EPAC targetry developments for high repetition rate operations

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Introduction

To fully exploit the capabilities of EPAC, targetry technology needs to evolve to supply well-characterised targets at repetition rates of up to 10 Hz. For experiments that seek to study the fundamental physics of high-power laser-matter interactions and laser-driven particle acceleration, a significant number of data shots will be required to explore laser and target parameter spaces and to study (and overcome) shot-to-shot variations. Once the production of reproducible secondary sources become established, there will also be a critical need to produce large quantities of targets (at relatively low cost) to produce sufficient average power.

There are many areas of development that need to be progressed to address the many scientific challenges that EPAC will be capable of exploring, including rapid batch fabrication (sometimes in situ), accurate alignment, characterisation, and issues of survivability in such extreme environments. For Experimental Area 2 in particular, there will be a requirement to field multiple targetry systems to meet the wide range of user requirements. It should also be noted that for future pump-probe set-ups (once an additional beam is available), it is likely that many targetry systems will be required to operate in parallel, which may present additional challenges in terms of target survivability and limited available space around the interaction point.

Several research and development projects are currently underway to support targetry for EA1 and EA2, including several larger collaborative efforts with a number of international institutions, including:

- the recently established UK-India innovation centre, EPIC (Extreme Photonics Innovation Centre) at the Tata Institute of Fundamental Research (TIFR), India
- engagement with the IMPULSE project (ELI Pillars) to develop targetry solutions that are mutually beneficial to EPAC and these facilities. The licences awarded from STFC to Scitech Precision have enabled the commercial supply of a system to Queen's University Belfast as part of their ion acceleration beamline development project for ELI.

Tape drive and tape targetry for high repetition-rate operations

Over the past few years, the CLF has made significant progress in the build and testing of an ultra-stable tape delivery system for targets (see Figure 1), plasma mirrors, and for beam diversion and beam dumps. [1] Such a system can either run simple, uniform tapes of a single material, or more complex tapes with machined features and additional materials coated in single or multi-layer geometries. This could be used to shoot a range of solid targets for HED studies or, using proven but more complex target manufacture technologies, ion acceleration targets of sub-micron thickness. Additionally, the tape technology could be suitable as a high repetition rate plasma mirror to improve laser contrast in EA2 or to dump the laser post-interaction in EA1.

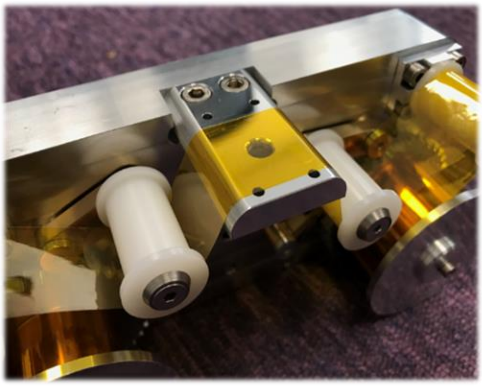

Figure 1: CLF-developed ultra-stable tape target system

A short period of access in the Gemini facility enabled the testing of a number of versions of these systems, with the specific aim of being able to divert the laser energy from the electron beam trajectory in an imaging experiment. Several geometries for the support of the tape were trialled with apertures and rollers being developed for specific requirements. EMP measurements were carried out to investigate the robustness of the system both on a shot and within the Gemini facility. This access provided the data to field a modified system for a commercial access run on Gemini, where a system was successfully fielded for the full experiment without issue.

Further work is now being carried out to develop strategies and test the delivery system for targets at higher repetition rates, with a system being tested at the University of Strathclyde on SCAPA at high repetition rate to test the survivability of the system to direct target shots and to evaluate the performance on a user experiment. Tests are also being carried out in TA1 to determine the pointing stability of reflected beams and to understand the potential limitations of the system as a plasma mirror. Alongside this, studies of the best tape material for each application are being carried out and will be implemented in subsequent experimental runs.

Tape targetry is being developed for future Gemini TA3 experiments through the CLF experimental programme, and this continues the work to provide a high repetition rate supply of complex targets for the drive. A parallel development is taking place in India through the EPIC collaboration to design and build a coating system with the specific aim of fabricating targets on a tape in sufficient lengths to run an EPAC experiment.

