High repetition rate microtarget delivery to the Astra Gemini laser

Contact christopher.spindloe@stfc.ac.uk

C. Spindloe, M. K. Tolley and E. Divall
Target Fabrication Group, Central Laser Facility,
STFC, Rutherford Appleton Laboratory, HSIC, Didcot,
Oxon, OX11 0QX, UK

G. Schaumann
Detector & Target Laboratory, Institute for Nuclear Physics,
Schlossgartenstr. 9, Technical University Darmstadt, Germany

W. Nazarov
University of St Andrews, School of Chemistry, Purdie
Building, North Haugh, St Andrews, Fife, KY16 9ST, UK

Background:
General strategies for high repetition rate microtarget production and placement

Over the next few years it seems certain that many high power laser systems which run at a high repetition rate are going to come on line. This will have significant impact on the future of HPL science and facilities. Immediate concerns might be for target production, diagnostic data analysis, debris mitigation and radiation production at rates between one and two orders of magnitude higher than currently. Clearly there are implications for many other aspects of facilities. Implications for how experiments are run might also be anticipated, for example, feedback into the shot schedule of experimental results.

This paper will mainly concentrate on the implications for microtarget production and placement at high repetition rates. In the several years run up to the LIBRA experiment on Gemini a range of microtarget technology responses to the foreseen demand were developed and the experiment was an ideal test bed for assessing their effectiveness. Some of the implications and early conclusions from the valuable lessons learnt will be given at the end of this paper.

Introduction

The LIBRA consortium experiment using the Astra Gemini Laser system at the Rutherford Appleton Laboratory was the first experiment that utilised the high repetition rate of the laser system to shoot a large number of high specification microtargets. Previous experiments using high rep rate laser systems have concentrated on shooting gas jet or solid slab targets that can be shot a large number of times, however, in such cases changing target parameters is restricted. To allow ranges of target parameters to be studied it was essential to be able to position and shoot a large number of targets without breaking vacuum, thus maximising the experimental time and using the full capability of the laser system. Delivering to this system meant moving into a new regime of target production with the target numbers required being one or two magnitudes higher than traditional complex target experiments on the Vulcan laser or other similar laser systems. To deliver microtargets for high repetition rates a number of new techniques were employed that enabled mass production of complex targets. Coupled with new target identification and mounting techniques an unprecedented number of complex targets were delivered within one experimental period.

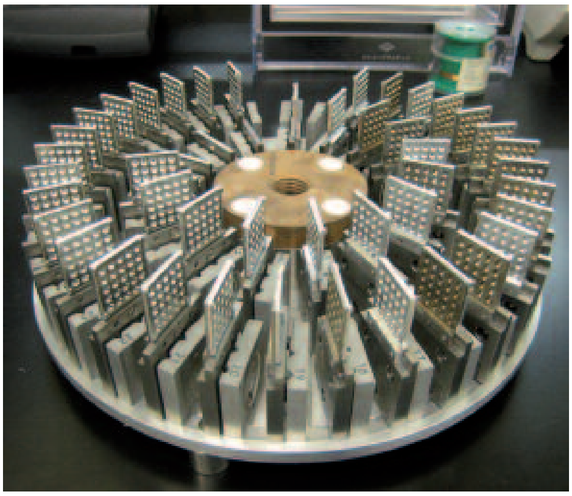

Figure 1a. Inserter carousel populated with 5×5 foil array.

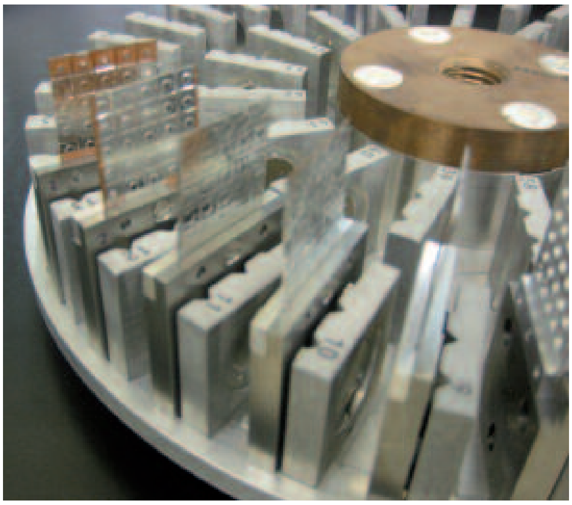

Figure 1b. Close up of populated inserter carousel.

