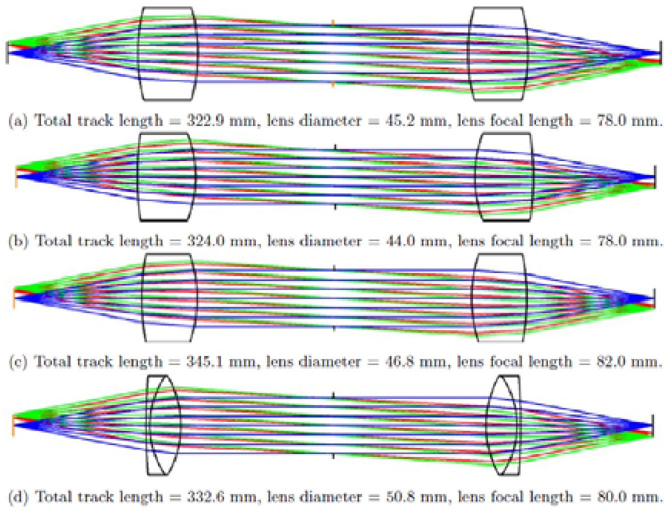
Laser science and development

Zemax OpticStudio Case Study: optical design of a finite conjugate, 4f, telecentric imaging system for re-imaging a VCSEL array

D.L. Clarke *(Central Laser Facility, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)*

The performance of a 4f imaging system for a 7.75 mm x 7.75 mm VCSEL (vertical-cavity surface-emitting laser) array is investigated for different optical configurations and magnifications by consideration of the RMS spot radius and encircled energy plots in Zemax sequential mode. In general, off-the-shelf components are preferred due to the costly nature of manufacturing bespoke lenses. While in the case of [1:1] magnification, the use of an off-the-shelf achromatic doublet requires a small compromise on performance over the use of aspheric singlet, in the case of [1:1.25] magnification, it provides the best system performance. Additionally, the use of an achromatic doublet will make for a more robust system that can be used for a range of wavelengths of light.



Right: Layout of an optimised telecentric, 4f imaging system for two identical (a) equiconvex, (b) biconvex, (c) aspheric singlets and (d) Thorlabs cemented achromatic doublets

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Design and performance of a 100 J pump laser front-end for use in a 10 Hz PW-class amplifier

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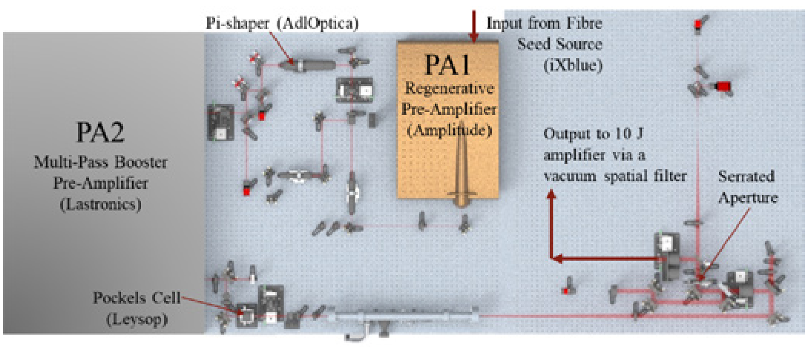
We present the front-end system for a diode-pumped solid state laser (DPSSL), optimised specifically for pumping a 10 Hz PW-class amplifier. The front-end provides 150 mJ, 1 - 15 ns pulses and has spatial and temporal pulse-shaping capabilities.

DPSSLs are a better alternative to flashlamps for pumping amplifiers of PW-class lasers, as they are capable of providing much higher repetition rates and have longer lifetimes. This method is applied in the upcoming Extreme Photonics Applications Centre (EPAC), a new national facility at the STFC Rutherford Appleton Laboratory (RAL), where a Titanium-doped Sapphire (Ti:Sa) femtosecond amplifier will be pumped by a 120 J DPSSL. EPAC will house a PW-class 10 Hz laser, feeding radiation-shielded experimental areas, that will provide academia and industry with a range of applications from laser plasma acceleration to imaging with secondary sources of radiation.



Layout of the front end of the DPSSL pump laser for the Extreme Photonics Applications Centre

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Response of silicon nitride ceramics subject to laser shock treatment

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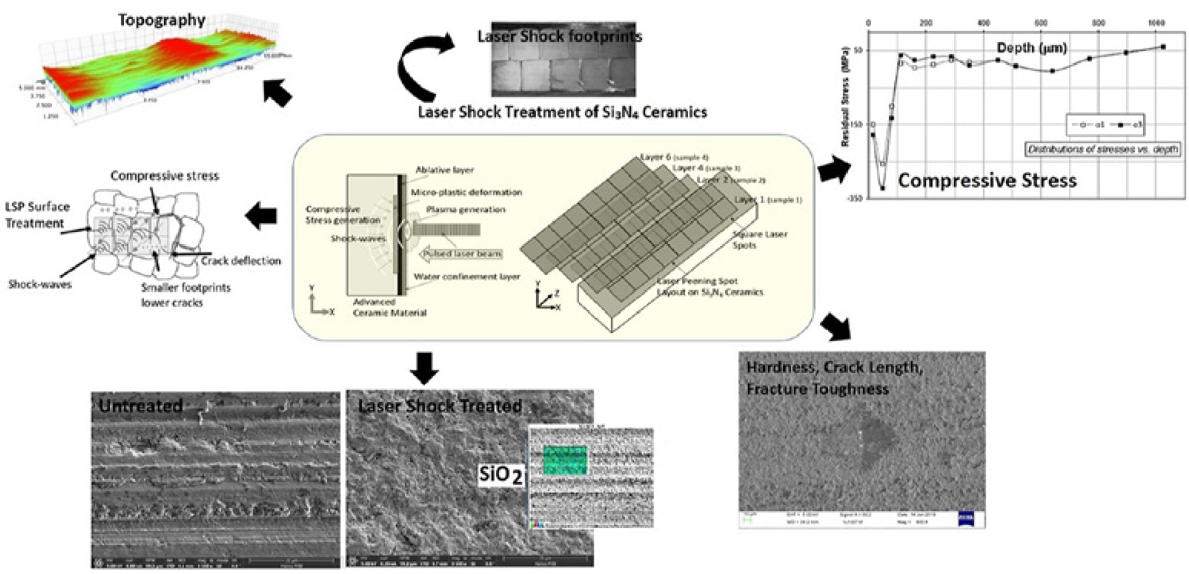
S. Robertson, R. Crookes, H. Wu *(Department of Materials, Loughborough University, UK)*
A. Zammit *(Department of Metallurgy and Materials Engineering, Faculty of Engineering, University of Malta, Malta)*