Tape provision is also being addressed through EPIC, and a supplier for a tape coating system has been identified. This industrial supply will build on the work carried out to understand the masking and coating techniques carried out in the collaboration.

Testing of the tape drive as a plasma mirror source for the initial operation of EPAC has been completed, with beam pointing variations measured. Promising results in terms of beam stability and divergence (x= +/- 1 mrad and y = +/- 2.5 mrad) have been observed that will allow Day 1 operation of the system with a tape drive.

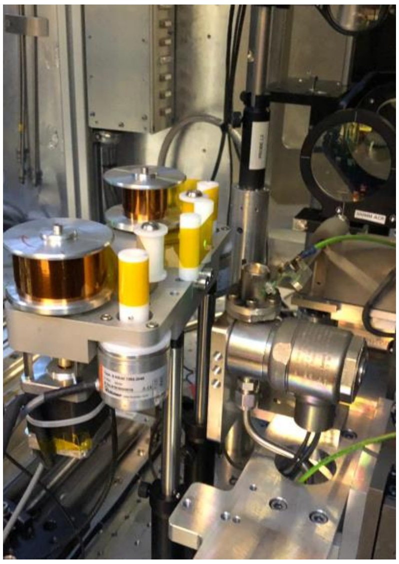

Figure 2: The tape drive in the TA3 chamber for the imaging run

Robotic assembly and array targets

Some complex targets are not possible to field on a tape system due to design features such as multi-layer stacks that will disrupt the tape travel. These targets can be fielded on an array-based system. Such an approach is common across facilities such as Gemini, XFEL, LCLS etc.; however, the limitation to shot numbers is the fabrication of the targets and the mounting onto the arrays.

Work is ongoing to design a robust set of stages that can cope with the large numbers of targets and fit in the experimental geometries. Together with developments in rapid manufacture and assembly this will permit the rapid shooting of hundreds of individual targets at a time. An upgrade to implement a target frame exchange system could see more targets loaded into the EA2 interaction chamber without the need to break vacuum.

It is possible to produce large numbers of targets via micro-electro-mechanical systems (MEMS) manufacturing techniques onto silicon wafers. The CLF's Target Fabrication Group already has experience of using a combination of lithography, coating and etching technologies to produce large numbers of targets in this way, and has commissioned a lithography laboratory to enable this process. Further commissioning of a dedicated will enables batch manufacture and allows standard processes and geometries to be used repeatedly at a relatively low cost per target.

Figure 3: The CLF Deep Reactive Ion etching system

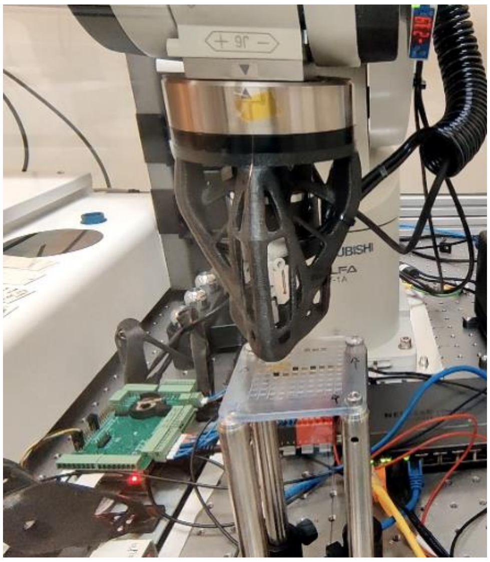

Figure 4: The robotic assembly set-up

In addition, R&D will continue on the CLF-developed High Accuracy Microtarget Supply (HAMS) [2] as an alternative approach to irradiating large numbers of complex targets (or sub-micron foils).

