Laser science and development

Laser shock peening of tungsten and its dependency on polarisation of light for induced compressive stresses

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We report on laser shock peening (LSP) of tungsten, a material used as a divertor in Tokamak machines for magnetic confinement fusion reactions such as the ITER facility (France) and JET facility (UK). Peak compressive stresses of -370 MPa and depths of up to 1.75 mm were recorded when 0.25 cm^2 area of tungsten (99.95% pure) was irradiated by a 1030 nm Yb:YAG laser operating at 10 J, 10 ns.

Furthermore, we demonstrate enhancement of compressive stresses in one direction, by application of circular polarised light in hard material like tungsten. However, no enhancement of compressive stresses with circular polarisation was observed in soft material like aluminium.

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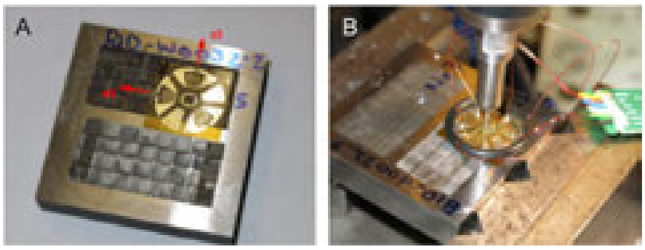

Figure 1: Incremental Central Hole Drilling (ICHD) on tungsten samples (A) Gauge attached to the tungsten sample (B) Hole drilling for residual stress measurements.

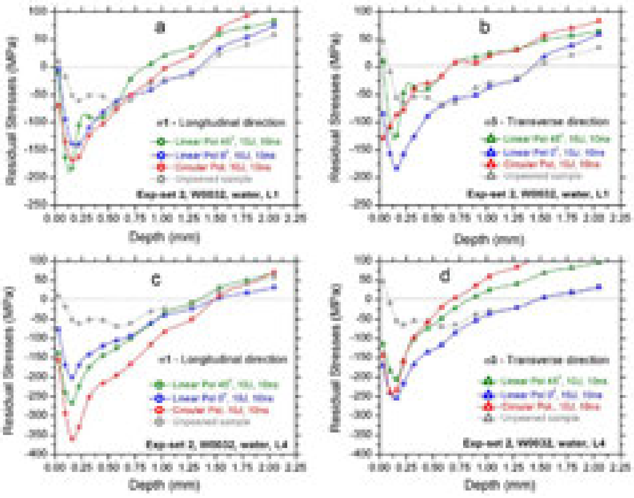

Figure 2: Residual stresses developed during laser shock peening of tungsten in experiments set 2 (repeat) for pulse energy (10 J), different polarisation (Linear and circular) and different shots (L1 and L4)
(a) Residual stresses in longitudinal direction (σ1) for one shot (L1)
(b) Residual stresses in transverse direction (σ3) for one shot (L1)
(c) Residual stresses in longitudinal direction (σ1) for four shots at same location with 100% overlap (L4) (d) Residual stresses in transverse direction (σ3) for four shots at same location with 100% overlap (L4).

Development of an automated null ellipsometer for characterising large-aperture, high-reflectance optical coatings used in DiPOLE systems

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Characterising the properties of high-reflectance, optical coatings for high-power laser systems is important for improving optical-to-optical efficiency and extending system capabilities. In particular, removing the phase delay introduced by these optical coatings is important for reducing a large cause of loss in high-power laser systems, known as depolarisation.

To remove phase delay, it must first be quantified. Null ellipsometry is a method for measuring phase delay, hence, a partially-automated, null ellipsometer has been commissioned to characterise coatings over a wide range of angles. Automation of the null ellipsometer has both reduced measurement time and increased accuracy.

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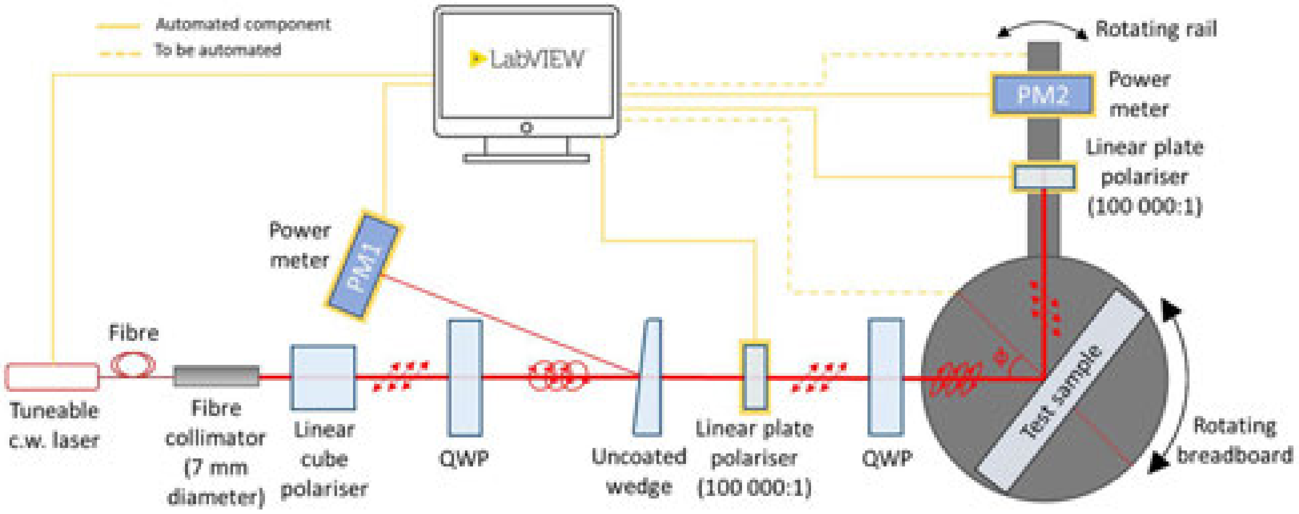

