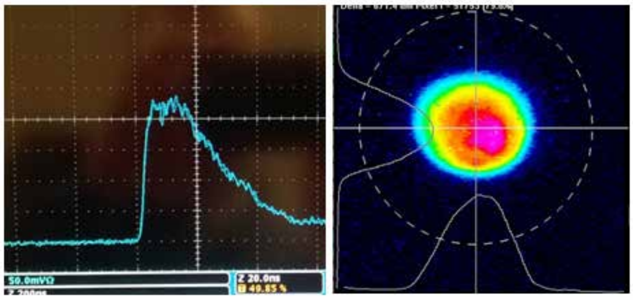
A new long-pulse beamline has been commissioned on the Gemini laser as an improved shock-driver beam. A single 1.053 micron beam from the north Quantel pump laser was sent directly to the target chamber, via one of the floor penetrations for auxiliary beams. The rise-time of the pulse was shortened to ≈1ns by a Pockels cell in the beam after the 9mm amplifiers. The output pulse energy measured after shaping was up to 50 joules, and the focal spot quality of the 50 mm diameter beam was confirmed to be suitable for driving shocks into solid targets. The delay of the laser Q-switch trigger was adjustable from the target area control room, allowing the timing of the shock to be controlled as an experimental parameter. The progress of the shock through the metal foil targets was imaged using Betatron x-rays from an electron beam driven by the south beam of Gemini.



Temporal (left) and spatial characteristics of a 50J pulse on the Gemini long-pulse beamline.

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Recent Improvements to the Gemini Laser

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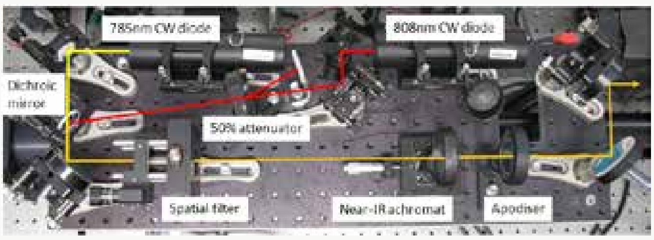
A number of improvements have been made to the Gemini laser, with the goal of making operations easier and enhancing the capabilities of the facility. A CW diode alignment beam combining two different wavelengths has been installed in LA2. The beam can be injected into either the TA2 or LA3 beamlines, to simplify the alignment of the pulse compressors. A pair of reflective polarisers with a throughput of 95% has been installed in the beamline to TA2, giving around 40% more energy on target. The slide-in beam attenuators in LA3 have been replaced with 1% transmitting mirrors to eliminate the scatter caused by the original lens-tissue versions, allowing good-quality focal spot measurements with the attenuated beams. Finally, rotating waveplates and polarisers have been installed at the output of the Gemini North and South amplifiers to provide precise energy control during shot runs.



Photograph showing the layout of the dual wavelength CW diodes in the Gemini front end room, with beam lines indicated.

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Software developments on Gemini

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In addition to the finer north and south amplifier energy control there have been a number of other developments in the software used in Gemini.

Operating system upgrade

We took advantage of the cessation of support for Windows XP to upgrade of all of our control and monitoring PCs to Windows 10. Many of these machines have been running since 2009, and unsurprisingly, the requirements for operations have altered considerably during this time, so the software was modified to streamline the process. We took the opportunity to add some useful features such as better configurability of parameters, and automatic switching of filters for cameras according to laser energy mode. We also replaced many of our outdated Firewire cameras with GigE equivalents, and are in the process of upgrading some of the original motion stages. Although this exercise has been complex and not straightforward, these changes will put us in a good position to continue to support the facility in the future.

User control and shot automation

A recent experiment in TA2 required a fairly fast (every few seconds) feedback loop between the Dazzler in the Gemini front end and a PC which analysed the parameters of the laser-produced electron beams, then modified the settings for the Dazzler to optimize the beam parameters. The most effective way of achieving this type of feedback was to allow the analysis software to "control" the main laser Control System, initiating shots via the PC that was performing the analysis. After some debugging the system worked well, and could potentially be expanded to include other semi-automated functionality. It is important to note here that the range of Dazzler parameters that the analysis software could apply was restricted to a relatively small range. This is because the pulses are delivered alternately to Target Area 2 and Gemini, and large changes to the Dazzler settings for the TA2 pulses can change the thermal conditions in the amplifiers, thereby affecting the pulses sent to Gemini.