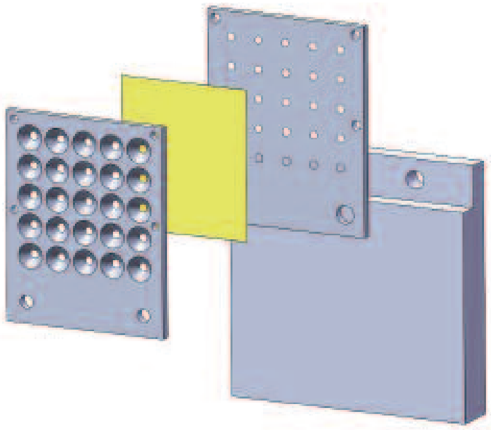

Figure 2. Carrier showing foil clamp plates.

LIBRA experiment target placement

The initial placement technique for the experiment was to use the custom designed target inserter that was supplied by General Atomics. In brief; the inserter uses a carousel to hold 50 target carriers and on top of each carrier microtargets are mounted either individually or in raster arrays. (See figures 1a and 1b.) The carriers are lifted one at a time by a gripper on an extending linear arm and delivered onto a holder on a hexapod located in the chamber ready to be shot. A used target carrier can then be returned to the carousel and replaced by an unshot one without breaking vacuum. The method of operation of the inserter is described more fully in a separate paper [1].

A volume of 20×20×6 mm is available on the top of each carrier in which target(s) can be mounted. In the case of the arrays holders these were designed to enable 25 foil targets to be mounted evenly spaced in a 5×5 grid within the permitted working volume (see figure 2).

During the later phases of the experiment a wheel target holder was used instead of the inserter. The 5×5 foil arrays could be clamped into a 8 or 10 position target wheel that was on a motorised alignment mount (see figure 3).

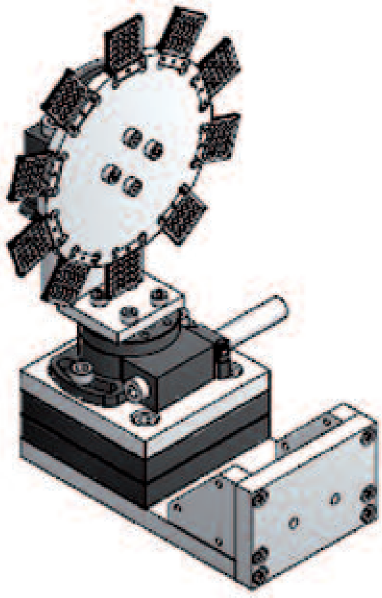

Figure 3. Wheel target holder populated with clamped 5×5 foil arrays.

1. Basic target arrays

Thick (1-100 μm) foils of a number of different materials, such as aluminium, gold, carbon and plastic (CH) can be mounted between clamp plates with relative ease within a standard array target as shown in figure 2. Such foils are purchased from stock and can be cut to size and clamped into place. Care needs to be taken to ensure the foil is flat but large numbers of relatively simple targets can be produced in a short period of time.

Variations on these standard foils were also introduced with coatings such as thin gold layers and thicker plastic layers on one or both sides fabricated with the use of thin film coating plants available in the laboratory. Such targets take longer to fabricate and cannot easily be replaced or the parameters varied in a short timescale.

2. Thin foil and ultra thin foil targets

The main target designs for the Libra experiment were thin and ultra thin foils with thicknesses from a maximum of 1 μm to a thinnest foil of 2.5 nm. The experiment required that the foils be as flat as possible with an almost mirror finish and there was a need for large numbers of these throughout the experiment in a variety of different materials. Previous experiments in Astra TA2 showed that the production of foils on a single holder could not keep up with even a medium rep rate system and that a new way of producing targets was required.