Experimental setup of the partially automated null ellipsometer for characterising phase delay introduced by the coating of the test sample over a range of angles.

Second and third harmonic conversion of a kilowatt average power, 100-J-level diode pumped Yb:YAG laser in large aperture LBO

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We report on the successful demonstration of second and third harmonic conversion of a high pulse energy, high average power 1030 nm diode pumped Yb-doped yttrium aluminium garnet (Yb:YAG) nanosecond pulsed laser in a large aperture lithium triborate (LBO) crystal. We demonstrated generation of 59.7 J at 10 Hz (597 W) at 515 nm (second harmonic) and of 65.0 J at 1 Hz (65 W) at 343 nm (third harmonic), with efficiencies of 66% and 68%, respectively. These results, to the best of our knowledge, represent the highest energy and power reported for frequency conversion to green and UV-A wavelengths.

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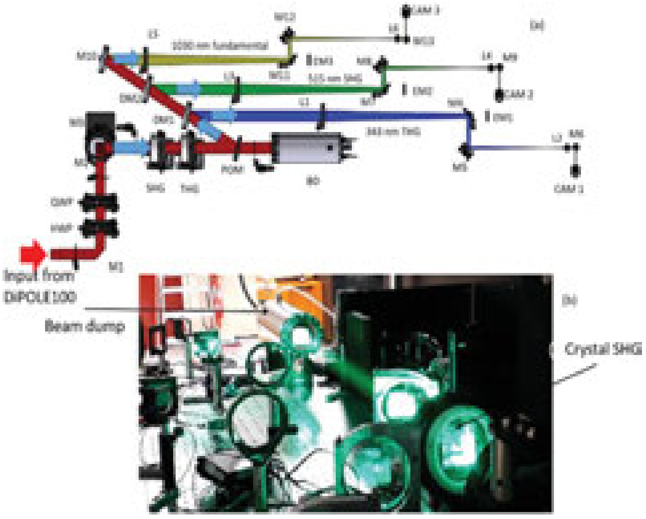

Figure 1: (a) Schematic of the experimental setup for SHG and THG of DiPOLE100. Arrows indicate beam travel. (b) Photograph showing the SHG crystal and the beam dump during the experiment with reflections showing the incident and generated beams.

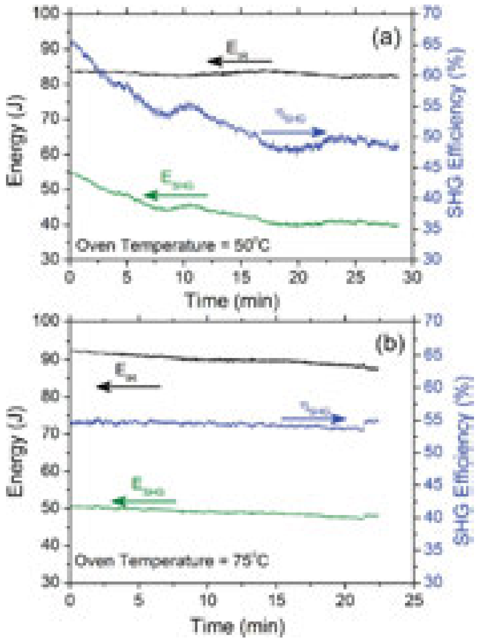

Figure 2: Long-term energy stability of SHG (a) LBO crystal oven temperature at 50°C and (b) oven temperature at 75°C. Green curve of 515 nm energy, black curve of 1030 nm input energy, and the blue curve is the efficiency, with the arrows indicating their respective axis.

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Confinement and absorption layer free nanosecond laser shock peening of tungsten and its alloy

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Traditionally, nanosecond laser shock peening (ns-LSP) of metals requires an additional application of an absorption layer (black paint) and more importantly a confinement layer (typically water or transparent material) on the workpiece for introduction of compressive stresses.

In this paper, we demonstrate for the first time, to the best of our knowledge, introduction of compressive stresses in pure tungsten and its alloy TAM7525 (75% tungsten and 25% copper) without any absorption and confinement layer for ns-LSP. Peak compressive stresses of −349 MPa and −357 MPa were measured in pure tungsten and TAM7525, respectively, when a 0.25 cm^2 area was irradiated by a Yb:YAG laser (1030 nm) operating at ~5 J, ~2 ns with circular polarization.