Improvements in data analysis

One problem experienced by users is the synchronisation of their experimental data with laser diagnostics across multiple, embargoed, networks. To address this problem we recently installed a tool called DARB (Diagnostics, Analysis, Review and Backup), written in collaboration with the University of Strathclyde. DARB is described in more detail elsewhere.
As part of their on-going international scientific data curation programme, the Scientific Computing Department have upgraded the ICAT database on which eCAT is based to the latest version – version 4.8. One feature of this upgrade is the introduction of a more SQL-like query language which should enable more complex queries to be performed in the database rather than code, thus improving performance.

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Measurement of femtosecond-scale drift and jitter of the delay between the North and South Beams of Gemini

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We describe an experimental technique for measuring femtosecond-scale drift and jitter in the delay between Gemini's North and South beams. This technique, based on spectral interference, was successfully employed in both an off-shot and on-shot capacity for an f/2-f/40 setup. However, the technique itself could be adapted with little difficulty to other focusing geometries.

The delay between the North and South beams was monitored over long periods with a precision of (10.3 ± 0.7) fs using both the off-shot and on-shot diagnostics. It was found that the delay oscillated on the scale of tens of fs over 10-20 minute timescales and correlated strongly with temperature variations of 1°C measured in the laser area.

The on-shot diagnostic showed good agreement with the off-shot measurements and could, in the future, be used in the development of an automated timing stabilization system.

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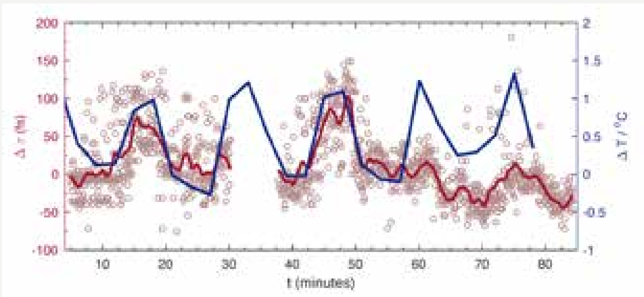

Change in delay between North and South beams measured in TA3 (moving average in red line) against time compared to temperature measured in LA3 (blue line).

Progress on delivery of a cross-polarised wave generation temporal filter for the Gemini laser

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We report on progress of work to integrate a temporal contrast enhancement unit in the Gemini laser system. The temporal filter (shown in the left-hand figure) comprises a specially designed double stage compressor and a cross-polarised wave generation (XPW) stage along with a hollow-core waveguide for spatial filtering. The system produces a pulse having a spectrum that is 35% broader than that of the seed and an overall energy conversion efficiency of 15%. The performance of the unit is thoroughly characterised in terms of the spatial and spectral characteristics of the seed and generated pulses. The characterisation and the dispersion tolerance of the system are investigated by employing a scanning routine with dispersion of three different orders. With an energy booster and a dispersion control unit, the system will be an intermediate stage that can contribute significantly in enhancing the temporal contrast and the spectral properties of the Gemini laser output.

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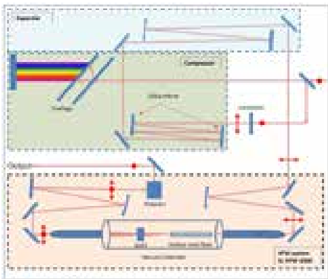

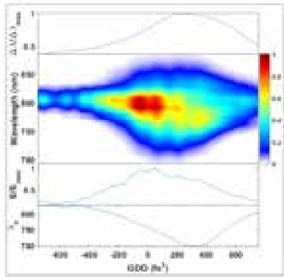

Left: Schematic of the experimental setup of the XPW generation system.

Right: The characteristics of the generated XPW pulse as a function of GDD of the input pulse. $\Delta\lambda_{max}$ is the maximum achievable bandwidth, E_{max} is the maximum achievable energy.

Magnetic Detection by Longitudinal and Transverse MOKE at Artemis

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The understanding of ultrafast spin dynamics in ferromagnetic materials is attracting wide scientific interest owing to its potential applications for spintronics and high-density data storage. The use of a laser source to providing ultrashort pulses is very exciting as it offers the possibility to explore dynamics that operate on sub picosecond timescales, such as the photo-demagnetisation of a ferromagnet.

A Magneto Optical Kerr Effect (MOKE) detector has been built and commissioned at Artemis in order to study ultrafast demagnetisation. This new detector is compared to an existing demagnetisation detector, which uses Transverse MOKE, and results show that it can be used as a complementary diagnostic to the electron spectroscopy techniques.