A comprehensive and novel investigation on multiple-layer, square-beam laser shock treatment ("laser peening") of Si_3N_4 ceramics is reported in this work. Surface topography, hardness, fracture toughness (K_{Ic}), residual stresses, and microstructural changes were investigated. The evaluation of fracture toughness via the Vickers hardness indentation method revealed a reduction in crack lengths produced by the indenter after laser shock treatment. Upon appropriate calculation, this revealed an increase in K_{Ic} of 60%, this being attributed to a near-surface (50µm depth) compressive residual stress measured at –289 MPa. Multiple layer laser shock treatment also induced beneficial residual stresses to a maximum measured depth of 512µm. Oxidation was evident only on the top surface of the ceramic post laser shock treatment (<5µm depth) and was postulated to be due to hydrolyzation. The surface enhancement in K_{Ic} and flaw-size reduction was assigned to an elemental change on the surface, whereby, Si_3N_4 was transformed to SiO_2, particularly, with multiple layers laser shock treatment. Compressive residual stresses measured in the sub-surface were attributed to mechanical effects (below sub-surface elastic constraint) and corresponding shock-wave response of the Si_3N_4. This work has led to a new mechanistic understanding regarding the response of Si_3N_4 ceramics subject to laser shock treatment (LST). It is significant because inducing deep compressive residual stresses and corresponding enhancement in surface K_{Ic} are important for the enhanced durability in many applications of this ceramic including cutting tools, hip and knee implants, dental replacements, bullet-proof vests and rocket nozzles in automotive, aerospace, space and biomedical industries.

*Reproduced from the accepted manuscript version (https://pureportal.coventry.ac.uk/en/publications/response-of-silicon-nitride-ceramics-subject-to-laser-shock-treat) of P. Shukla, P, Shen, X, Allott, R, Ertel, K, Robertson, S, Crookes, R, Wu, H, Zammit, A, Swanson, P & Fitzpatrick, ME 2021, 'Response of silicon nitride ceramics subject to laser shock treatment' under the terms of http://creativecommons.org/licenses/by-nc-nd/4.0/
A definitive version was subsequently published in Ceramics International, 47:24, (2021) © 2021, Elsevier. doi: 10.1016/j.ceramint.2021.08.369*



Graphical abstract from https://www.sciencedirect.com/science/article/pii/S0272884221027711

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Stable high-energy, high-repetition-rate, frequency doubling in a large aperture temperature-controlled LBO at 515 nm

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

We report on frequency doubling of high-energy, high-repetition-rate ns pulses from a cryogenically gas cooled, multi-slab Yb:YAG laser system, using a type-I phase-matched lithium triborate (LBO) crystal. Pulse energy of 4.3 J was extracted at 515 nm for a fundamental input of 5.4 J at 10 Hz (54 W), corresponding to a conversion efficiency of 77%. However, during long-term operation, a significant reduction of efficiency (more than 25%) was observed owing to the phase mismatch arising due to the temperature-dependent refractive index change in the crystal. This forced frequent angle tuning of the crystal to recover the second-harmonic generation (SHG) energy. More than a five-fold improvement in energy stability of SHG was observed when the LBO crystal was mounted in an oven, and its temperature was controlled at 27°C. Stable frequency doubling with 0.8% rms energy variation was achieved at a higher input power of 74 W when the LBO temperature was controlled at 50°C.

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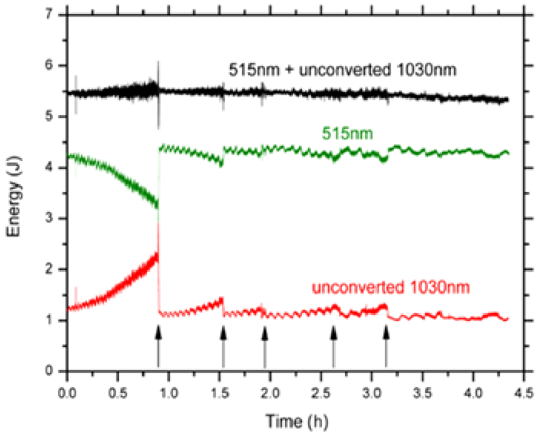

Figure 1: Long-term energy stability of type-I SHG in LBO in a thermally isolated mount using a 1 cm² beam. The black line shows total energy (515 nm + unconverted 1030 nm), the green line shows frequency converted energy (515 nm), and the red line shows the unconverted fundamental (1030 nm). The arrows indicate the times at which the crystal angle (theta) was changed to restore the second-harmonic energy.