Developmental programmes in ultra thin foil mounting showed interesting results when a foil was floated onto a photo-etched shim mount; the grooves in the mount that were there as a result of the photo-etching production process acted as a mechanism to remove the water left behind under the thin foil after the standard floating off process. The grooves wicked away the water in the direction of the grooves and pulled the foil flat in that direction. The process, however, left the foil wrinkled perpendicular to the grooves. Further work showed that by introducing a raised area around the hole in the target mount a thin foil is tensioned evenly to leave a mirror finish. (As the water evaporates and wicks away from under the foil it pulls the foil flat around the circumference of the hole. This process leaves a foil that has a mirror finish and was significantly above the specification for the experiment (see figures 4 and 5).

This development work was included in the design of the target holders for the thin and ultra thin foils. The holder was again based on a 5×5 array within a 20×20 mm area. The holder was made from a photo-etched foil 50 μm thick and included a raised area around the holes that was an additional 50 μm high to produce the mirror finish foil. The mount also included other raised areas which acted as debris shields to stop damage to adjacent targets to the one being shot as a result of shrapnel coming off the target. The raised grid proved successful in mitigating debris damage to all adjacent targets with the exception of just the thinnest (10 and 4 nm targets) not surviving the laser shot. Because the mount was etched from one side the internal stresses imparted an inherent curvature and therefore the foil support was itself mounted to a thin stainless steel support to keep it flat and enable all the targets in the array to be shot with minimal realignment.

Employing such a mounting procedure then using thin films that were coated in the Target Fabrication Laboratory complete arrays of 25 targets could be produced down to 25 nm thick in aluminium, gold and plastic. Commercially produced 10n m carbon could be floated onto an array of 25 targets but the 2.5 nm commercially produced carbon was so fragile that it could only be floated over one or two of the holes before the foil disintegrated. Diamond like carbon (DLC) could be produced at 10 nm and 4 nm and floated over the array with about a 50% success rate.

3. Thin foam targets

Foam targets have traditionally been produced by methods amenable for single shot experiments. Production and placement techniques had to be modified to be suitable for the high number requirements of the LIBRA experiment. Generally, due to the dielectric nature of the (low density) foam materials, the formed foam can become electrostatically charged and consequently free-standing foam microtargets are difficult to produce and mount on a suitable target holder or positioner. Lower density foams (below 10 mg/cc) are more successful when they are shot while still supported in a tube or washer (to maintain their structural integrity). Free standing foam microtargets can be produced from sizes of about 1×1×1 mm down to about 100×100×100 μm.

To enable foams to be viable high rep rate laser targets and to meet the requirements of the LIBRA experiment of having the thinnest foams possible a new target design was required. The design also needed to enable low density foams to be produced quickly and easily with a good structural integrity that would survive multiple shots on targets on the same mount. Initial tests used 25 μm thick photo-etched mounts in the standard design with a 5×5 array. A stainless steel support was used to hold the mount flat and then an aluminium foil of 1.5 μm thickness was placed on the rear of the mount. This was then used as a multi-pocket former and a variety of densities of foams from 1-20 mg/cc were produced in the holes. The foams were made by filling one hole in the array at a time. A multi-fill process would reduce the production time but this has to be developed further. The foam targets had a yield of about 50% and most of the failures were due to the thin foil on the rear of the target not being sufficiently flat; the foam came away from this backing during the drying process (and in some cases fell out of the hole).

A second attempt used a mount that was the same design as for ultra thin foil targets. The foil on the rear was changed to a 50 nm thick aluminium foil and due to the mount design it could be applied with a mirror finish. The thickness of the mount was 100 μm (because the mount and raised area were both 50 μm thick). The foil-backed holes were again filled with a variety of densities of foam from 1-20 mg/cc and the yield was much higher (in the order of 80%). The foam filling of the pockets was a delicate process, specifically any contact with the 50 nm rear foil destroyed it. Also, in some cases, the surface tension of the foam precursor during the filling process ruptured the rear foil. Viable foam targets were shot and there was a good survival rate of adjacent targets after a laser shot.