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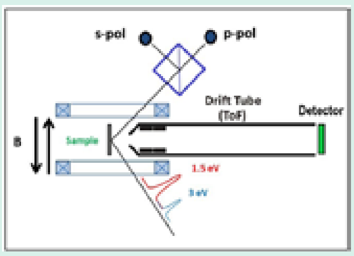

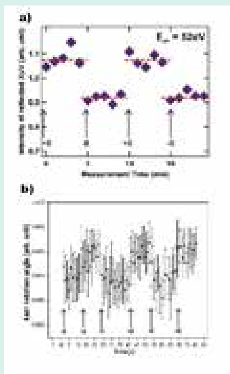

Top: Experimental chamber geometry configured for measuring L-MOKE
Bottom: a) Asymmetry in the reflected intensity for positive and negative magnetisations using T-MOKE. b) Kerr rotation for positive and negative magnetisations measured with L-MOKE.

Adhesive-free bonded crystalline Yb:YAG for high energy laser applications

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We report on the application of the adhesive-free bonding (AFB) technique to form Yb-doped crystalline Yttrium Aluminum Garnet (Yb:YAG) gain media slabs. We performed experiments to characterise mechanical strength, optical quality and laser-induced damage threshold (LIDT) of bonded substrates. We demonstrate that mechanical properties of bonded samples are similar to those of monolithic substrates. We show that the presence of a bonding interface does not introduce unwanted wavefront deformations and does not increase the probability of laser-induced damage onset. Results indicate that the AFB technique constitutes a viable alternative for producing large aperture gain media slabs required for high-energy laser systems.

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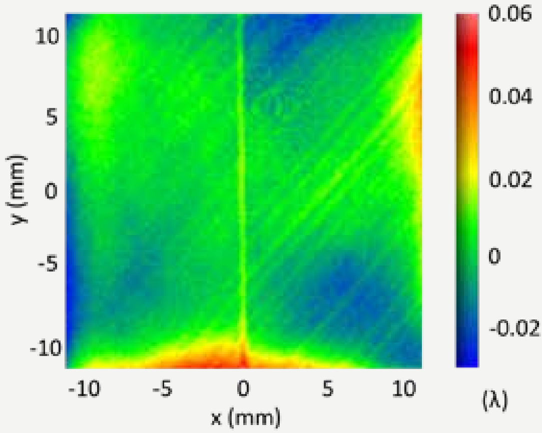

Fast Beam Stabilisation of a Large Diameter CW Laser in its Far Field Using 3 inch Piezo Mounted Mirrors

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We have successfully stabilised a CW beam in the far field at frequencies up to ~200 Hz, using a 3" mirror mounted on a piezo tip/tilt platform. The work is a step towards realising coherent combination of multiple large aperture beams as part of the HAPPIE project.

Key advances enabling the fast stabilisation were:

- The use of a hardware PID control loop with parameters optimised using a Monte Carlo method.
- The implementation of a custom vibration isolating mounting system for the piezo mirror.
- Hardware based pointing determination using fast quadcell photoreceivers.

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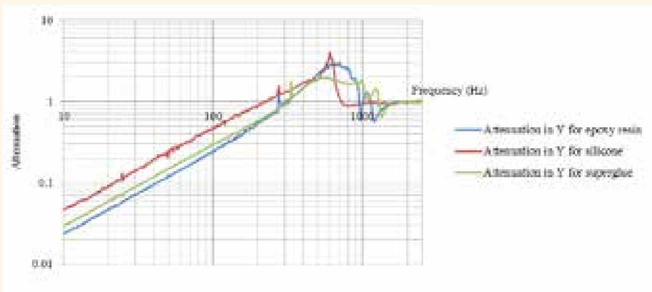

Attenuation of vibrations in the far field across a range of frequencies from 10 Hz up to 2500 Hz. Different adhesives for attaching the mirror substrate to the piezo platform produce varying responses.

20 W Upgrade to the ULTRA Facility

G. M. Greetham, N. Chandarana, I. P. Clark, P. M. Donaldson, E. Gozzard, I. V. Sazanovich and M. Towrie *(Central Laser Facility, STFC Rutherford Appleton Laboratory, Chilton, Didcot, UK)*

The ULTRA facility has been upgraded by addition of a new 20 W Ti:Sapphire amplifier. Higher energy and better shot-to-shot stability of the new laser can provide improved signal to noise in experiments. Dedicated 2D-IR and SFG beamlines have so far increased the range of capabilities in the facility and enable additional parallel operations capability, to increase the throughput of number of weeks access available.