The HAMS system has already been designed and tested on Gemini to support MEMS targetry, allowing high accuracy target placement, although at modest repetition rates (0.1 Hz). This system is being integrated with an interferometric feedback system to provide positional accuracy and this work will be progressing over the coming period. Whilst there is potential for this system to also act as a plasma mirror system, with thin films suspended over small apertures able to be supplied in large number there are challenges to address in adapting such a system to operate at 10 Hz, including requirements for rapid target translation, accurate position monitoring, and supporting sufficient target numbers for larger data sets.

Liquid targets

In order to scale to higher repetition rates for extended periods of continuous operation, a number of liquid-based targetry systems are being considered for EPAC, both for use as targets and as plasma mirrors. Most of these liquid-based systems are capable of operating for extended periods of time and at high repetition rates, making them ideal candidates for operation in EA1 and EA2. However, significant R&D is required to evolve many of the systems already tested elsewhere, in order to achieve a high level of performance in terms of target quality and reproducibility.

There are a number of promising liquid-based targetry systems currently being commissioned and tested on HPL and XFEL facilities. These typically rely on colliding streams of liquids (and possibly gas) to produce thin sheet targets of thicknesses down to tens of nanometres. The CLF is undertaking collaborations with SLAC and Queen's University Belfast to develop a liquid target [3] that would be highly suited to high repetition rate operations. As part of this work, tests are underway to evaluate a number of methods of producing thin liquid sheets that could be suitable for both targetry and plasma mirror applications (Figure 5).

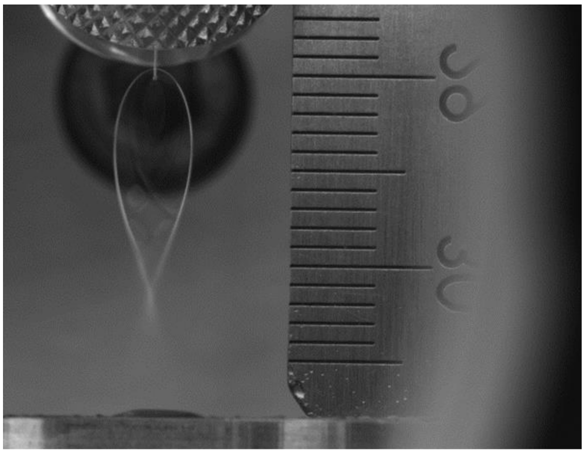

Figure 5: Testing of a high repetition-rate, thin liquid sheet target for EPAC EA2

A liquid target system developed by SLAC has been fielded on Gemini TA2 in a collaboration led by Queen's University Belfast. The system required a large amount of engineering effort to ensure that the catcher was suitable for purpose within the TA2 chamber, and this was successfully provided through the CLF programme. Our ambition to develop such a system for EPAC is progressing, with QUB and SLAC being key organisations with which we are looking to engage. The knowledge that has been gained by the CLF in catcher design, the SLAC knowledge in designing the system, and the world-class engineering that can be delivered in nozzle manufacture at STFC, will put us in a position to build and test a system that could successfully be fielded on EPAC.

Liquid Crystal Technology is also a promising medium to enable high repetition rate plasma mirror operation in EA2 [4]. A collaboration between the CLF and Ohio State University will focus on refinements of the technology to improve film formation, repetition rate and stability.

References

[1] W. Robins *et al*., Advances in Tape Target Technologies towards 1Hz Operation for EPAC and other High Repetition Rate Facilities, *CLF Annual Report 2021-2022*, p. xx

[2] N. Booth *et al*., High-rep rate target development for ultra-intense interaction science at the Central Laser Facility, Proc. SPIE 9211, Target Diagnostics Physics and Engineering for Inertial Confinement Fusion III, 921107 (2014) https://doi.org/10.1117/12.2061803 https://doi.org/10.1117/12.2061803

[3] J.D. Koralek, J.B. Kim, P. Brůža, *et al*. Generation and characterization of ultrathin free-flowing liquid sheets. *Nat Commun* **9**, 1353 (2018) https://doi.org/10.1038/s41467-018-03696-w

[4] P.L. Poole *et al.*, Liquid crystal films as on-demand, variable thickness (50–5000 nm) targets for intense lasers, *Physics of Plasmas* **21**, 063109 (2014) https://doi.org/10.1063/1.4885100