Laser Science & Development

Laser shock peening of aluminium and titanium using the DiPOLE laser system

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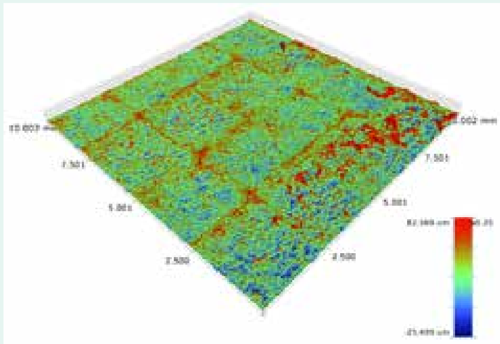
Successful laser shock peening (LSP) of aluminium and titanium was demonstrated using the DiPOLE laser system operating at 7 J, 10 ns. Peak compressive stress of 220 MPa and 170 MPa was measured in Al7075 and Ti6Al4V with a confinement medium (water). Both peak compressive stress as well as the depth of compression increased on the application of repeat laser shocks. Aluminium foil coating as an absorptive layer showed best results when no confinement condition (no water) was used for LSP.



Surface condition after laser peening with a roughness topography map

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Impact of gas cluster ion and accelerated neutral atom beam surface treatments on the LIDT of ceramic Yb:YAG

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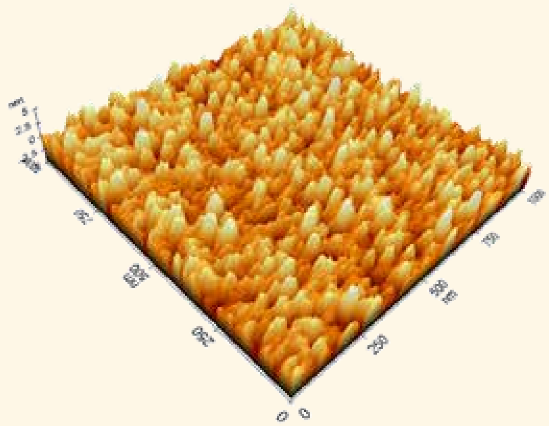
We describe the application of the gas cluster ion beam (GCIB) and of the accelerated neutral atom beam (ANAB) surface treatments to ceramic Yb:YAG. We demonstrate that these techniques allow accurate control of ceramic Yb:YAG surface characteristics and constitute an alternative to conventional surface finishing techniques. In this study, we analyse the impact of angstrom level polishing and surface nano-texturing on laser induced damage threshold (LIDT) in the nanosecond pulsed regime of uncoated and antireflective coated ceramic Yb:YAG samples. We show that both techniques allow meeting the requirements on resilience to laser irradiation at fluence levels characterising high-energy laser systems. Moreover, we show that surface nano-texturing improves the LIDT of coated samples, possibly through an improvement in adherence of coatings to ceramic Yb:YAG substrates.



1 µm x 1 µm atomic force microscope 3D reconstruction of a GCIB nano-textured Yb:YAG sample surface.

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The Prospect of a kW-Class, Multi-TW, ps Laser