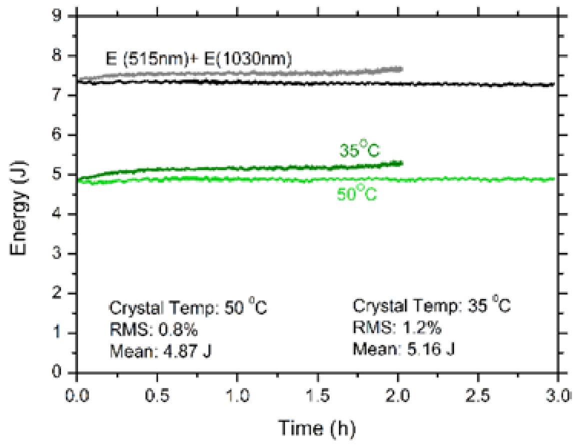

Figure 2: Long-term energy stability of type-I SHG in LBO in an oven set to 35°C and 50°C using a 1.4 cm² beam. Total input energy of 7.4 J (grey and black lines) and average power of 74 W, 515 nm energy 5.0 J (green lines), 50 W average power.

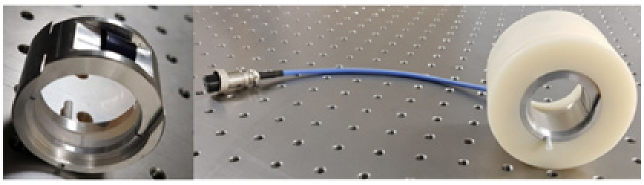

Figure 3: Photographs of LBO crystal oven components: (left) spring-loaded metallic crystal holder with the crystal in place. This is placed inside the oven unit (right). The oven is then connected to a separate temperature control unit.

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Modelling and measurement of thermal stress-induced depolarisation in high energy, high repetition rate diode-pumped Yb:YAG lasers

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In this paper, we present a model to predict thermal stress-induced birefringence in high energy, high repetition rate diode-pumped Yb:YAG lasers. The model calculates thermal depolarisation as a function of gain medium geometry, pump power, cooling parameters, and input polarisation state. We show that model predictions are in good agreement with experimental observations carried out on a DiPOLE 100 J, 10 Hz laser amplifier. We show that single-pass depolarisation strongly depends on input polarisation state and pumping parameters. In the absence of any depolarisation compensation scheme, depolarisation varies over a range between 5% and 40%. The strong dependence of thermal stress-induced depolarisation on input polarisation indicates that, in the case of multipass amplifiers, the use of waveplates after every pass can reduce depolarisation losses significantly. We expect that this study will assist in the design and optimisation of Yb:YAG lasers.

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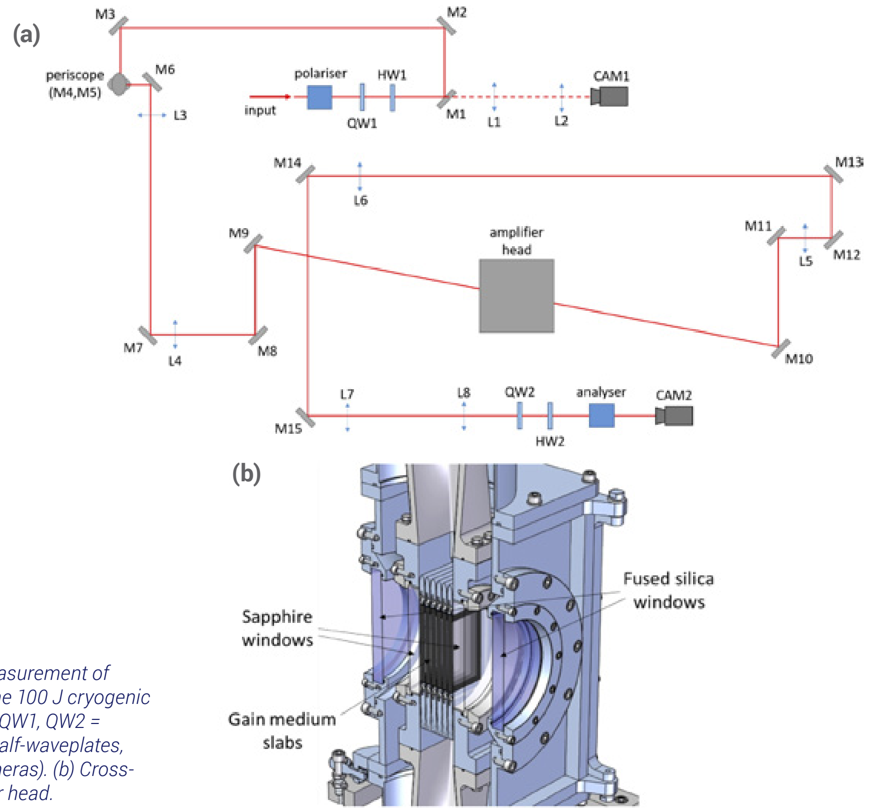

Figure 1: (a) Setup used for the measurement of stress-induced depolarisation in the 100 J cryogenic main amplifier (M1-M15 = mirrors, QW1, QW2 = quarter-waveplates, HW1, HW2 = half-waveplates, L1-L8 = lenses, CAM1, CAM2 = cameras). (b) Cross-sectional rendering of the amplifier head.