These peak compressive stresses (without confinement layer) compare well to those with tungsten ns-LSP done with water as confinement layer at twice the energy at 10-ns pulse duration. Furthermore, compared to femtosecond laser shock peening (fs-LSP) of aluminium at atmospheric pressure, the depth of compressive stresses recorded in tungsten and its alloy (~7 times denser than aluminium) is nearly four times more in the case of confinement layer free nanosecond laser shock peening (CLF-ns-LSP).

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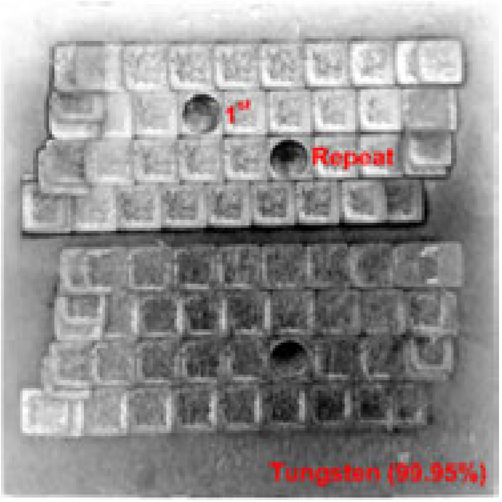

Figure 1: Laser shock peening locations (bottom 7.5 J, 2 ns, and top 5.2 J, 2 ns) without any absorption and confinement layer for pure tungsten.

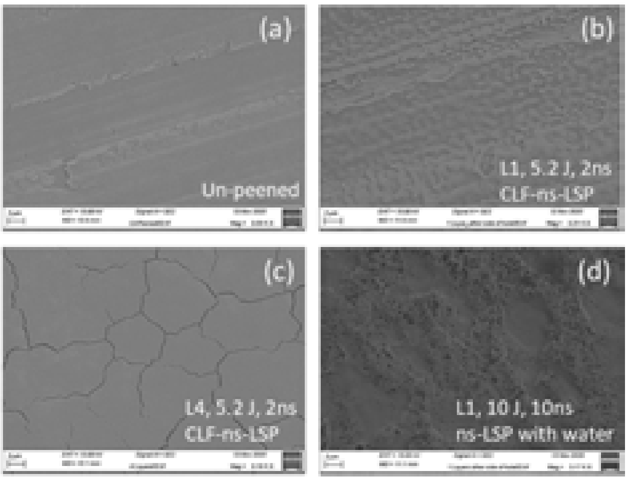

Figure 2: SEM image for tungsten at 2 µm resolution: (a) surface profile for an un-peened sample; (b) surface profile after CLF-ns-LSP with one shot (L1); (c) surface profile after CLF-ns-LSP with four 100% overlapping shots (L4); (d) surface profile after ns-LSP with water.

Modernisation of the Gemini TA2 vacuum control system

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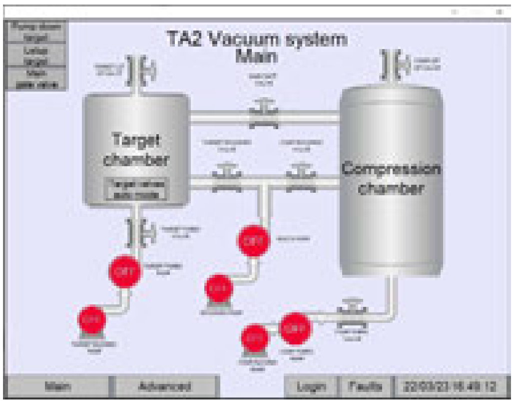
The new Gemini Target Area 2 (TA2) Vacuum control has been built around the Siemens S7-1200 PLC with a Weintek HMI. Advancements in industrial controllers since the original development have enabled the implementation of several improvements, which provide increased machine safety through more robust monitoring and fault reporting, while maintaining a simple user experience.



The new graphical user interface for the TA2 vacuum control system.

The approach taken with the user interface was to provide operators a clear overview of the system, showing the status of important elements through text and iconography with particular attention paid to colour to ensure it remained readable while wearing laser safety glasses. Additionally the processor's increased resources offered the opportunity to incorporate the area's gas control system, which will provide a single point of interaction and simplify operations.

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Full Automation of Thompson Chamber for Gemini Experiments

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A new, fully automated vacuum chamber for Thompson plates has been constructed for experiments in Gemini, with an integrated automatic vacuum control system and interface. The system features an HMI giving users the ability to start and stop fully automated pump downs and let ups, as well as open the gate valve between the Thompson chamber and the main chamber to take shots. The gate valve is interlocked by measuring the pressure differential in both chambers, thus preventing users from opening the gate valve in conditions that could potentially cause damage to expensive vacuum equipment, such as the turbo pumps.

The system also features a chamber pressure evaluation in the pump down sequence, which can save time for users during pump downs if the chamber has not been fully let up. The chamber achieved an excellent vacuum of 7.72 x 10^{-7} mBar during testing and was recently used in a Gemini experiment, led by Queen's University Belfast, studying solid targets irradiated at grazing incidence. The experiment employed three Thomson parabolas at 0°, 5° and 10° incidence to the target as the main diagnostics.