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Recent developments in the Thomson Parabola Spectrometer diagnostic for laser-driven multi-species ion sources

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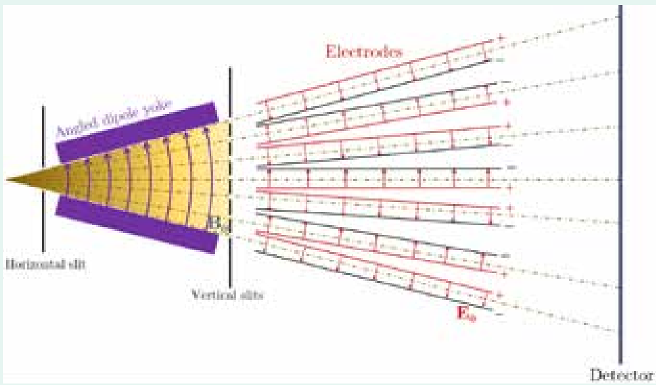
Ongoing advances in laser-driven ion acceleration require modifications to the standard Thomson Parabola Spectrometer (TPS) arrangement in order to match the diagnostic requirements associated to the particular and distinctive properties of laser-accelerated beams. An overview of recent developments by our group of the TPS diagnostic, aimed to enhance the capability of diagnosing multi-species, high-energy ion beams, is presented. A recursive differential filtering technique was implemented at the TPS detector in order to facilitate the discrimination between ions with equal charge-to-mass ratio, allowing only the lightest of the overlapping ion species to reach the detector, across the entire energy range detectable by the TPS. In order to mitigate the issue of merging, and eventually overlapping, ion traces towards the higher energy part of the spectrum, an extended, trapezoidal electrode design was proposed and experimentally demonstrated, which enables a high energy-resolution at high ion energies without sacrificing the lower energy part of the spectrum. Finally, a novel multi-pinhole TPS design is discussed, that would allow angularly resolved, complete spectral characterization of the high-energy, multi-species ion beams.



Schematic top view of a large collection angle Multi-Pinhole TPS, capable of providing an angularly resolved, complete spectral characterization of high-energy, multi-species ion beams.

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Detector for imaging and dosimetry of laser-driven epithermal neutrons by alpha conversion

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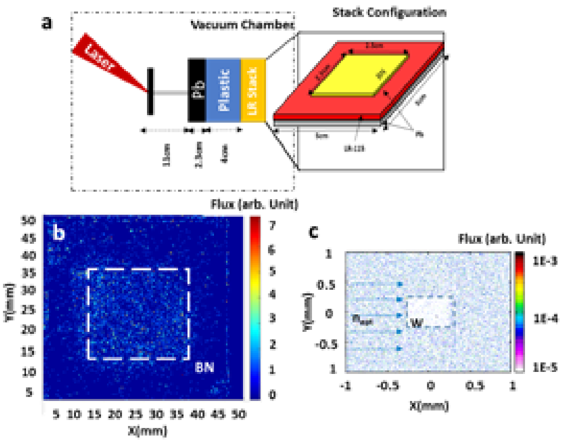
In recent years the development of laser-driven neutron sources has demonstrated potentials for various applications in science, industry, security and healthcare. Neutrons generated from laser-driven neutron sources are typically in the MeV energy range known as fast neutrons. Although, fast neutrons are highly penetrating, for many applications lower energy neutrons (1 eV – 100keV) are required otherwise known as epithermal neutrons. Epithermal neutrons are highly suitable for radiographic applications due to their excellent capability to penetrate through many materials and reveal their compositions due to the strong difference in their material dependent scattering cross-sections.

Here we have presented an epithermal neutron imager based on detecting alpha particles created via boron neutron capture mechanism. The diagnostic mainly consists of a mm thick Boron Nitride (BN) sheet (as an alpha converter) in contact with a non-borated cellulose nitride film (LR115 type-II) detector. While the BN absorbs the neutrons in the thermal and epithermal ranges, the fast neutrons register insignificantly on the detector due to their low neutron capture and recoil cross-sections. The use of solid-state nuclear track detectors (SSNTD), unlike image plates, microchannel plates and scintillators, provides safeguard from the x-rays, gamma-rays and electrons.

The diagnostic was tested on a proof-of-principle basis, in front of a laser driven source of moderated neutrons, which suggests the potential of using this diagnostic (BN+SSNTD) for dosimetry and imaging applications.



Top: (a) showing the experimental setup inside the interaction chamber. The fast neutrons were generated by nuclear reactions in the catcher target induced by the MeV ions accelerated from the laser irradiated pitcher target. Epithermal neutrons produced by the plastic block were diagnosed by the BN+SSNTD stack as shown in (b). (c) Imaging capabilities, the FLUKA simulation done for tungsten, shows very good contrast because of the high neutron elastic cross section and atomic number for epithermal neutrons.