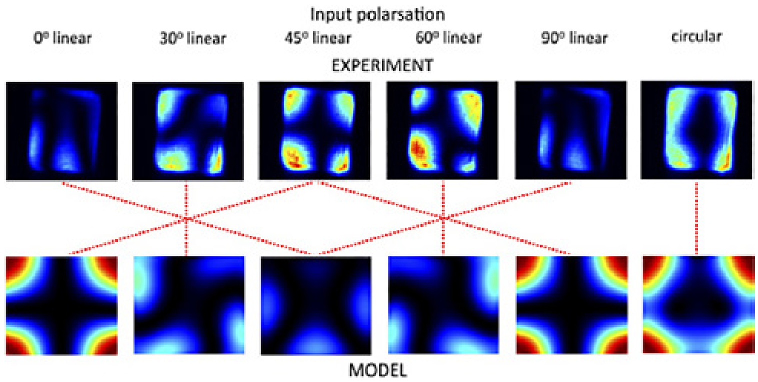

Figure 2: Experimental (upper row) and theoretical (lower row) depolarisation patterns for the "180 g/s, 3.77 kW" scenario and for a number of input polarisation states. Red dashed lines link images with similar depolarisation patterns. The colour scales for experimental and theoretical patterns are the same for all experimental and theoretical images, respectively.

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Use of Recast3D for real-time reconstruction

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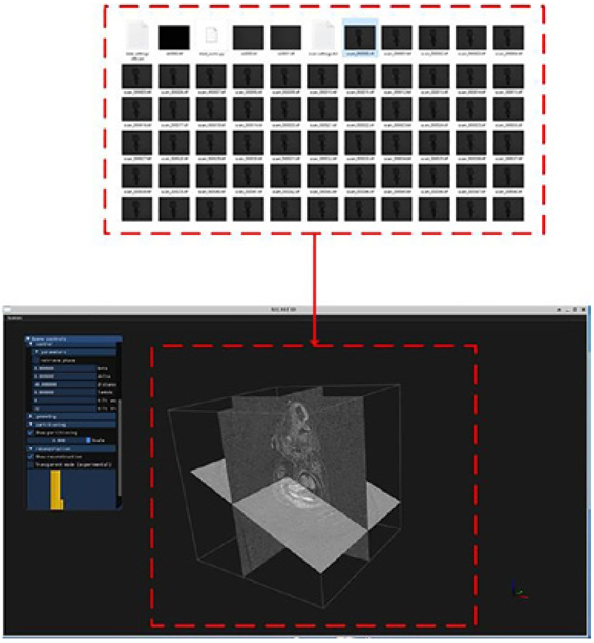
This paper is going to introduce our work on developing a distributed real-time tomography reconstruction platform for EPAC based on Recast3D with the collaboration of Diamond Light Source (DLS).

Recast3D is a visualization platform for tomographic imaging based on on-demand reconstruction of arbitrary slices, and is built for use in a distributed, real-time, and online construction pipeline. It is a useful real-time tomography reconstruction software toolkit that avoids the high computational cost of full 3D tomographic reconstructions. Through the work completed, we established the prototype platform and carried out performance tests. Further work is planned to reduce reconstruction time.



Right: The raw scanned slice images (top) and the reconstructed 3D image in Recast3D

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Ø320 mm beam positioning mirror mount for the EPAC project with 1 µrad stability

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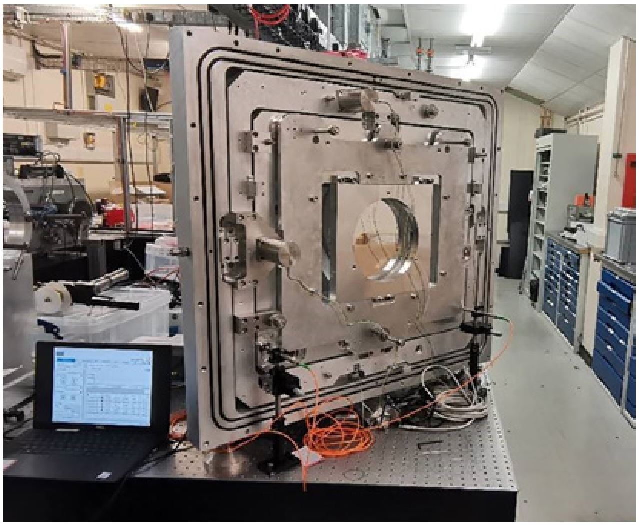
For the new Extreme Phonics Application Centre (EPAC) at the Central Laser Facility (CLF) a beam positioning mirror mount was designed to propagate a laser beam measuring up to 320 mm in diameter with 1 µrad stability under vacuum.

The end design consisted of the novel approach to integrate the mechanics within a solid aluminium vacuum chamber. This improved the rigidity of the mirror mount and exceeded the stability specification by offering less than 500 nano-radians peak to peak.



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Deploying the SLAC liquid target at RAL

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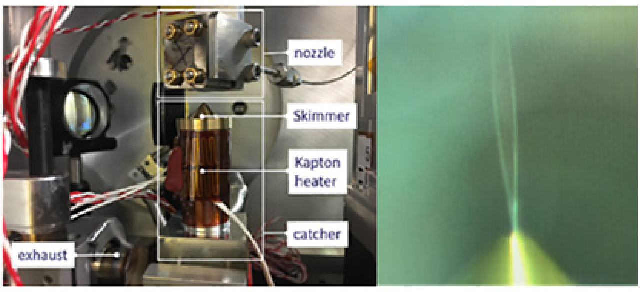
G.D. Glenn, C.B. Curry, F. Treffert, M. Gauthier, S.H. Glenzer *(SLAC National Accelerator Laboratory, High Energy Density Science (HEDS) Division, USA)*
C.A. Palmer, M. Streeter *(Centre for Plasma Physics, Queen's University Belfast, UK)*

A water-jet target developed at SLAC is capable of generating liquid sheets ranging in thickness from 100 nm to 100 microns. This device was successfully deployed in the ATA2 target area during a recent experiment, in which many thousands of laser shots were taken on the jet. High-purity water is forced through a thin nozzle to form the liquid jet, the thickness of which can be controlled by varying the pressure and flow rate. The water is collected in a catcher, which must be heated to prevent the water freezing before it can be pumped out of the chamber into a trap. To avoid exposing the compressor optics to water vapour, a thin silica window was placed in the beamline before the target chamber. An auxiliary vacuum pump was used instead of the turbo pumps normally used for pumping the target chamber, to prevent damage by water droplets.



