Progression of a tape-drive targetry solution for high rep-rate HPL experiments within the CLF

Contact *sam.astbury@stfc.ac.uk*

S. Astbury, C. Spindloe, M. Tolley
Target Fabrication Group, Central Laser Facility, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, Oxfordshire OX11 0QX

L. Harman, P. Sykes
Scitech Precision Ltd, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, Oxfordshire OX11 0QX

R. Sarasola, K. Rodgers
Electrical and control group, Central Laser Facility, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, Oxfordshire OX11 0QX

W. Robins
Precision Development Facility, RAL Space, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, Oxfordshire OX11 0QX

Introduction

With high repetition rate (HRR), high power lasers (>1 Hz, 1PW) coming to the fore for laser plasma physics experiments there is an ever increasing need for a target delivery method capable of realizing the potential of such systems. While shot rates in the kHz regime is not a particularly recent achievement, utilizing such shot rates typically employs a non-solid target material such as gas jets, or liquid droplets.

One of the solutions to the solid target supply limitation issue which the Target Fabrication Group have developed is a multi-axis, MEMS-based system, known as HAMS (High Accuracy Microtarget Supply), which employs a hexapod to drive a target to a very precise location with automated interferometric fed-back focal positioning.[1] The limitation of such a system however is that the total shots on a pumpdown cycle is ultimately limited by the size of the target wheel/segments and the spacing between adjacent targets. Target supply methods for next-generation driver facilities such as ELI and XFEL will require a delivery method capable of supplying tens of thousands of targets without pausing.

Over the last 18 months, the Target Fabrication Group have developed a novel target manufacturing method which comprises user-defined target materials, sizes and thicknesses on a polyimide tape substrate ideal for HRR applications. Complementing the development of the target technology, collaboration with the RAL Space Precision Development Facility has led to the development of an ultra-stable tape-drive system to deliver such targets to HPL experiments with minimal focal drift.

Motivation

Experimental delivery for the Mangles Gemini campaign in February 2018 warranted a large dataset to realize for the first time experimentally the Breit-Wheeler process by which the collision of two photons creates matter in the form of a positron-electron pair. The targets required for the experiment were 50 nm thick germanium dots mounted on a 5 µm polyimide substrate and over 1500 data shots were required for the campaign to ensure confidence in the results; fabrication of which would have been extremely difficult to achieve using conventional single-target delivery methods.

Existing tape-drive system

Due to the large quantity of targets required for a reliable dataset and that the beam was to be defocused to a ~450 µm spot, the ideal target/delivery medium for such an application was deemed to be a tape-drive system. Tape-drives are typically suitable for plasma mirrors due to the tape inherently drifting in the focal plane - tape drives used on Gemini in the past have had a z-accuracy in the region of 100 µm. Figure 1 shows the design of Gemini's previous tape drive system.

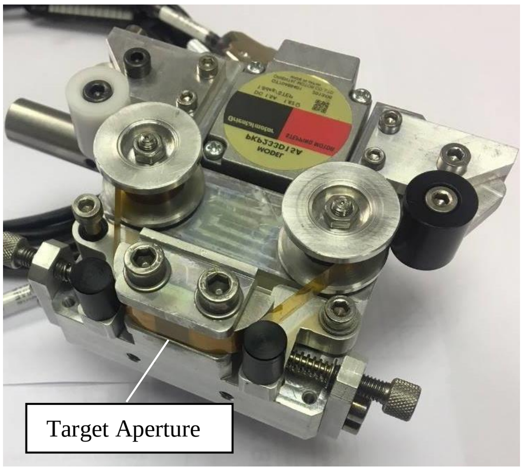

Figure 1: Gemini's existing tape drive system, designed in 2013

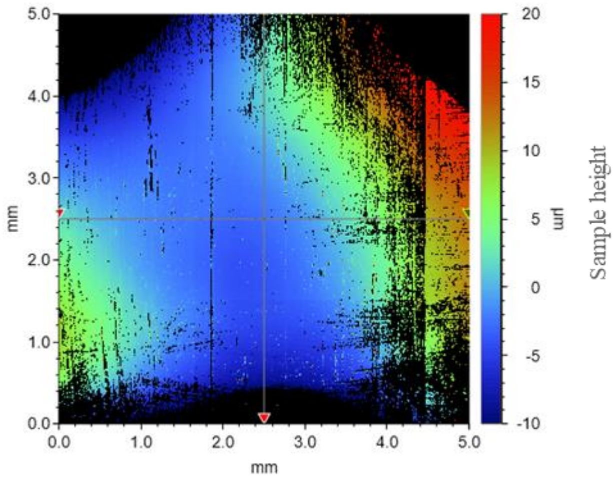

Figure 2: Topography of the tape aperture surface of the existing tape drive system using a white light interferometer

As evident in Figure 2, the form of the tape mounted on the existing Gemini tape drive system varies by more than 30 µm over a 5x5 mm area. The black areas of the scan are areas that were out of the scan range of the interferometer and so the actual peak-trough is > 30 µm. The Gemini TA3 laser typically runs with a f/2 aperture giving a Rayleigh range of ~10 µm. Thus using the existing tape drive as a target delivery method on setups using such parabolas would not be feasible, providing the necessity to create a more stable drive system along with developing a method of fabricating semi-complex solid targets on a tape substrate.

