Production of embedded metallic microdots for study of fast electron collimation in high power laser experiments

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Abstract

Targets consisting of a central titanium microdot embedded in a plastic disc were requested & delivered to a TAP experiment initially in August 2007 and then again in January 2008 to study the magnetic collimation of fast electrons. A method is under development to produce similar targets consisting of an iron microdot embedded in an aluminium disc for further studies of fast electron collimation.

Introduction

In a recent paper [1] it was proposed that when irradiated by an ultra-intense laser a target consisting of a cylindrical microdot embedded in a disc of material of lower resistivity would result in a magnetic field that would serve to collimate the fast electrons produced in the laser-target interaction along the length of the microdot. The fast electron density profiles produced from simulation of the laser interaction with an aluminium foil target compared with an aluminium dot embedded in lithium are shown in figure 1.

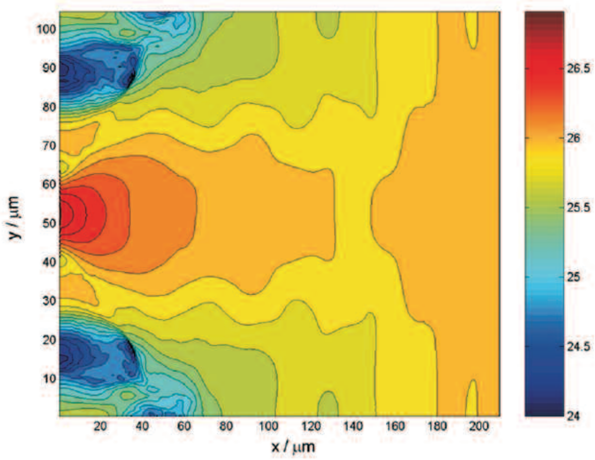

Figure 1(a). Fast electron density profile at 1 ps from simulation of ultra-intense laser interaction with aluminium.

It can be seen in figure 1 that the fast electrons are collimated parallel to the x-axis in the simulation of the interaction with the aluminium microdot embedded in

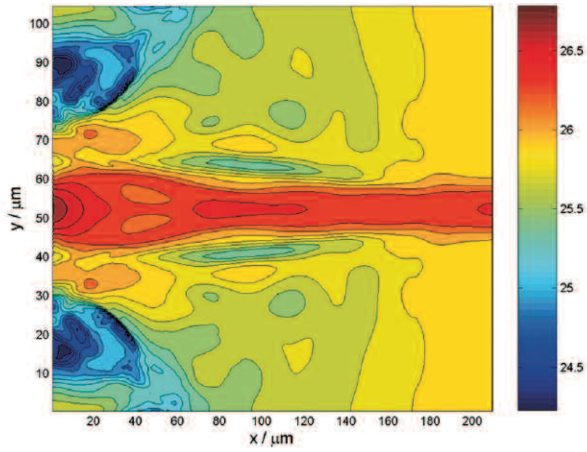

Figure 1(b). Fast electron density profile at 1 ps from simulation under same laser conditions as in 1(a) for aluminium dot embedded in lithium.

lithium whereas the fast electrons produces in the interaction with the aluminium foil target are not.

In Target Fabrication, an existing technique for the production of 10-20 µm thick microdot disc targets was adapted to produce 100 µm and 200 µm thick disc targets consisting of titanium microdots embedded in plastic. These were delivered for an experiment on Vulcan in January 2008. A technique for the production of iron microdots embedded in aluminium is under development for a future experiment on Vulcan.

Production technique

A. Plastic/titanium targets

A mould was machined consisting of a plastic tube with an internal diameter of 2 mm with a removable cap on each end. A 0.5 mm diameter hole was drilled through each cap and a 75 µm diameter pinhole was glued over each hole enabling a 50 µm diameter titanium wire to be threaded through the pinholes, stretched along the centre of the plastic tube and then glued in place at each end.

The titanium wire was subsequently embedded by filling the tube around the wire with two component epoxy. To ensure that the epoxy fully encapsulated the wire and flowed along the full length of the tube it was necessary to mix it on a hot plate to reduce its viscosity. A syringe was used to insert the epoxy into the tube and this also had to be heated in a water bath to keep the epoxy sufficiently liquid for it to flow into the tube. The epoxy was left to cure for 2 days.

Next, the mould was turned away on a lathe to leave a rod consisting of the 50 µm wire embedded in a 2 mm cylinder of epoxy, as shown in figure 2.

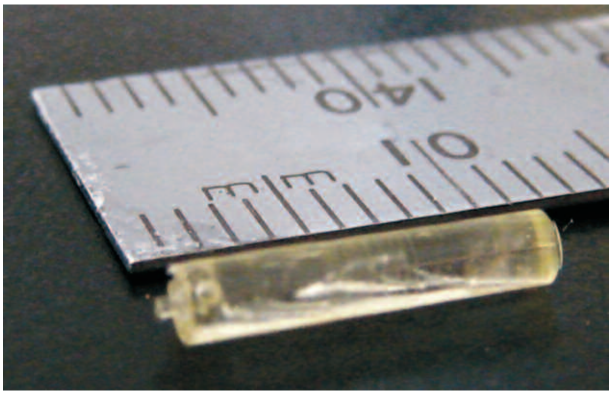

Figure 2. 50 µm diameter titanium wire embedded in epoxy.