Ultra-thin liquid sheet generation. Picture of the nozzle and catcher in the vacuum chamber (left). A Kapton film heater is used to prevent the water freezing under vacuum. Image of the liquid sheet (right). The nozzle output is at the top, the liquid is flowing downwards.

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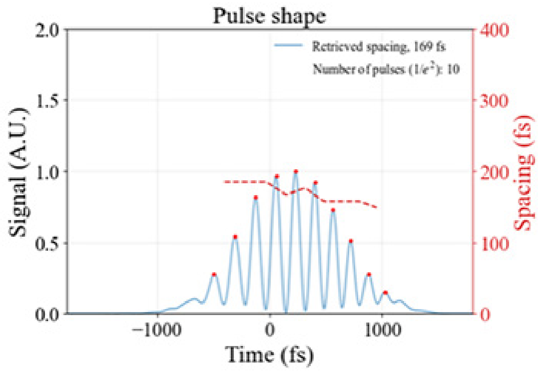
A Michelson interferometer for pulse-train generation on Gemini

C.J. Hooker *(Central Laser Facility, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)*

An experiment to investigate the effectiveness of multiple pulses for laser wakefield acceleration required a means of generating pulse trains from the Gemini laser facility. A compact Michelson interferometer was set up in the output of the south amplifier of Gemini, to modulate the spectrum of the beam and thereby produce a pulse train after the compressor. A small angle between the input and rejected beams prevented damage to the laser amplifier by back reflected energy. The compressor was de-tuned to give a pulse duration of approximately 1 ps, and with the modulated spectrum the output was a fully-modulated pulse containing ten sub-pulses with a duration and spacing of around 170 fs. The spacing and uniformity of the pulses could be remotely controlled by the experimenters. Although not part of the regular configuration of Gemini, the interferometer can be re-installed if required for future experiments.



Pulse train generated after compression of the modulated pulse
NOTE: this figure was provided by the Oxford Plasma Physics group specifically for use in the Annual Report.

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Software developments in Gemini

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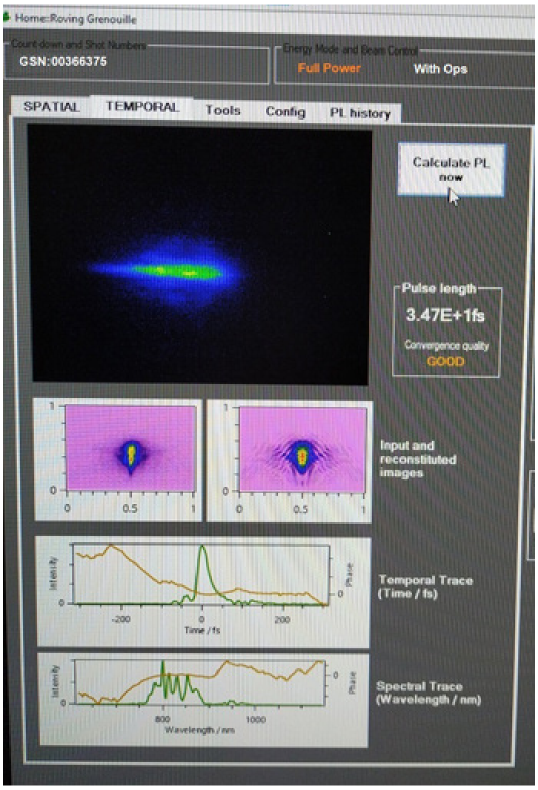
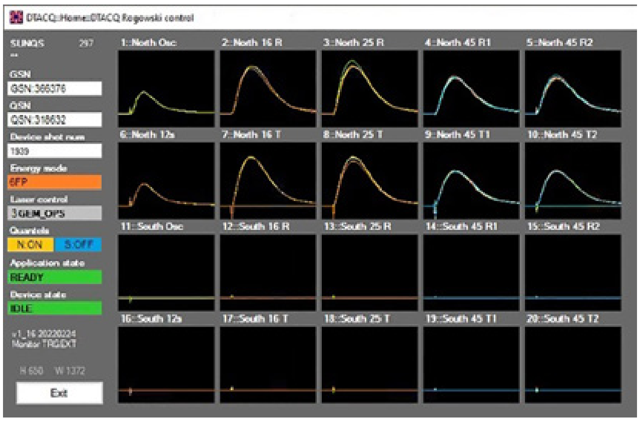


Over the last year there have been two significant updates to the Gemini diagnostics. Firstly, a new Grenouille analysis application, using EPICS PVs to streamline operations, and a reconstruction algorithm based on that described by Sidorenko *et al*. Secondly, a control and data acquisition application for the new D-TACQ ACQ2106 device, reading data from Rogowski coils to diagnose lamp failures in the two Quantel lasers.



Left: Figure 1: Grenouille application "Temporal" image window showing a false-colour image of the beam, reconstructed images, analysis traces and best-convergence pulse length. The operator is poised to initiate an on-demand analysis.

Above: Figure 2: Typical Rogowski curves. Only the North Quantel is on, and it can be seen that a couple of the 16T and 45T2 lamps are failing.