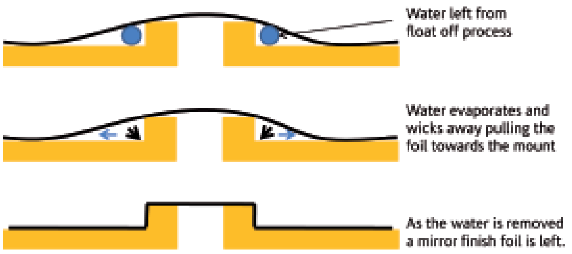

Figure 4. Cartoon of ultra thin foil tensioning process.

4. Aerogels

For the LIBRA experiment aerogel targets were mounted as single targets. Blocks of aerogel of approximately 1 mm volume were mounted onto glass fibres. There could be up to five aerogel targets mounted on a target carrier. Although time consuming it can be seen from the development work carried out with foams that arrays of aerogel targets could potentially be fabricated in a range of different densities.

5. Limited mass targets

There are two types of limited mass targets that were specified for the experiment. Simple limited mass targets of 100×100 μm or larger can be cut by hand using a scalpel and mounted onto a thin 7 μm carbon fibre using traditional micro-assembly techniques. This process is time consuming and requires significant skill at micro-assembly. For this reason the numbers of targets that are produced in this way are limited to about 20. Some limited mass targets can be produced using through mask coating techniques and this can produce sizes from 100 μm to 20 μm square in large numbers. But, there is still a need to assemble these onto a mounting fibre and so the limit on the target numbers is still a factor. These targets can be mounted in batches of up to 5 on a target mount with enough separation between them so that they survive the adjacent target being shot.

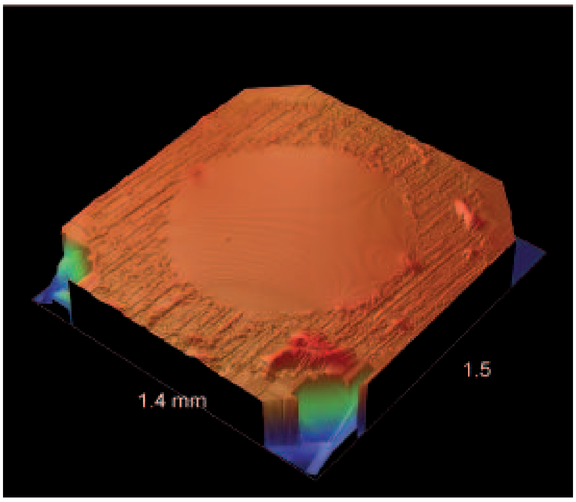

Figure 5. White light interferogram showing high flatness ultra thin foil.

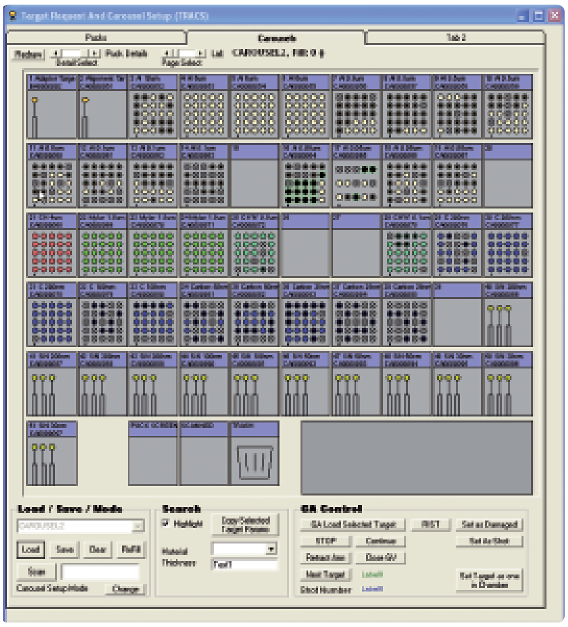

Figure 6. Carousel data displayed on TRACS.