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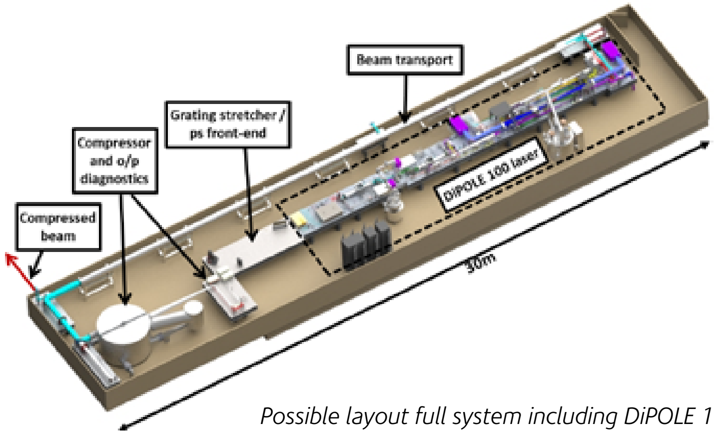
We explore how DiPOLE-type laser systems, based on cryo-cooled, diode pumped, multi-slab Yb:YAG amplifier technology, can be adapted for direct-CPA ps-pulse generation. This adaption would open up the possibility of producing pulses with 10s of TW of peak power, 10s of J of energy, at the kW average power level, without having to resort to more complex and less efficient schemes like OPCPA or Ti:Sapphire amplifier chains. Initial calculations indicate that the narrow gain-bandwidth of cryo-cooled Yb:YAG is challenging in terms of stretching and recompression of the laser pulses, but nonetheless should allow the generation of 2 ps pulses at nearly the same energy and at the same repetition rate as in ns mode.



Possible layout full system including DiPOLE 100 laser, front-end with stretcher, compressor, and beam transport

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Frequency conversion at 5.5 J, 10 Hz with an LBO Crystal in DiPOLE for greater than 4 hours operation

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We report on type-1 phase matched frequency conversion in LBO (X-Y Plane), of 5.5 J, 10 Hz cryogenic gas-cooled Yb:Yag laser operating at 1029.5 nm. LBO exhibited an efficiency of > 80% at a peak fundamental of 5.5 GW/cm^2 for 10 Hz operation at 10 ns. This was without any degradation or damage in the crystal.

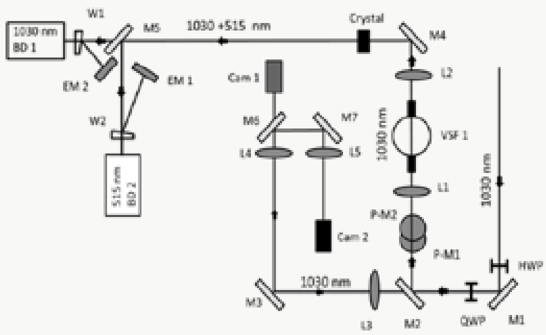

Figure 1 Schematic of the experimental setup to increase the fluence on LBO crystal. M1-M7: Mirrors; L1-L5: Lenses; HWP: Half-wave Plate; QWP: Quarter-wave plate; VSF1: Vacuum spatial filter; W1, W2: Wedges; Cam 1, Cam 2: Cameras, EM1, EM2: Energy meters; BD1, BD2: Beam dumps.

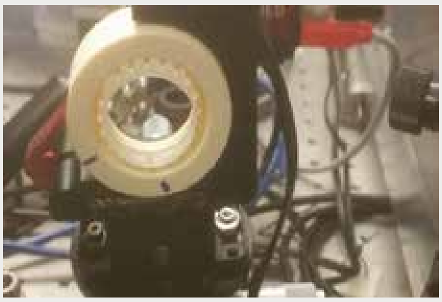

Figure 2 LBO crystal held in place by a laser printed holder which is fixed in a 50 mm mirror holder with electronic actuators for changing the angle of the crystal remotely.

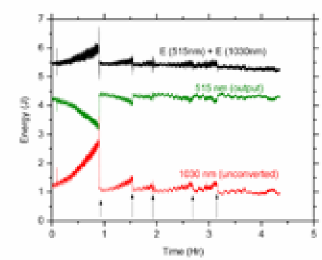

Figure 3 Long term energy stability for LBO crystal. The arrows indicate the time when the angle of the crystal is changed to recover the frequency conversion to the level at the start. The black line is the total energy, green line is the converted 515 nm and the red line is the unconverted 1030 nm.

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Engineering upgrades to the DiPOLE-100 laser system for the D100X project

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The 'state of the art' DIPOLE-100 laser system, commissioned at the HiLASE Facility in 2016, was 18 m long by 3 m wide. For the laser system being supplied to the European XFEL, available space in the HED Instrument laser hutch is severely constrained at 5 m x 11 m, posing an engineering challenge to reduce the footprint radically without major modification to the proven multi-pass architecture. In collaboration with European XFEL, the layout was reconfigured and developed to provide a seamless interface with existing and in-progress service designs for the laser hutch (see Figure 1).