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New mounting for grating G1 of the Astra TA2 compressor

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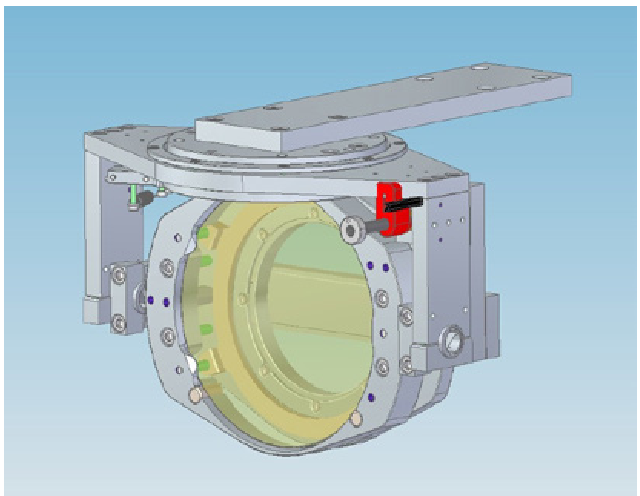
A new mount for the first grating of the Astra TA2 compressor has been installed in the compressor chamber. The goals of the design were to increase the accuracy of aligning the grating, eliminate instabilities that had previously caused the compressor to become misaligned, and make changing the grating simpler and less risky.

The new mount uses higher-quality bearings for the rotation axes, and vacuum-compatible picomotors for the pitch, yaw and groove rotation adjustments, giving angular sensitivities of less than 1 micro-radian per step. The grating is held in a cassette that locates easily onto the mount, and ensures that the groove face always lies in the same plane. Replacement gratings with different thickness and diameter can be accommodated by making custom-designed cassettes. The accuracy and stability of the new mount have been tested during several experiments, and it has significantly improved the ease and reliability of operations.



CAD drawing of the new grating mount. The mount is supported from a frame (not shown) inside the compressor chamber.

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mJ-level 5 Hz probe beam for Gemini target area

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For a recent experiment on Gemini, the experimental team requested a mJ-level probe beam operating at 5 Hz, in order to build up a large number of probe shots before and after the main target shot. This probe beam was derived from a portion of the 5 Hz input to the Gemini area, taken in transmission through a mirror, and sent down the existing probe beam path. An optical delay line in the form of a cavity was built in the target area, to allow the probe and main pulses to be synchronised. After losses in the delay optics and the probe pulse compressor, the energy in the probe pulse was about 2.5 mJ, but there is potential for this to be improved for future experiments.

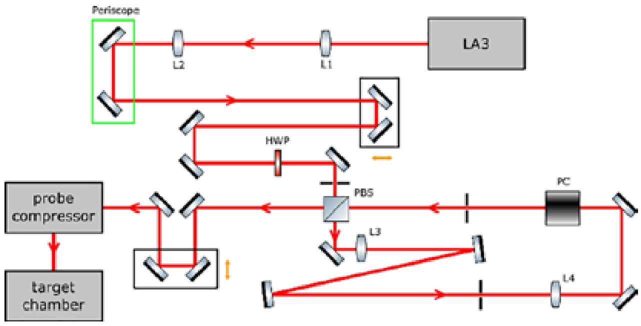

Diagram of the experimental setup. L1: f = 3 m; L2: f = 2 m; L3: f = 1 m; L4: f = 1 m; HWP: Half-wave plate; PBS: Polarising beamsplitter; PC: Pockels cell (Gooch & Housego TX 7595)

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Microassembly of Buried Wire Targets for the European XFEL

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M. Oliver *(Experimental Science Group, Central Laser Facility, RAL Space, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)*

Scitech Precision Ltd were tasked with fabricating buried wire targets for the European XFEL, to be used for experiments to study transport properties and hydrodynamics at a metal/plastic interface, as well as for detector testing. Four target arrays in total were fabricated, two with 4 µm tungsten wire and two with 10 µm tungsten wire, in each case with the wires coated with 50 µm (100 µm diameter) of Parylene C (PyC). The wires were fixed by hand to an additive manufactured jig on which they were coated. The coated wire was then attached to a micro-machined silicon mount with target assembly completed manually.

The targets were deployed successfully on experiments.

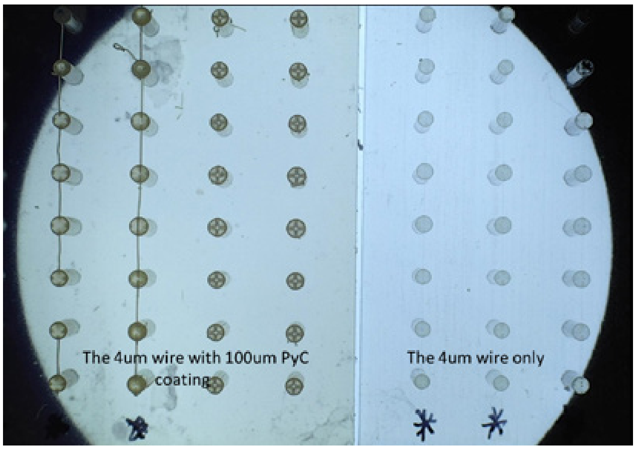

Figure 1: An optical image comparison of the 4 µm wire post and pre PyC coating. The lighter half (right) is before the coating, and the left shows the wire after the PyC coating.