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EPICS Laser Control System GUI using Blazor

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The software team at Central Laser Facility (CLF) is developing a modern, cross-platform Graphical User Interface (GUI) for the Extreme Photonics Applications Centre (EPAC). In contrast to the traditional control system GUI for EPICS, the team utilized Blazor, allowing for unified back-end and front-end code using C#.

Over the last couple of years, our team has built an ecosystem of libraries to facilitate C# to EPICS communication and GUI components development. The EPICS compliant Blazor components enable the real-time updates based on the Process Variable (PV) changes and do not need hidden scripts for complex logic. These libraries are easy to use, debug and test.

Overall, our new Blazor-based control system GUI provides users with a secure, accessible, and user-friendly control system which can be rolled out with any EPICS installations we support across the CLF.

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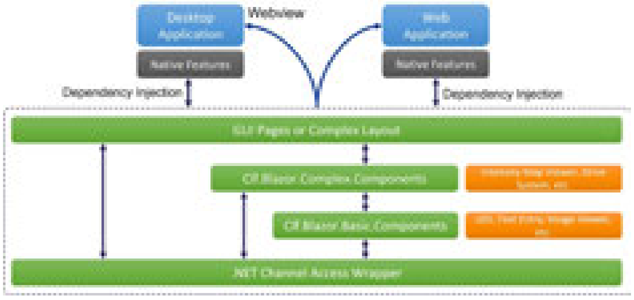

Figure 1: Architecture of the Control system user-interface application for EPAC.

Figure 2: The summary view of the Front end for the Pump Laser in EPAC.

VOPPEL Compression chamber grating stages fault finding, characterisation and testing

I. Symonds, R. Sarasola, A. Stallwood, N. Stuart *(Central Laser Facility, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)*

The new VOPPEL project for Vulcan Target Area Petawatt (TAP) includes the design and development of two ultra-high vacuum, five axis, precision stages used as grating mounts for laser alignment and manipulation. The stages were designed by Andy Stallwood of the CLF's Mechanical Engineering Design Group, and assembled in-house by the Mechanical Technician Group. The Controls Team was involved in the testing and development of these stages, to ensure that the motors, encoders and drive system could deliver linear and rotational movement to a high degree of accuracy, repeatedly and reliably.

These stages were developed and characterised ready to be integrated with the existing Parker drive system employed in TAP, as well as the ACS drive system. Work carried out included replacing motors that were unable to deliver enough torque, aligning optical encoders to achieve the best read-back signals, and setting limit ranges to prevent collision.

The results of testing these stages demonstrated capabilities of repeatable and accurate incremental linear motion as low as 2 nanometres and minimal angular movement to 0.2 microradians.

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Software developments in Gemini

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The Gemini laser system software consists of a network of distributed applications used to control sections of the laser and monitor parameters both on-shot and continuously.

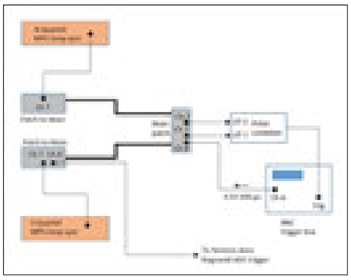

Figure 1: Circuit logic of pulse-combiner box, designed to give a TTL-level pulse of 300 μs duration which is fed to the new data acquisition device.

Figure 2: EMP noise generated by the two capacitor banks in the area in which the data acquisition device operates can interfere with the trigger.

Over the last year we have consolidated work on Gemini diagnostics, including an investigation into the effects of EMP on the ACQ2106 data acquisition device and the installation of a back-reflection prevention flipper.

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Figure 3: Flipper control interface configured to move a flipper into the alignment section of the beamline on-shot, to block back-reflections from the full power section.

Proposed Target Area 2 work-plan in preparation for EPAC

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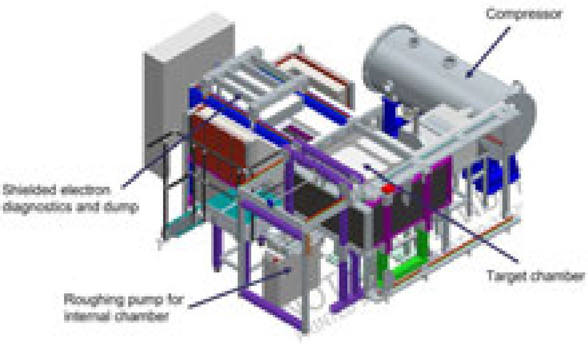
The Extreme Photonics Applications Centre (EPAC) will provide a major upgrade of high-power laser capability in the UK with a laser energy and repetition rate higher than Gemini. Many new systems are being developed such as control software, high frame rate detectors, targets, and electron beam components. It is important that iterative design and prototyping takes place before EPAC commissioning in 2025.



Experimental arrangement in TA2 for producing high repetition rate 100 MeV electron beams.