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Measurement of the x-ray emission source size from solid targets irradiated with intense laser pulses

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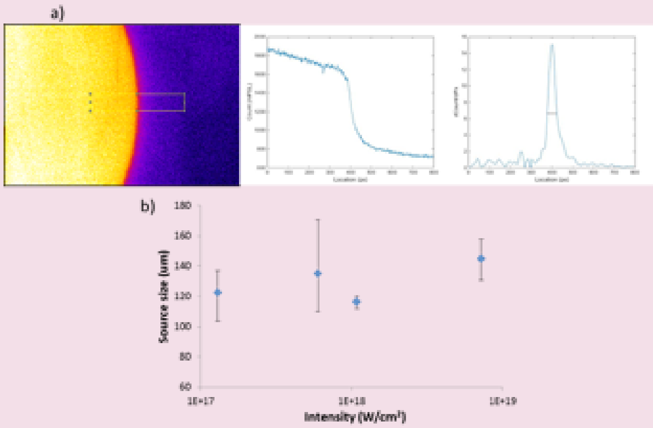
The x-ray source from a high intensity laser interaction with a solid target is key in both diagnosing the internal electron dynamics, and in the radiography of large scale industrial objects. By measuring the high energy x-ray source size (>100keV) from laser-plasma interactions we are able to infer valuable information about the dynamics of the hot electron beam traveling within the target, and determine a limit on resolution for industrial radiography. We present the design and first results from a novel penumbral measurement diagnostic, and detector stack capable of measuring the source size of high energy x-ray beams.

The penumbra of a shadow is a convolution of the source size, the object transmission, and the detector point spread function (PSF). Minimising these is key to achieving higher resolution measurements of the x-ray source. The report discusses the difficulties in achieving this for higher energy x-rays.



a) an example image cast by the penumbral aperture, with the two subsequent inlet graphs being a lineout and the gradient showing the source size b) shows the results from the defocus scan on 100µm tantalum, error bars shown account for the asymmetry of the source and variance in the source further corrections can be made by accounting for the point spread function (PSF) of the filter layers.

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Optimal resolution for a fibre bundle imaging system using a phosphorus based pinhole camera

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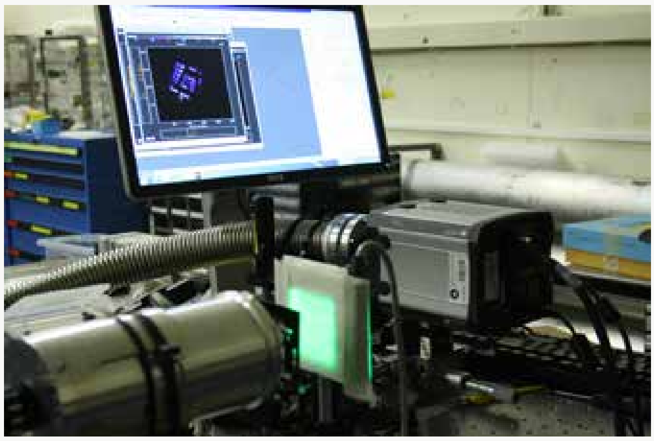
An active pinhole camera has been developed which uses a phosphorus plate detector to convert the x-ray image into visible light. This light is imaged to a camera outside the vacuum chamber by a fibre imaging bundle system. In this report the imaging resolution of the lens and fibre bundle system is characterized. The lower resolution limit is found to be 0.75 cycles/mm; this means the smallest feature on the phosphorus that can be resolved is 670 microns. For a pinhole camera with x10 magnification this results in a resolution at the x-ray source of 67microns.



Equipment setup including back lighter, resolution target, cylinder, fibre and camera.

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Surface roughness of NaCl coating used in thin film production

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This report looks at the surface roughness of a salt (NaCl) coating. Salt coatings are widely used within Scitech Precision Ltd and the Target Fabrication Group at CLF as a release layer when creating thin film targets.

In this experiment salt was coated using thermal evaporation and a surface scan was done straight from the vacuum. A further scan was done after the coating had been left out in the atmosphere for a few days. Data was collected for a plain salt coating as well as a salt coating with an aluminium coating on top.

The surface scans were done using an Atomic Force Microscope (AFM) and the data analysed with Gwyddion, software dedicated to studying AFM images. The research showed that there was an increase of around 50% in the roughness of salt once left out in the atmosphere.