The original amplifier head had a maximum allowable working pressure (MAWP) of 11 bar. An engineered increase in MAWP to 20 bar negates helium inventory depletion, a significant advantage in operation for the new design. To achieve this, the thickness of the main amplifier body has been increased, based on findings from complex technical models. This modification has resulted in a five-fold reduction in the deflection in critical regions of the amplifier head (Figures 2a and b).

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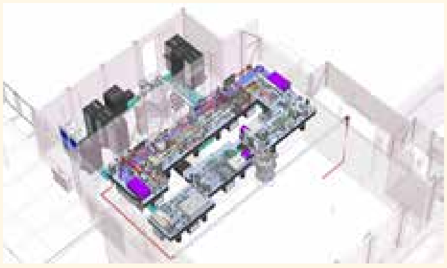

Figure 1: (left) CAD model of the DiPOLE-100X Laser System in the HED Instrument laser hutch at the European XFEL

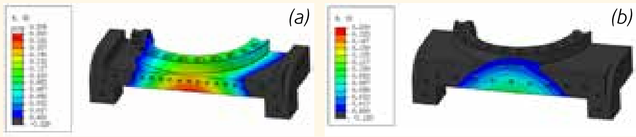

Figure 2: (above) Deformation (mm) outwards in the direction of the sapphire window for steady state operating conditions for (a) the original amplifier head design and (b) the revised amplifier head design

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

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The implementation of the XPW pulse-cleaning technique on the Gemini laser is progressing, with the completion and testing of all the major components of the system. Pulses from the kHz front end amplifier are compressed by a transmission grating pair before the XPW stage itself. The cleaned output has greater bandwidth and improved spatial and spectral quality, but lower energy. The pulses are stretched again, using chirped mirrors and then a glass block, before amplification in a multi-pass Ti:sapphire amplifier to restore the pulse energy to the required level. The stretching has been characterised to show that the spectral and phase quality is maintained, and the performance of the amplifier has been verified. The next phase of the project will involve injecting the amplified beam into the input of the amplifier chain, and measuring the spectral and temporal characteristics of the amplified and compressed pulses at the output of Gemini.

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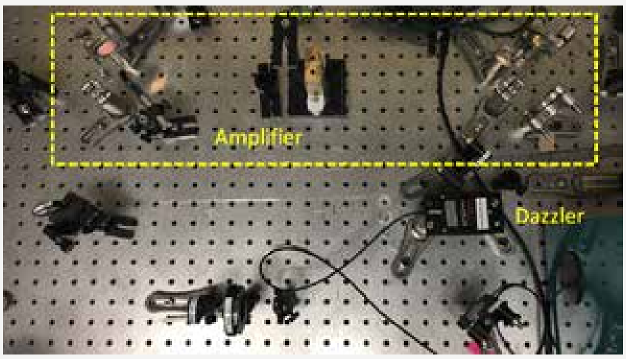
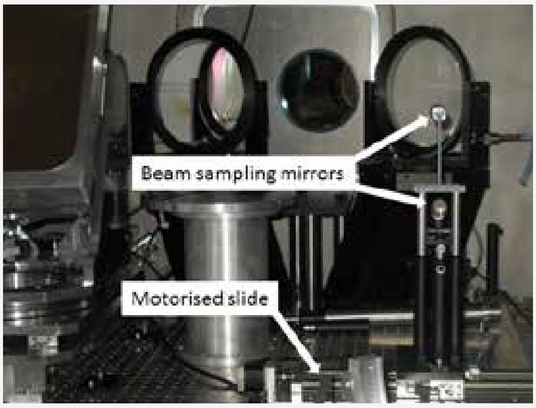