We describe our proposed work-plan to use Target Area 2 to address technical challenges and confirm that our design is robust and suitable. We will install active stabilization systems in the TA2 beam and improve our gas targets to produce more consistent laser-wakefield accelerated electron beams. The use of machine learning algorithms will be explored to find stable operating parameters and offer flexible, tunable secondary sources. High repetition rate solid target technology based on tape drives and liquid sheets will also be developed.

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Contrast enhancement by the transmission grating in the stretcher

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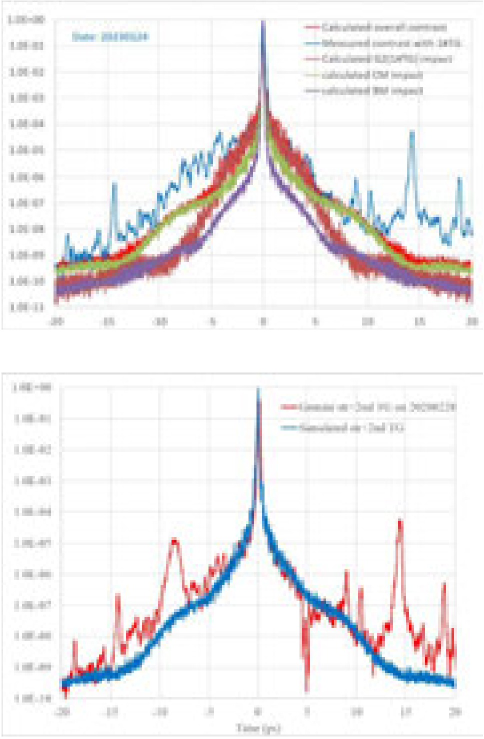
Ultra-high intensity lasers based on the chirped pulse amplification technique (CPA) have proven to be a very powerful drive source to accelerate electrons and protons, producing ultrafast coherent X-ray pulses and high quality bright proton beams.[1,2]

The temporal contrast of such lasers plays a crucial role in these experiments. The contrast pedestal (CP) is a well-known common feature of such lasers. The CP appears in the temporal profile in a triangular shape, extending a few tens of picoseconds, typically at a level of 10^{-5} to 10^{-4} of the peak intensity close to the main peak.

This feature has a very detrimental effect on laser-matter interactions with solid state targets due to the pre-plasma formation prior to the main peak that alters the subsequent interaction, or destroys the target. In this report, we demonstrate the contrast enhancement by using transmissions gratings (TGs) in the stretcher. We also report a novel method to accurately evaluate the CP induced by the stretcher and impact of individual components in the stretcher on the CP by precise quantitative characterisation of the surface roughness of large optics. This way, we are able to predict the CP of the high power laser pulses even before the actual laser system is constructed.



(a) Measured and calculated contrast with 1#TG and contribution of individual optics; (b) measured and calculated contrast with 2#TG.

1. S.-W. Bahk, P. Rousseau, T. Planchon, V. Chvykov, G. Kalintchenko, A. Maksimchuk, G. A. Mourou, and V. Yanovsky, Opt. Lett. 29, 2837 (2004)
2. D. Umstadter, Phys. Plasma 4, 1774 (2001)

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Vertically aligned nanowire arrays as laser targets

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Vertically aligned nanowire arrays have become a more prevalent type of target for high-powered laser experiments in recent years and have garnered interest due to their applicability to various fields. In this paper, nanowire arrays were formed by electrodepositing nickel from its sulphate into nano-porous anodized aluminium templates. The dimensions of the arrays were tuned by altering reaction conditions. Arrays were shot in Pisa in collaboration with Dr Kate Lancaster at the University of York to obtain Optical Transition Radiation (OTR), ion, x-ray and reflectivity data. This could allow the Target Fabrication department to provide tuneable nanowire arrays as targets for high power laser experiments. The benefits of nanowire arrays are their high absorbance of incident light and their ability to form a high-density plasma on laser ablation.

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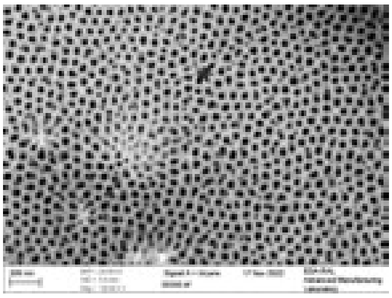

Figure 1: Nano-porous template made by two-step anodization.

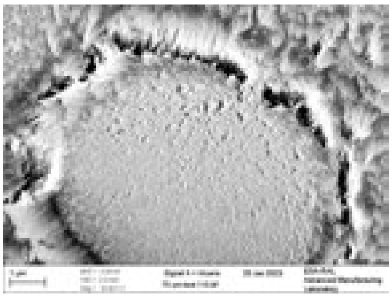

Figure 2: Nanowire array from two-step anodized template.