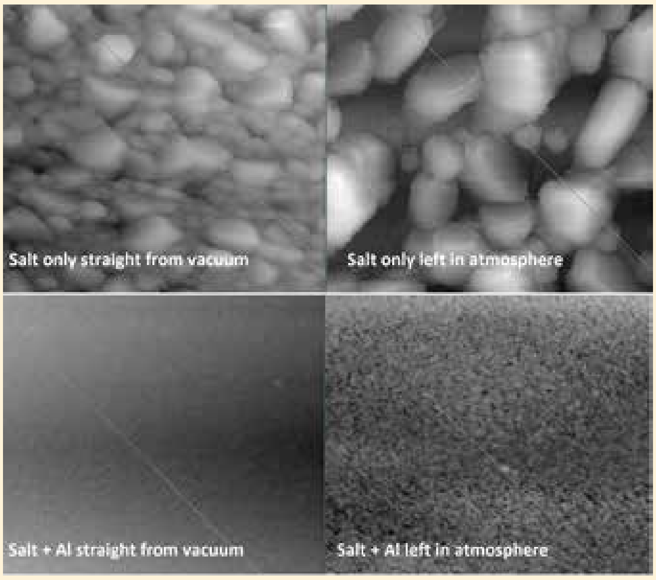

Figure showing the AFM scans of the salt and salt + aluminium coatings straight from vacuum and after being left in the atmosphere.

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MEMS Fabrication of Silicon Microwire Targets

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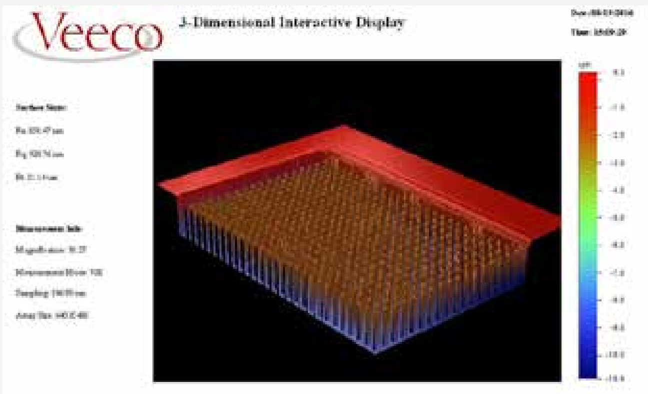
Some recent experiments at CLF have specified surface structures which give an increase in the absorption of the incident laser light. One of the best routes is to use MEMS-based fabrication to create regular arrays of close-packed micron-scale pillars (microwires), which give the desired optical behaviour. This manufacturing technique allows pillars, grating or similar structures to be defined over specific areas which are both highly uniform and scalable.

This paper describes the basic processes of MEMS-based fabrication and continues by outlining the process steps required to manufacture arrays of microwires over the required area. Microwire arrays, as seen in the figure, were successfully created and have been used in a recent experimental campaign.



Wyko white light interferometer scan of a 2µm microwire array target.

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Target characterisation and pre-alignment for the HAMS high throughput targetry system

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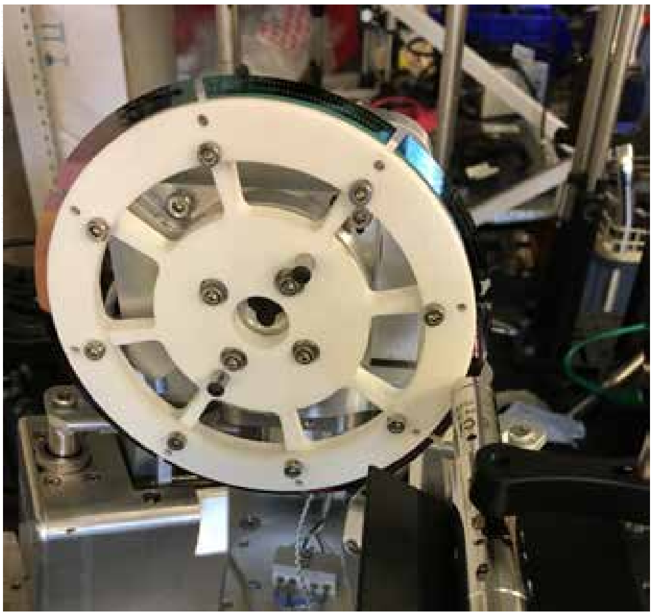
With more and more high repetition rate ultra-intense laser systems coming online, the necessity to increase solid microtarget production increases dramatically. The CLF have designed a High Accuracy Microtarget Supply (HAMS) system which is capable of mass production, rapid positioning, and in-situ focal distance measurement of MEMS-based targets for ultra-intense laser experiments.

This paper discusses the need and methods for pre-characterising silicon target sectors using a suite of measuring equipment available to the Target Fabrication Group at the CLF.

The surface roughness of silicon nitride targets, and the flatness and roundness of the interface wheel upon which they are mounted, is measured using white light interferometry, surface metrology probing and rotational scanning probing respectively.