Booster amplifier, consisting of six folding mirrors and the Ti:Sapphire crystal in the middle of the amplifier

Gemini Facility Improvements

C.J. Hooker, O. Chekhlov, C.D. Gregory, S.J. Hawkes, B.T. Parry, Y. Tang, P.P. Rajeev, S. Hook, T. Zata *(Central Laser Facility, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)*

During the year, several new diagnostic capabilities have been implemented on the Gemini laser. A new suite of diagnostics, comprising near- and far-field images and a moiré collimation diagnostic, was installed after Amplifier 3 to allow better monitoring of its performance. In the Gemini pulse compressors, a drive-in periscope was installed for obtaining short pulse diagnostic beams. This was done at the request of the users, because the diffraction from the hole in the final mirror, previously used to obtain the diagnostic beam, was causing damage to optics in the target. The new setup does not provide pulse length information on every shot, but experience shows that there is no significant change in the pulse length during the day. Finally, new Glan-Thompson polarisers were installed in the pulse stretcher cavity to replace the polariser cubes, and eliminate some spectral losses that were adversely affecting the bandwidth of Gemini.



The new beam-sampling setup in the Gemini south compressor

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Software developments in Gemini

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During the year, a number of software changes have been made as part of the continuing programme of upgrade work in Gemini. The main Control System was finally moved off its obsolete platform and onto a more up-to-date operating system. This move forced the replacement of some obsolete hardware controlling the energy delivered to the two target areas with more modern and reliable devices (see Figure 1). During this process, the opportunity was taken to revise the layout of the control system windows, bringing most functions into a single front-panel window.

In response to user requests, a new operating protocol was developed for TA2 to permit multiple-pulse 'burst' operation at 5 Hz repetition rate, and this has given the area a useful new capability.

New applications were written so that data from a new spectrometer system and the on-shot Dazzler settings could be integrated into the numerical sequence of shot data.

LA3 wave plate motion stage application

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Operation of Gemini Target Area 2 at 5 Hz repetition rate

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S. Eardley, R.A. Smith *(Blackett Laboratory, Imperial College London, London, UK)*
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S. Tata, M. Krishnamurthy *(Tata Institute of Fundamental Research, Homi Bhabha Road, Colaba, India)*
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D. Hazra *(Laser Plasma Section, Raja Ramanna Centre for Advanced Technology, Indore, India)*
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Modifications were made to the control and safety systems in Gemini TA2 to trial operations at the full repetition rate of 5 Hz. This allowed implementation of a feedback control code to optimise experimental parameters as shown in Figure 1. The laser performed well with 3% energy stability (see Figure 2) and no noticeable degradation in compressor performance during of order 100,000 shots. The main concerns with higher repetition rate of optic damage and radiological safety are discussed, with suggestions for fast response actions that will ensure safe facility operation.

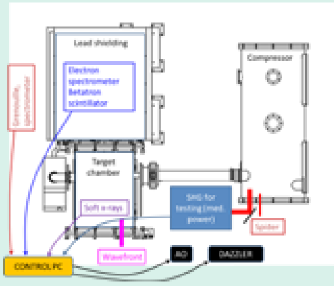

Figure 1: Layout for operating TA2 at high repetition rate. The gas jet is housed in an internal chamber directly connected to an Edwards iGX vacuum pump. Data from diagnostics are fed into a control code that can manipulate the pulse properties using the AO and Dazzler to improve experimental performance.

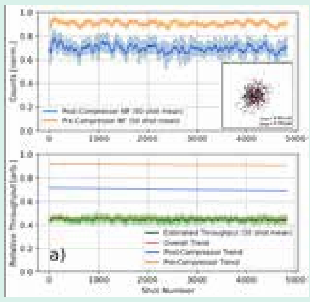

Figure 2: Pre- and post-compressor energy measurements and relative throughput for 4950 laser shots at 5 Hz. The inset shows the beam pointing variation relative to the 20 μm focal spot size.