MATLAB-based Analysis of Micro-target Surfaces for Evaluation and Optimal Laser Shot Positioning

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A. McIlvenny, M. Borghesi *(Centre for Light-Matter Interactions, School of Mathematics and Physics, Queen's University Belfast, UK)*

The purpose of this project was to assist an experiment aiming to shoot a laser along the surface of a metal target ranging in thickness from 1-25 µm. The assembly of such targets is a significant challenge, and, as a result, the target foil is never fabricated completely to specification. Thus, it is important to evaluate each target to maximise its value to the experiment and to account for its imperfections. This project involved mapping the surface of each foil using a white light interferometer and analysing the data using MATLAB scripts. The result was an estimate of the best location for a laser shot for each target foil. This quasi-automated evaluation of individual targets proved to be very useful for the experiment, and the approach could be adapted to be effective in typical high-power laser experiments shooting at target-normal incidence.

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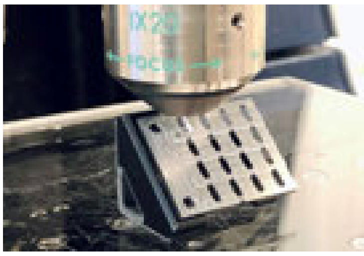

Figure 1: The target array for the Borghesi experiment under an interferometer lens. It is positioned at a 45° angle so that the foil sits quasi-normal to the interferometer's optical axis.

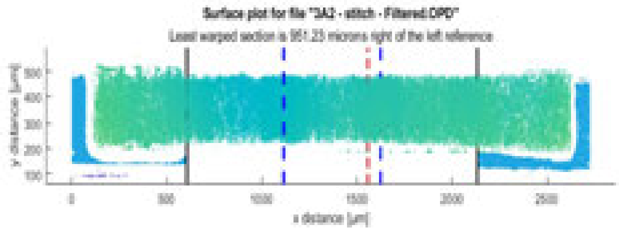

Figure 2: The output plot from the MATLAB script. The red dotted line indicates the best location for the laser shot; the blue dotted lines mark the searched area; the black lines are reference markers, chosen as the edges of the foil mount.

Particle Functionalisation for Dispersion of inorganic ‘Dust’ within Low Density Polymeric Targets

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

Low density materials are often desired for high power laser targets, because the length of laser-matter interaction can be increased without increasing the mass of material relative to solid targets.

Dispersion of nano and micro particulate within the ‘foams’ provides routes to generating x-rays which are often desired for high power laser experiments, as well as simulating astrophysical phenomena.[1]

Dispersion of the particles can prove to be difficult due to aggregation caused by unfavoured interactions between the chemical phases. Methods of improving particle dispersion in the low density phase have clear benefits for the quality of laser targets available to users. This paper reports on experiments carried out on the use of silanization to improve particle dispersion in foams.

[1] *M. Manuel, et al. (2018). Conceptual design of an experiment to study dust destruction by astrophysical shock waves. High Power Laser Science and Engineering, 6, e39*

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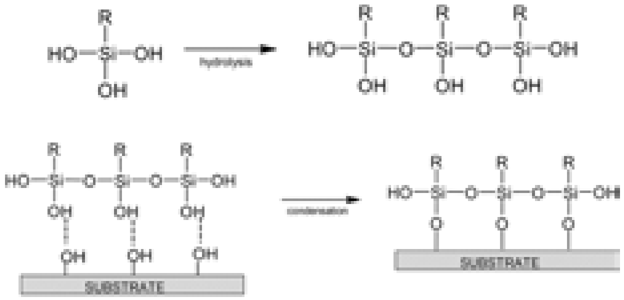

Figure 1: Schematic of the silanization process.

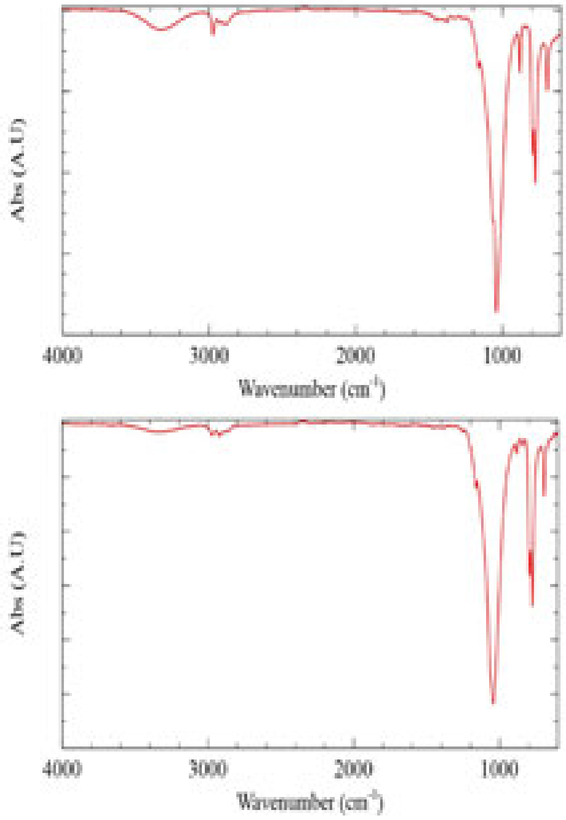

Figure 2: FTIR spectra of silica powders before (top) and after coating (bottom).