Through use of Coordinate Measurement Machine (CMM), the alignment of target segments after wheel assembly has been characterised and segment deviation in the z-axis due to stresses in mounting are measured using a chromatic confocal displacement sensor.



Chromatic confocal displacement setup on the HAMS interface wheel and silicon wafer target segments.

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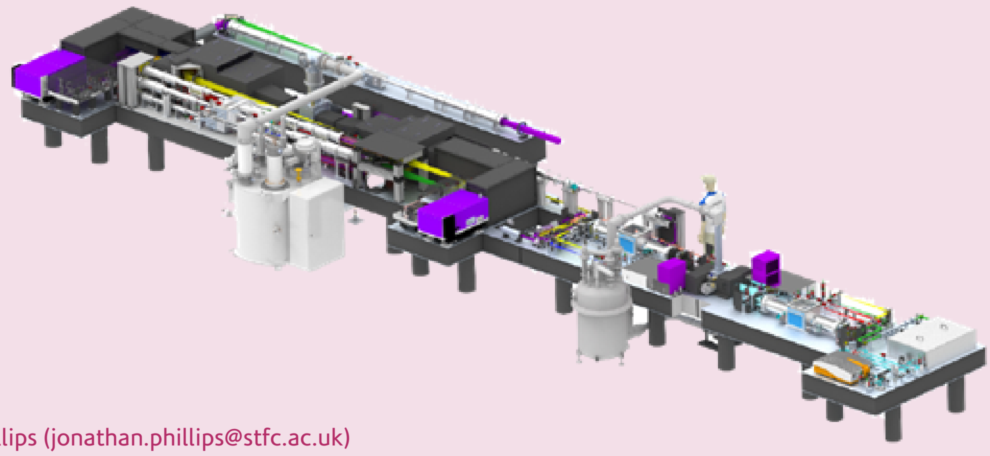
DiPOLE100 - World's first diode pumped kilowatt average power 100J-level Laser

J. Phillips, S. Banerjee, P. Mason, T. Butcher, K. Ertel, M. De Vido, J. Smith, I. Hollingham, B. Landowski, J. Suarez-Merchan, A. Thomas, M. Dominey, L. Benson, A. Lintern, B. Costello, S. Tomlinson, S. Blake, M. Tyldesley, C. Hernandez-Gomez, C. Edwards, T. Mocek, J. Collier
(Central Laser Facility, STFC Rutherford Appleton Laboratory, Chilton, Didcot, UK)
M. Divok, J. ilar, Mihai-George Muresan, A. Lucianetti, T. Mocek
(HiLASE Centre, Institute of Physics Dolnì Břežany, Czech Republic)

We report efficient and stable operation of world's first multi-joule DPSSL delivering 1 kW average power in 105 J at 10 Hz, confirming the energy scalability of multi-slab cryogenic gas-cooled amplifier technology. We also report on the commissioning of DiPOLE100 at the HiLASE Centre at Dolnì Břežany in the Czech Republic. The laser system, built at the Central Laser Facility (CLF), was dismantled, packaged, shipped and reassembled at HiLASE over a 12-month period by a collaborative team from the CLF and HiLASE.



Contact: J. phillips (jonathan.phillips@stfc.ac.uk)

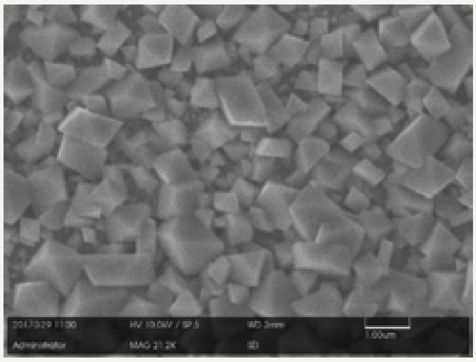
Factors Affecting the Quality of Electroplated High Power Laser Target Foils

A. Hughes *(Central Laser Facility, STFC Rutherford Appleton Laboratory, Chilton, Didcot, UK)*

Experimental target design and production are key areas of research and development in the CLF Target Fabrication Group. Targets have always presented challenges in their fabrication and consequently new production techniques can improve precision and efficiency.

The work carried out in this report focuses on the factors affecting the thickness and quality of copper electroplated foils. This area of research is being carried out to investigate the possibility of generating intricate target designs through machining inexpensive materials, plating expensive metals on to the substrate, then removing the inexpensive substrate. Preliminary work has been carried out using electroplated copper, an inexpensive material but acting as a surrogate high value material, with the plan to apply the generic production principles to expensive metals as the research progresses.