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LIGA and its potential application to High Power Laser Science

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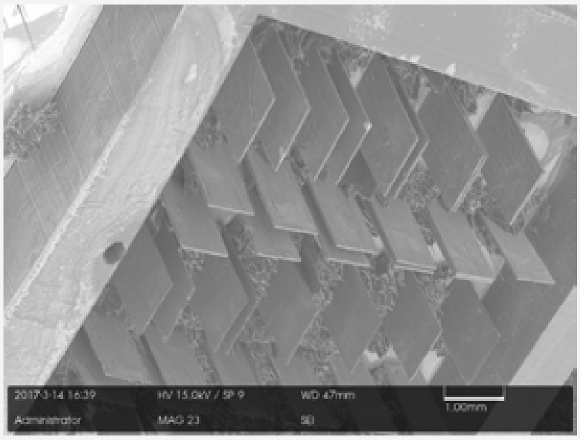
The **LIGA** - **Li**thographie, **G**alvanoformung, **A**bformung (Lithography, Electroplating, Moulding) - process is the ultimate lithographic technique for making high aspect-ratio microstructures. Synchrotron x-rays are used for exposure, and resist walls with the ultimate in wall straightness and smoothness are obtained. Exposures in resist with thicknesses >1 millimetre and aspect ratios up to 100:1 are possible. The structure is used as a mould for subsequent electroplating to form a metallic structure which can either be used 'as is', or as the master for mass production by injection moulding.

This paper describes some early-stage research and development carried out by Scitech Precision in collaboration with Diamond Light Source with the objective of producing high aspect-ratio pinholes in gold. Structures in PMMA resist, from an early exposure, are shown in the figure.



1.3mm thick PMMA after exposure and development

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Characterisation of the oxide effects on aluminium opacity targets

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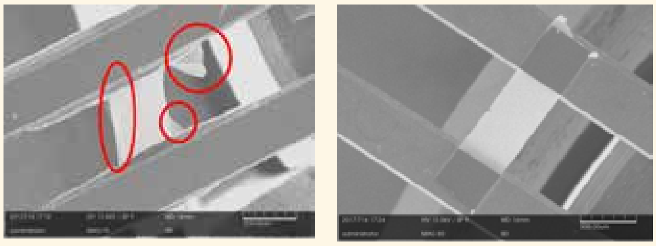
This paper presents the production and characterisation of an aluminium strip target made by Target Fabrication. Strips were required to be supported over an aperture held only at each end. To support the strip a plastic support layer was used which could be removed by oxygen plasma etching. This process was advantageous as it reliably batch-produced flat strips within specification. However there was contamination caused by the oxygen plasma which increased the relative abundance of oxygen rendering the targets unusable for the experiment. The contaminant was found to be made of carbon and some oxygen by Energy Dispersive X-ray Spectroscopy suggesting a chemical reaction between the oxygen plasma and the surface of the plastic.

In response a manual float-off method was used that was successful in producing the strips without contaminant.

Characterisation methods used included Scanning Electron Microscopy (SEM), Bright-field and Dark-field light microscopy and Interferometry.



Left: SEM Image of aluminium strip produced by removal of a plastic support layer. Areas of contaminant can be seen circled in red.
Right: SEM image of an aluminium strip produced by method of "float-off". No contaminant seen.

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LA4/Vulcan Pointing Mismatch Investigation

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The pointing of the Vulcan beam on target in Target Area Petawatt was found to be not accurate enough for some experiments, leading to questions in the alignment procedure. The shift in the pointing was due to the weight of the sliding mirror in the laser area, which delivers the beam into the target area (Figure 1). To resolve the problem, the sliding mirror was fixed directly onto the frame of the table, improving the pointing stability (Figure 2).

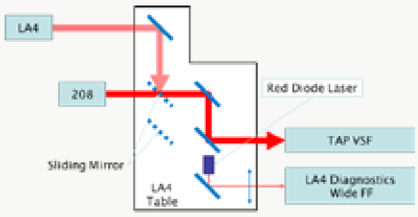

Figure 1 (top): LA4 table with the sliding mirror, showing the test setup using the red diode laser.