Target design

Fabrication of the proposed target design for the experiment required the use of several technologies at Target Fabrication's disposal. The requirement was a ⌀ = 750 µm, 50 nm thick germanium dot coated onto a 25 µm polyimide substrate, the area under which was to be etched back to a thickness of 5 µm. Targets were to be spaced 10 mm apart and assembled as a tape to allow for maximum shot rates. Fabrication of such targets required use of both excimer and 355 nm laser-machining systems, magnetron sputtering plants along with various optical characterisation techniques.

The targets were fabricated on large polyimide sheets and then diced using a 355 nm laser and assembled into precisely aligned strips using a compressed layer of epoxy and a 3D printed alignment jig.

Figure 3 below shows the final design of the tape target delivered for the experimental campaign mounted on a low stability tape drive system. The fabrication process for the targets are more comprehensively documented in *Development of patterned tape-drive targets for high rep-rate HPL experiments, S Astbury et al, CLF Annual Reports 2017-2018* [2]

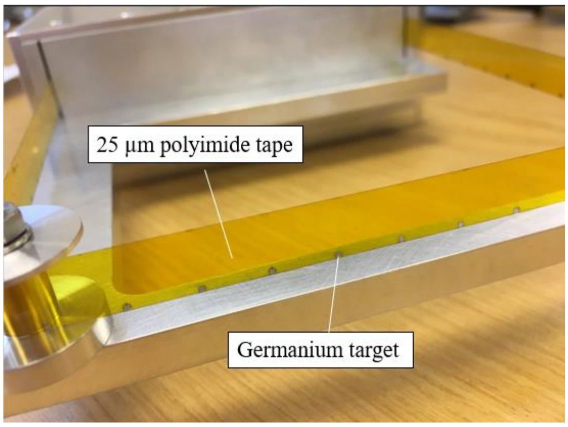

Figure 3: Germanium dot tape targets delivered for the GTA Mangles experiment in February, 2018

Improved tape drive design and characterisation

In order to maximize the potential of the target technology, development of an improved tape drive design was necessary. Target Fabrication have been collaborating with RAL Space Precision Development Facility as well as CLF Electrical and Control Group to manufacture the mechanical structure and control software with the aim of creating a highly-stable system capable of driving targets at > 1 Hz to within < ±10 µm in the laser axis.

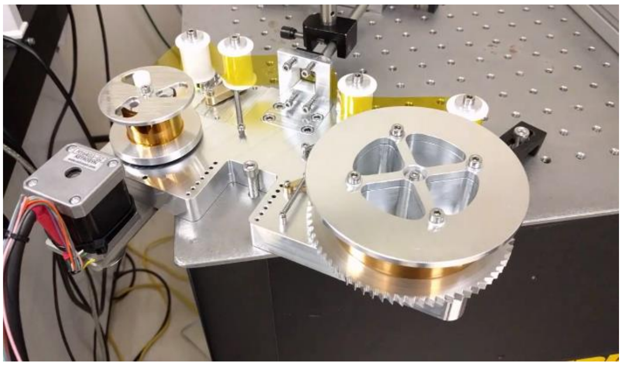

Figure 4: Design of new high-stability tape drive system

The system, as shown in Figure 4, is designed to hold 25.4 mm wide rolls of tape of various thicknesses and materials. During development this has this has been focused on 25 µm thick polyimide. A sprocket and spring-loaded roller system provides constant tension as the tape is spooled onto a take-up roll by a single motor and passes through a precision-machined and highly polished aperture plate (150 nm Ra) which minimizes friction and thus vibration in the laser axis.

The robot is controlled using a multi-axis driver and a touchscreen HMI allowing for adjustable driving velocity and programmable drive distance.

Characterisation

The form of the tape while stationary was characterized as before using white light interferometry to compare to the previous tape-drive over the same surface area. Figure 5 below shows the improvement in the tension and thus flatness of the tape over the target aperture which lies flat to within ± 3 µm.

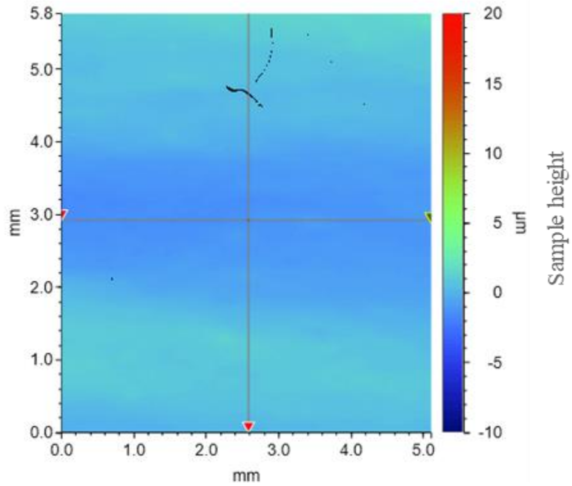

Figure 5: Topography of the tape surface while stationary on the new tape drive system using a white light interferometer

Figure 5 above shows the flatness of a stationary section of tape on the drive. This however is an ideal scenario due to there being minimum vibration acting on the system. A study into the displacement of the tape in the z-axis while driving was necessary to ascertain the ultimate performance of the system in a HRR application.