Advances in Tape Target Technologies towards 1 Hz Operation for EPAC and other High Repetition Rate Facilities

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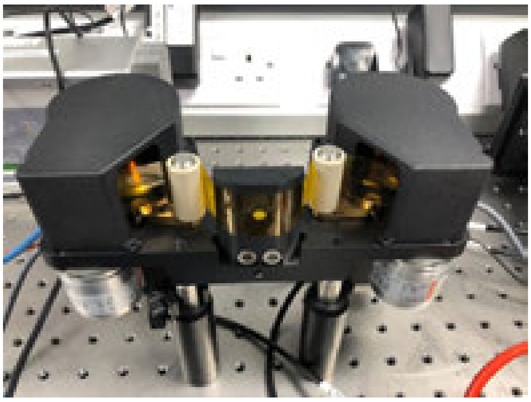
To meet the demand for the number of shots required for higher repetition rate, higher power experiments, a stream of targets is required, at rates far above any that have previously been supplied for intense laser interactions. In response to this demand, the Target Fabrication Group has continued the developments of a tape target delivery system [1,2], which has applications across a broad range of experimental platforms from use as an interaction target to use as a plasma mirror or a beam block. We discuss the development of a range of these systems in the CLF based on a standard architecture, and share the results of a range of test experiments across different facilities.

1. S. Astbury et al, Development of patterned tape-drive targets for high rep-rate HPL experiments, CLF Annual Reports 2017-2018
2. S. Astbury et al, Progression of a tape-drive targetry solution for high rep-rate HPL experiments within the CLF, CLF Annual Reports 2018-2019



The latest version of the CLF tape drive with 2µm stability in the laser direction and a range of debris mitigation shields in place, to ensure repeatability and reliability over long runs at high rep rate.

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Time-resolved multiple probe UV-vis transient absorption spectroscopy at 100 kHz

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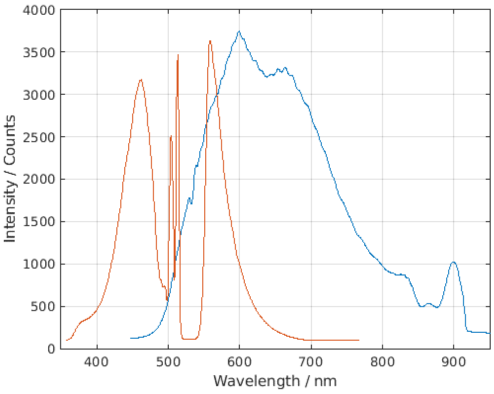
G.F. Karras *(Diamond Light Source Ltd, Harwell Science & Innovation Campus, Didcot, UK)*

Transient-absorption spectroscopy, whether in the UV-visible or mid-infrared, is a powerful tool for studying transient species, enabling a wide breadth of research, from DNA photo-oxidation, to catalysis, and protein folding. The Ultra facility has introduced new UV-visible transient absorption capabilities. The development enables, for the first time, 100 kHz time-resolved multiple probe UV-visible transient absorption spectroscopy (TRMPS). As well as high signal to noise, the system is capable of measuring femtosecond to millisecond dynamics in a single experiment.



Spectra of continuum generated using both 515 nm driven (red) and 1030 nm driven (blue) calcium fluoride.

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Kerr-gated Raman experiment driven by 100 kHz Ytterbium based OPCPA laser system

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Optical Kerr gating is the most efficient approach so far to suppress the strong fluorescence background when detecting weak Raman signals. Here we report the first implementation of the Kerr gated Raman setup driven by a 100 kHz Ytterbium laser source.

The driving laser Dira 200-100 from Trumpf Scientific delivers 200 W average power at 1030 nm and provides a sufficient pulse energy to expand the beam spot size at the Kerr medium, whilst maintaining efficient Kerr effect.

This enables an increase in the probe spot size and a reduction in the probe beam fluence to collect Raman signal from photosensitive and/or degradable samples of interest. In this setup, we have achieved efficient Kerr gating, reaching 70% for 0.75 mm diameter gating spot and demonstrated 12 cm^{-1} spectral resolution (see figure). We have also confirmed that Kerr gated Raman can be done efficiently with 3 mm diameter gating spot.

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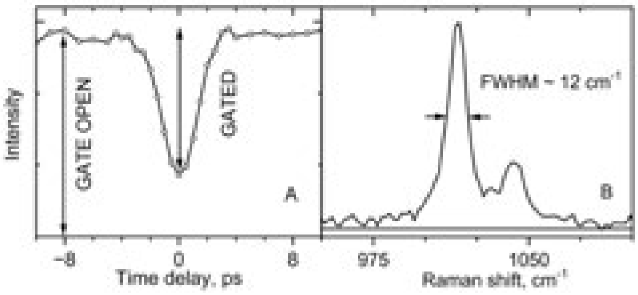

(A) The time profile of the Kerr-gated Raman signal of toluene at 1006 cm^{-1} obtained in the "inverted gating" approach with the gating beam spot size of 0.75 mm x 0.75 mm. The Kerr gate efficiency is estimated as the ratio of the negative "GATED" peak intensity to the "GATE OPEN" intensity. (B) The illustration of the spectral resolution achieved in the Kerr-gated Raman experiment, toluene used as a sample.