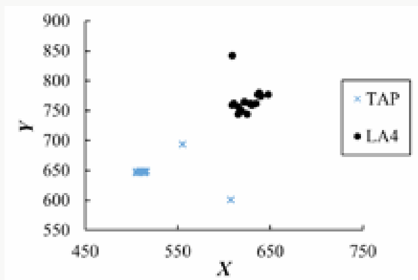

Figure 2 (bottom): Centroid data comparison between LA4 and TAP during the Lancaster experiment.

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Vulcan Laser Timing System Upgrade

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The Vulcan Laser Timing and Synchronization System is a large conglomerate of analogue and digital electronics that provides a range of repetitive signals and single-shot triggers and which, over several decades, has evolved to match the ever-growing complexity of experimental requirements. As a result of having a cascade of varied time delay generators, electronic gating devices, fan-out units and long electrical cable runs, ±250ps optical jitter could be observed between short-pulse (ps) and the electrically driven long-pulse (ns) oscillators, which was becoming a limiting factor for running certain user experiments or high-speed diagnostics such as streak cameras.

A commercial Master / Slave timing system has now been sourced from Greenfield Technology, and has had an initial installation and commissioning within the Vulcan Front-End, as shown in the figure. Recent tests with this system have demonstrated a dramatic reduction of the temporal jitter to around 25ps RMS. Consequently, other fibre-optically coupled Slave units are expected to be deployed around the Facility over the coming months.

Installation of the Greenfield Master Oscillator and Slave Unit in the Front-End Oscillator Room.

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Observation of harmonic conversion efficiency clamping for nanosecond pulses due to wavefront distortion in Nd: Glass amplifier systems

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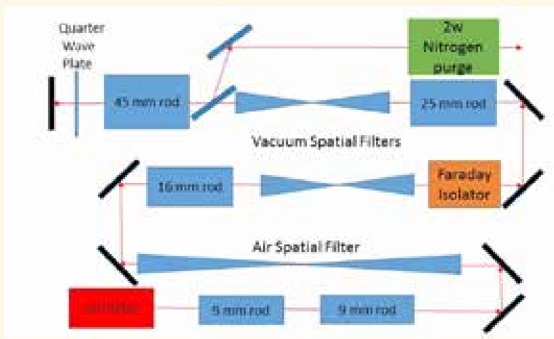
In this report we discuss our observation of second harmonic efficiency clamping from Nd:Glass amplifiers as we increase the crystal length. Initial measurements with 22 mm long KDP crystals demonstrate 50% conversion efficiency, and simulations for longer crystals predict this should increase to 90%. However, for longer crystals we do not observe this increase in efficiency and attribute this to on-shot aberrations that produce a curved wavefront and reduced conversion efficiency. We present simulations results based on our experimental observations to support this. These results have implications for the short-pulse OPCPA beamline being developed for Vulcan.



Schematic representation of the Component Test Lab with frequency doubling stage.

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Design and Implementation of a Test Compressor for the Vulcan Front End

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H. Owen, P. Oliveira, B. Parry, M. Galimberti, I.O. Musgrave *(Central Laser Facility, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)*

The Vulcan front end nanosecond OPCPA compressor was commissioned with the purpose of providing additional and improved diagnostic capabilities for the Vulcan Petawatt beamline. Practical constraints, such as available space and cost, dictated a quadruple passed folded design, aiming to provide an analogue of the single passed target area compressor.

Linear sonograms were used for the initial setup, enabling the linear and quadratic dispersion to be set approximately before fine tuning using a single-shot autocorrelator. The compressed pulses were measured to be less than 400 fs in duration using the autocorrelator. Despite showing indications of higher order dispersion, the compressed pulses are sufficently short to enable contrast measurements to be performed, allowing for pulse contrast from the front end to be routinely measured and optimised for user experiments.