To monitor the stability in the focal axis, a chromatic confocal displacement sensor was set up and aligned to the surface of the tape. The sensor has a 1.5 mm working distance with a measurement resolution of 100 nm and is capable of sampling at a rate of 5 kHz. Due to its high sampling rate this is capable of detecting higher frequency instability sources which may be prevalent when driving the tape at 10 Hz repetition rate velocities (~100mm s^{-1}).

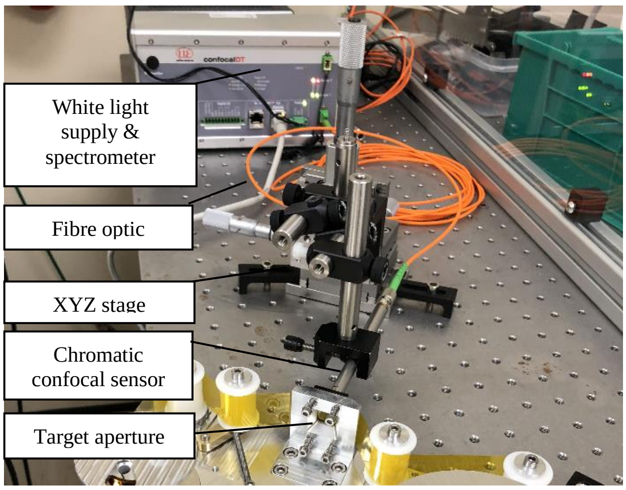

Figure 6: Chromatic confocal sensor setup on tape drive

The sensor was focused onto the surface of the tape over the centre of the 6x6 mm target aperture which was driving at a velocity of 15 mms^{-1}, suitable for 1.5 Hz laser repetition rate, over 150 mm.

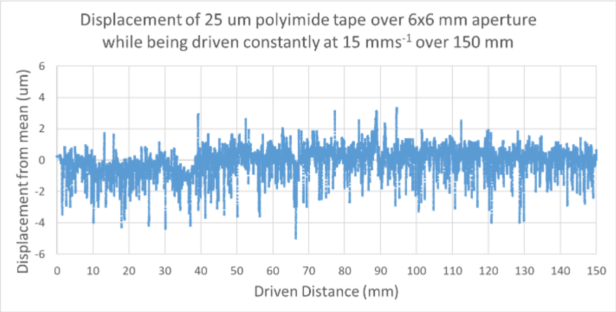

Figure 7: Displacement scan of tape driving at 15 mms^{-1} over 150 mm

As detailed in Figure 7, the positional stability of the tape while driving is very good, with a range of 8.3 µm and a standard deviation of 0.8 µm. Driving the tape in a stop-start manner showed less stability (±12 µm) due to the tensioning arms relaxing between cycles and so driving the tape continuously would be the modus operandi in a HRR environment.

Conclusions

In summary, the Target Fabrication Group have developed and improved upon a novel target production technology onto a tape substrate which has been successfully used in a 2018 Gemini experimental campaign for x-ray production.

Collaboration with the RAL Space Precision Development Facility along with CLF Electrical and Control and Mechanical Engineering Groups has led to the production of a high-stability tape drive system capable of operating within a ±5 µm window, which will allow for HPL operation at high repetition rates without the need for continuous refocusing.

Future work

Following on from the promising results of the stability of the tape drive and the success of the tape-targets in highly reproducible x-ray production, work is ongoing to further improve both technologies.

A tape drive system compatible for mounting directly inside a sputter coating plant has been designed and currently undergoing manufacture which will enable coating directly onto a roll of tape, foregoing the need to assemble individual strips of tape.

Research is also underway in etching back the tape substrate to leave a free-standing target foil for ion acceleration experiments as well as improving the masking method to allow for a significant increase in the number of target foils along the tape length.

The tape drive system is being modified to allow for dual direction drive and improved positional feedback and is to be tested for HPL operation over the next year, looking into debris studies, EMP resilience and stability between shots.

Acknowledgements

The authors would like to thank Wayne Robins from RAL Space Precision Development Facility as well as the CLF Electrical and Control, and Mechanical Engineering groups, as well as Brendan Kettle from Imperial College for initial testing of the tape-target technology on the Gemini laser.

References

[1] *"Target characterisation and pre-alignment for the HAMS high throughput targetry system"*, S Astbury *et al*, CLF Annual Reports 2015-16

[2] *"Development of patterned tape-drive targets for high rep-rate HPL experiments"*, S Astbury *et al*, CLF Annual Reports 2017-2018