Dispersion management in the Vulcan OPCPA petawatt laser using a grating-prism compressor

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The residual dispersion of femtosecond petawatt lasers can limit their output pulse duration and temporal contrast. We have designed a pulse stretcher and a grating-prism compressor based on transmission gratings to control the residual dispersion in the VOPPEL (Vulcan OPcpa PEtawatt Laser) CPA system up to the fifth order.

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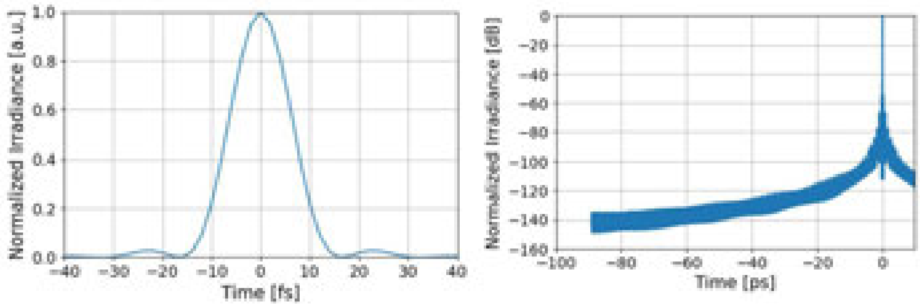

The calculated temporal contrast and pulse duration of the CPA output is not affected by the residual dispersion.

Progress on improving stability of the short picosecond pulse by fast stabilisation in Vulcan

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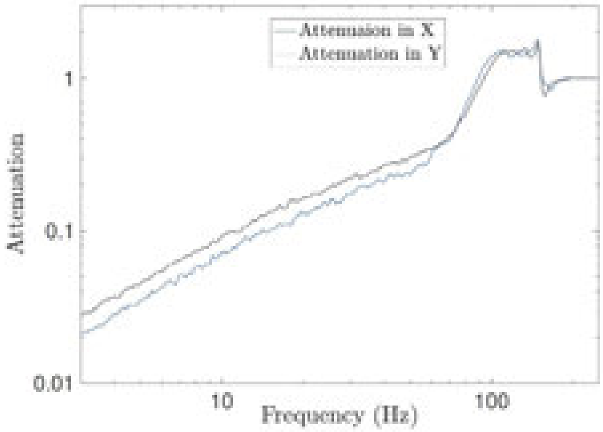
Energy stability of the short picosecond CPA pulse in Vulcan can vary over time. This creates operationally dynamic conditions as the energies between shots can deviate from user requested energies. We present progress in stabilising the beams near-field while identifying future interventions to improve stability.



Log-log plot showing the closed loop attenuation as a function of frequency for the lock-in amplifier

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Novel active near-field and far-field fast beam stabilisation of a picosecond short pulse

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We describe the use of an active fast beam stabilisation to achieve spatial locking of the beam in the near-field and far-field references. The beam stabilisation scheme comprises a PID feedback loop between two position sensitive detectors (PSD) and two fast piezo mirrors, improving on previous work that locked one reference.

Our stabilisation scheme is operational in user experiments demonstrating that this proof of concept may be extended to other beamlines within the Central Laser Facility and other high-power laser facilities.

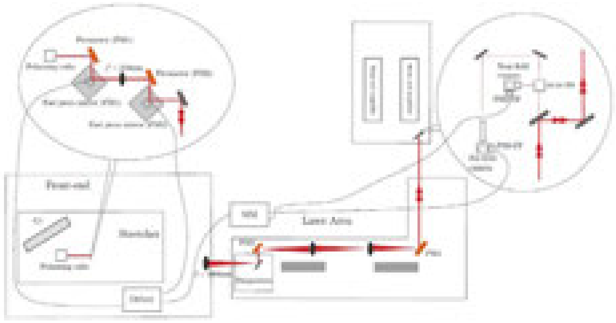

Figure 1: Operational set up showing the optical beam path. The beam propagates from the front-end stretcher with two output fast mirrors (FM1 and FM2) to the two position sensitive detectors (PSD) in the Vulcan laser area before amplification.

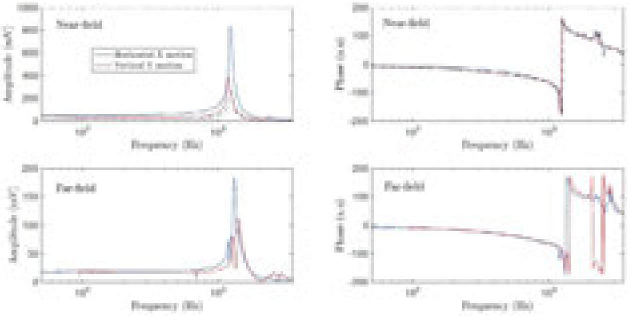

Figure 2: Stability characterisation: performing the frequency sweep between 30 Hz to 4.0 kHz with the near-field and far-field piezo mirrors. Black line shows the sweep after sufficient damping to the horizontal motion in the near-field.

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