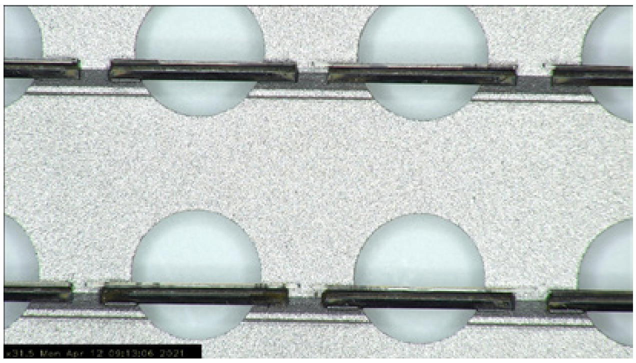

Figure 2: An optical image of the completed assembly mount showing the three parts of the completed target

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Experimental Testing and Fielding of the CLF Precision Tape Drive in the Gemini Target Area

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R. Sarasola, K. Rodgers *(Electrical and Control Group, Central Laser Facility, RAL Space, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)*
G. Hull, D. Symes *(Gemini Group, Central Laser Facility, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)*

As part of the ongoing development of the CLF high-precision tape drive for high repetition rate experiments access was given to Gemini. The deployment gave vital feedback under experimental conditions on robustness, EMP and debris. Initial runs highlighted issues which were difficult to diagnose. The Target Fabrication team were granted two additional days for testing of several modifications made to the set-up. A camera was installed pointing directly at the system which confirmed 400 shots with no non-recoverable faults. The system was deployed for a commercial run performing faultlessly on hundreds of 12 J (before compressor) shots and subjected to multiple electron beams.

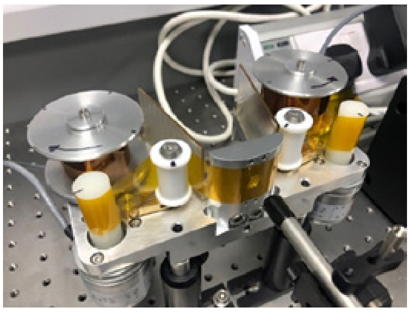

Figure 1: CLF High Precision Tape Drive

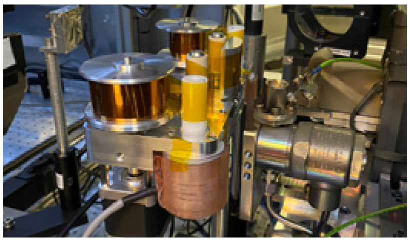

Figure 2: Tape Drive by the Gas Jet in GEMINI, CLF

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A systems engineering architecture for robotic microtarget production

P. Umesh, T. Neumann, S. Astbury, D. Haddock, C. Spindloe, M. Tolley *(Target Fabrication Group, Central Laser Facility, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)*

A robotic Target Array Assembly System (TAAS) is being developed by the Target Fabrication Group at the Central Laser Facility to automatically assemble microtarget arrays.

Currently all target arrays made by the Group are assembled by hand, but assembly of a single array (of 60 microtargets) can take at least two hours. However, the assembly process of target arrays includes many highly repetitive tasks that can be performed by robots.

This report outlines the main objective and requirements for the first TAAS prototype. From the design, integration, and testing of the prototype, a deeper understanding of the automated assembly process was gained enabling the specification of upgrades required to demonstrate the robotic assembly of high-precision (2D) microtargets.

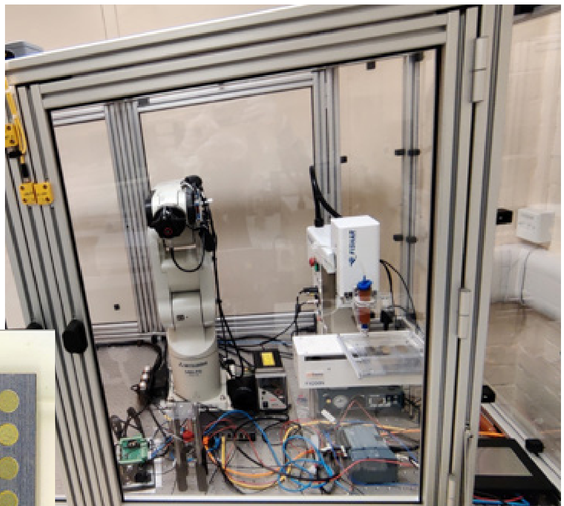

Figure 1: TAAS prototype

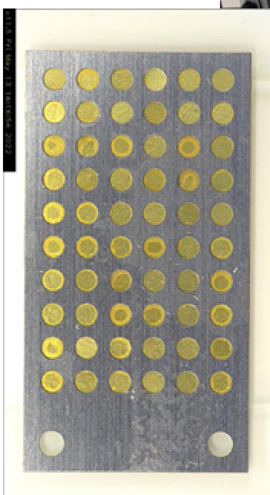

Figure 2: Laser-facing side of the Target Array with sixty 2.8 mm square gold foil targets that are 30 µm thick

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Wavefront-tilt correction of laser pulses by dispersion management

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A new diagnostic has been tested to visualise pulse-front-tilt in ultrashort laser pulses. Dispersive mediums (4° glass prisms) were rotationally controlled about the beam axis in accordance to the diagnostic, via an automated loop, to successfully minimise existing angular dispersion from a commercial oscillator output.