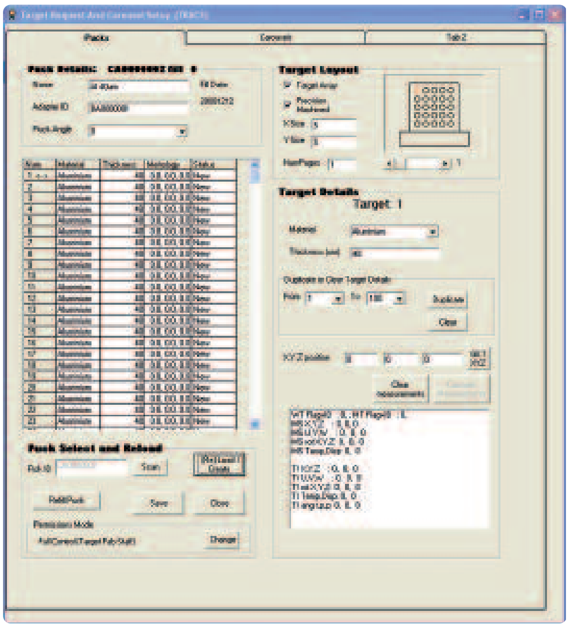

Figure 7. Carrier data displayed on TRACS.

A mass production technique for mass limited targets is to use MEMS based technology to produce small silicon chips with thin disk membrane targets on them supported by ultra thin arms. This technology was trialled to produce targets for the January 2006 TAP experiment. To increase yield the front pattern mask that was initially e-beam written was pattered using standard lithography techniques. This enabled production time to be shortened. These small chips can be mounted 3 next to each other on the target mount to enable the maximum number of shots to be achieved. This technology enables mass production of quite complex 2D targets, but laser shock damage is always an issue and tests are required to determine if adjacent targets survive the laser shot.

Target identification

With large numbers of different target types including material, thickness and geometry variations and with the inherent difficulty in distinguishing between similar target types after the fabrication process and inside the chamber there was a need for a reliable tracking system to describe the target characteristics. Target information needed to be traced from the fabrication process through the mounting, characterising, positioning in the chamber and shooting process to ensure that the data collected was reliable and correct. The target numbering system that was to be used for the automated target inserter and the carousel based target holding system was utilised and a database was created – Target Request and Carousel Setup (TRACS) – to allow the Target Fabrication group to store all the material property information about the target and also to allow the experimental group to pick certain targets from an array and to then be able to mark targets that had been shot. The TRACS system used the numbering from the GA target inserter where an individual target mount was labelled with an alphanumeric character (e.g. CA0000001) and then the individual target positions being number 1-25 for an array target. The system also has the ability to define anything from single targets on a mount through to multiple arrays of targets on a mount in varying array geometries as used for the Silicon Nitride targets. All target mounts were laser etched with a 2D barcode and an alphanumeric character that could be read by a barcode scanner enabling quick access to the target data for all the mounts.

Targets provided for the Astra Gemini Libra experiment

For the experiment in April 2009 almost 3000 targets were available for shots. These were accommodated onto 3 separate carousels that held a total of 140 bar-coded target carriers. Of these 140 carriers, the breakdown of these is as follows

Target type	Carriers	Targets
Basic target arrays	60	1500
Thin foil mounts 500nm and below	21	525
Ultra thin foil mounts 50nm and below	26	650
Foam array targets	3	75
Layered thick coatings	4	100
Complex wire arrays	4	20
Complex 3D assemblies	14	81
SIN chip targets	5	24
Alignment targets	3	3
	140	**2978**

Table 1. Breakdown of target numbers for Libra Experiment.

Conclusions

Initial steps towards production for high rep rate laser systems have shown that target fabrication numbers can be increased by a factor of 100 with the implementation of a number of relatively simple target engineering solutions. However, to fully utilize the laser systems that will become available in the next few years a more robust insertion system that can carry more targets than a simple target wheel needs to be installed. Work needs to be carried out to look into target survivability as the ultra thin foil targets did show signs of nearest neighbor damage. For more complicated foam, aerogel and 3D targets more work is required to be able to 'mass produce' the required geometries and although initial work has looked promising there are still a large number of technical issues to be solved before target numbers in the order of 1000's can be delivered with regularity.

The Astra Gemini Libra run also highlighted the need for accurate target tracking of characteristics and metrology data and highlighted the large amount of target specific data that is collected during such a target delivery campaign.

References

1. 'Commissioning of the Astra Gemini target inserter', J. Green.