This method of target production opens up the possibility of removing aspects of target assembly, removing adhesives from multi-component targets, and layering thin, structured metal foils without adhesives.



SEM image of copper surface formed on aluminium strip. Plating conditions: 18°C, 1mol dm^{-3} $CuSO_4$, not stirred throughout plating time, 10mA applied.

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Commissioning of a new Diamond Turning Capability for STFC

C. Spindloe
(Central Laser Facility, STFC Rutherford Appleton Laboratory, Chilton, Didcot, UK)

M. Beardsley, M. Harris
(RAL Space, STFC Rutherford Appleton Laboratory, Harwell Campus, Chilton, Didcot, Oxon, UK)

The Central Laser Facility has invested in a new ultra-high precision lathe for the manufacture of high power laser target components and small optical elements for its programme. The machine, a Single Point Diamond Turning (SPDT) lathe, shown in the photograph, is one of the most technically advanced machining centres in the world and is able to machine components with surface roughnesses of ~ 1nm Ra. Through an existing and productive collaboration with RAL Space Precision Development Facility (PDF), where the equipment will be located, the CLF will be able to manufacture a new range of ultra-precise components, furthering its leading position within the community.

The Nanoform X Lathe

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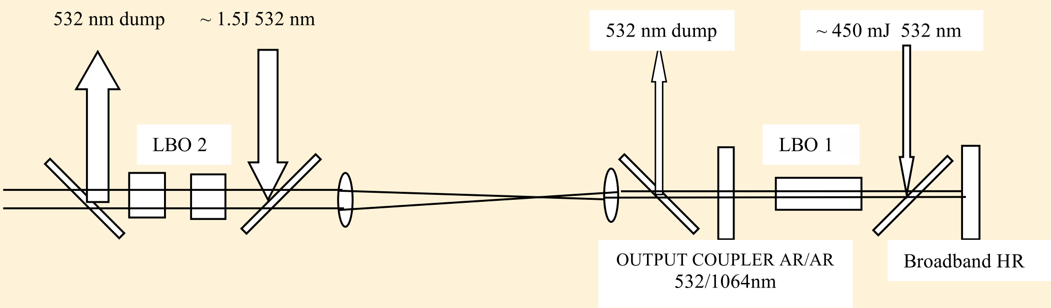
A stable ultra-broadband OPG/OPA source for the testing of 20 Petawatt Optical Parametric Chirped Pulse Amplifiers

W. Shaikh, P. Oliveira, I. Musgrave, M. Galimberti, A. Wyatt and C. Hernandez-Gomez
(Central Laser Facility, STFC Rutherford Appleton Laboratory, Chilton, Didcot, UK)

A LBO based OPG/OPA source is demonstrated with an energy exceeding 90mJ with a 6% RMS energy stability and tunability of 300nm between 750 to 1050nm. This novel source will facilitate the testing of MultiPetawatt OPCPA amplification schemes.



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Frequency doubling experiments carried out on the DiPOLE-10 amplifier at CLF

J. Phillips, S. Banerjee, P. Mason, T. Butcher, K. Ertel, M. De Vido, J. Smith, A. Lintern, S. Tomlinson, M. Tyldesley, C. Hernandez-Gomez, C. Edwards, J. Collier
(Central Laser Facility, STFC Rutherford Appleton Laboratory, Didcot, UK)

We report on suitable crystals for second harmonic generation (SHG) energy at high repetition rates: 1 kW average power in 105 J at 10 Hz.

SHG of the DiPOLE laser is a crucial step in the realisation of a multi-Hz PW class laser, where the second harmonic (515nm) of DiPOLE will be used as a pump for a Ti:Sapphire or OPCPA system. The SHG experiments reported in this annual report were performed utilizing the DiPOLE-10 prototype laser system capable of generating 10J, 10Hz with pulse duration variable from 2ns to 10ns.

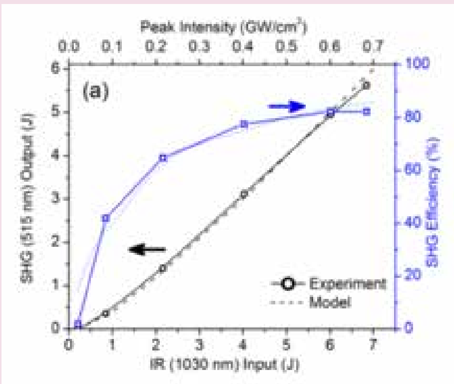

Figure: Type-I phase-matched SHG output energy and conversion efficiency in LBO crystal with 10mm square fundamental beam at 10Hz operation

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