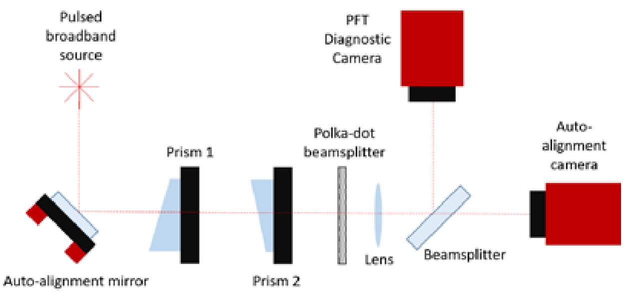

Figure 1: Schematic layout of the experimental setup: a broadband pulse from a commercial oscillator is directed by an automatic alignment loop through two 4° prisms, a polka-dot beamsplitter and a focusing lens

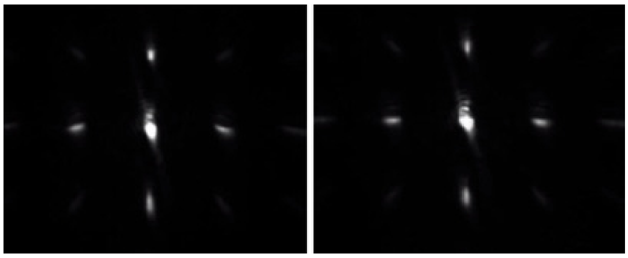

Figure 2: Angular dispersion (AD) diagnostic camera images of undeviated (left) and optimised (right) pulse

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Compressor grating optimisation using the D scan technique

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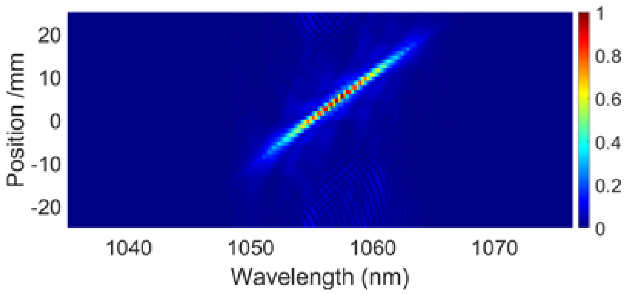
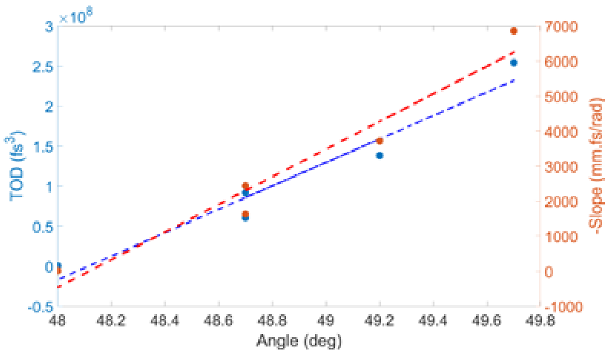
In this contribution we report on our use of the D scan technique to optimise a grating compressor in the Front-End of the Vulcan Laser Facility. We present theoretical and experimental results, and demonstrate that this technique is ideal to tune both the incidence angle of the grating and the distance between the gratings. Optimal compression is achieved by eliminating any residual second and third order dispersion, resulting in a shorter compressed pulse.





Top: Figure 1: Example of a D scan where the phase only contains third order dispersion

Bottom: Figure 2: Experimental results of TOD (blue) and slope (red) of the D scan trace as a function of the angle.

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Design of high contrast OPA system for the Vulcan Laser System

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Temporal contrast is a key feature of any high intensity laser. One method of improving contrast is short pulse Optical Parametric Amplification (OPA). Here we present a new high contrast Optical Parametric Chirped Pulsed Amplifier (OPCPA), which is specifically designed for the unique Optical Parametric Oscillator of the Vulcan laser system. We review the current high contrast OPCPA system at the Vulcan laser facility, discuss the new architecture of picosecond pump laser, and present simulations of two different regenerative amplifiers, each with different crystals (Nd:YLF and Yb:SSO) used as the gain material in the Regenerative Amplifier. This is followed by simulations on the non-linear processes of second harmonic generation, OPA and the output pulse.

An investigation of the relationship of the pump-seed pulse duration and the overall efficiency of the system is carried out. This ratio is then determined to maximise the output efficiency of the system.

Finally, a scan of the input and output intensities of the pulse is carried out, to determine the input spectrum and intensity of the pulse for the most stable configuration of the system.

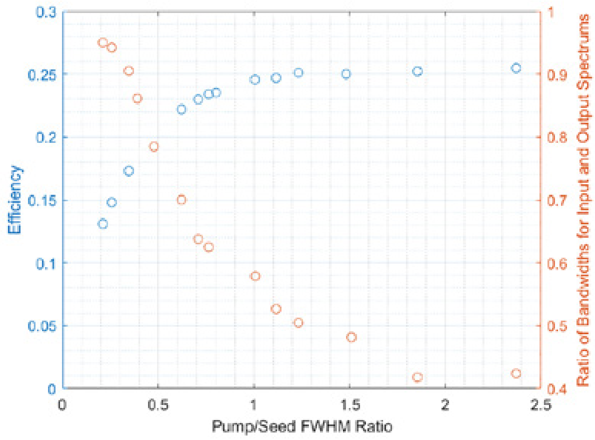

Figure 1: Relationship between pump/seed FWHM ratios, efficiency and bandwidth of the output seed of the OPA

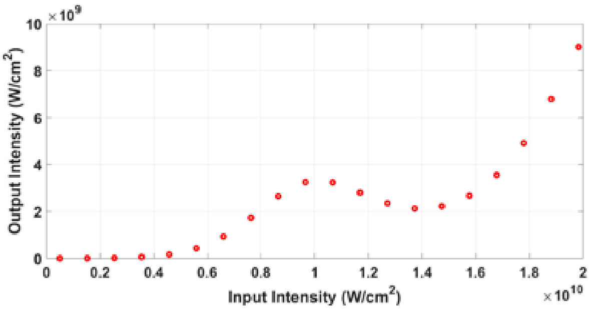

Figure 2: Intensity vs output intensity of OPA system

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