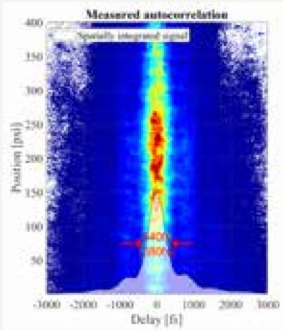

Figure 1: (left) Measured single-shot autocorrelation at the optimal grating separation indicating a 50% energy pulse width of 380 fs assuming a Gaussian intensity profile

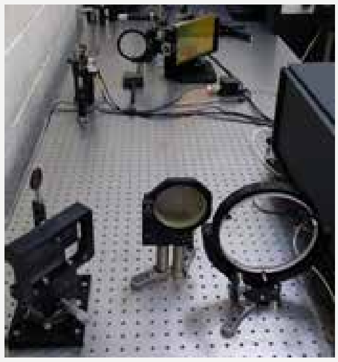

Figure 2: (right) Photograph of initial compressor setup. Beam enters from top right, G1 is located in the bottom-right, G2 top-left and RM1 bottom-left

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Characterization of Highly Chirped Ultrabroadband Optical Pulses

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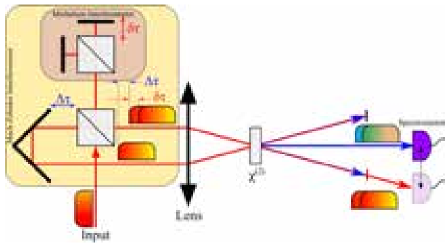
Highly chirped ultrabroadband pulses play an almost ubiquitous role in ultrafast laser science. An accurate means to quantify not only the linear, but also the nonlinear, dispersion of these highly chirped pulses enables optimal performance of the laser systems and improves the experimental capabilities of any applications that use them. In principle, FROG can reconstruct highly chirped pulses provided that a suitably long delay range is available. However, it was found that existing pulse retrieval methods do not converge for highly chirped pulses, and thus we developed an alternative algorithm based on the stationary phase approximation (SPA). Due to the limited delay range that can easily be achieved in a single-shot geometry, we then applied the SPA to a 'SPIDER-like' measurement and developed a new method that we call chirped heterodyne interferometry for measuring pulses (CHIMP) that in principle can enable single-shot characterization. Since SHG-FROG is already commonly utilized in many ultrafast laser labs, we believe existing users of the method can utilize this simple algorithm to robustly measure highly chirped pulses. By extending the SPA further to an interferometric geometry, we show that it is possible to extract the frequency dependent group delay dispersion (GDD) of the pulses using a direct (i.e. non-iterative) algorithm using our CHIMP method. We believe that the ability to rapidly measure, with single-shot capability, and reconstruct the nonlinear dispersion of highly chirped pulses will prove beneficial in the development of large-scale [OP]CPA laser systems, as well as finding uses in other applications that make use of them, such as dispersive Fourier transform spectroscopy.



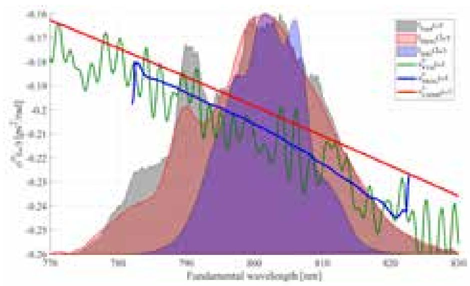


Figure 1: (above, top) Experimental FROG and CHIMP setups. An input chirped test pulse is split into two spatially separated beams using a Mach-Zehnder interferometer. In the upper arm, a Michelson interferometer is used to generate two time-delayed replicas. The two beams are focused and spatially overlapped in a $\chi^{(2)}$ nonlinear crystal whereby they frequency mix to generate the chirped signal pulses which are detected on a spectrometer.

Figure 2: (above, bottom) Measured and retrieved spectral intensity (shaded) and GDD (solid lines).

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