The 2 mm diameter rod was then sectioned by the Precision Development Facility (Space Science Department) using an ultra precise dicing saw to 100 µm and 200 µm thick discs producing numerous microdot targets consisting of 50 µm diameter titanium microdots embedded in epoxy. The finished target is shown in figure 3. Some surface features can be seen due to air pockets that were present in the epoxy. However, these were small scale and did not affect the experimental results.

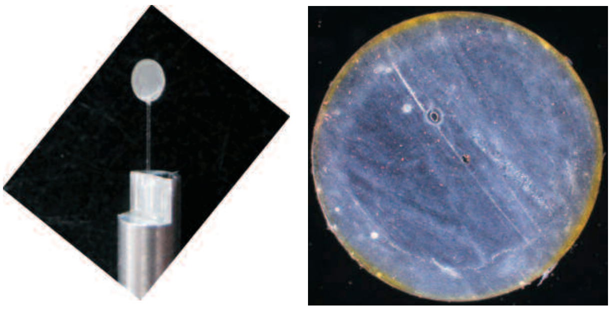

Figure 3. 50 µm embedded titanium dot mounted on target post and imaged using high resolution microscope using dark field illumination.

B. Aluminium/iron targets

Initial trails for the production of iron microdots embedded in aluminium have been carried out using a method similar to that described in section A. Producing the aluminium surround using this method requires the use of a vacuum oven to melt aluminium without it oxidising. A mould similar to that in section A was machined out of stainless steel and packed with aluminium powder with a grain size of ~500 µm. This was processed by the Special Techniques Group at the Culham Science Centre which involved heating the mould in a suitable vacuum oven to 600°C. The steel mould was subsequently turned down to reveal an aluminium cylinder 2 mm in diameter and this was successfully diced using precision machining to 100 µm, 250 µm and 500 µm thick discs by the Precision Development Facility. One of the resulting discs is shown in figure 4.

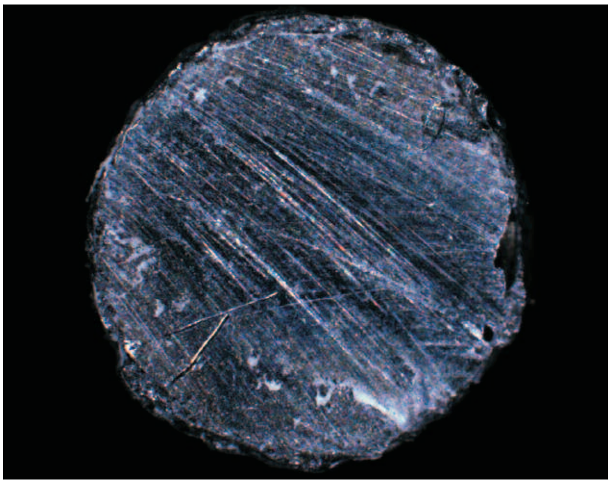

Figure 4. Dark field image of 2 mm diameter aluminium cylinder sectioned into 250 µm thick disc.

Following the successful production of the aluminium discs, work is ongoing to repeat this process with a 125 µm diameter iron wire threaded along the centre of the mould in order to produce the aluminium embedded iron microdots as required. However, in the meantime, an alternative method is being used which can be completed in house at RAL and delivered within the necessary timescale required for the upcoming experiment.

The method is to clamp a length of iron wire between two blocks that have been machined out of high purity aluminium and then screwed together, as shown in figure 5.

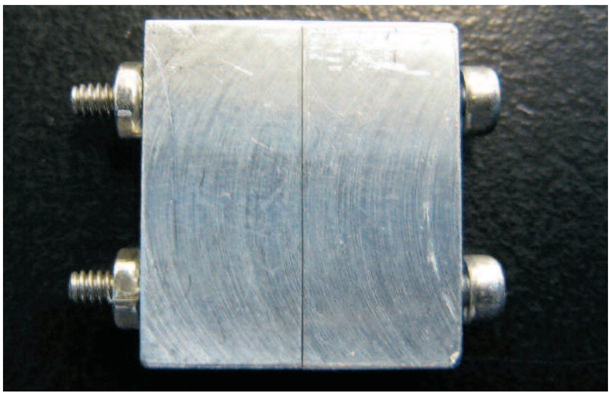

Figure 5. Aluminium block used to clamp iron wire.

Because the aluminium is very soft compared to the iron when the screws are tightened the aluminium deforms and bends around the wire. Figure 6 (a) shows a 50 µm diameter iron wire after it has been clamped between the two aluminium blocks. The deformation of the aluminium around the wire and the join between the two blocks can clearly be seen.

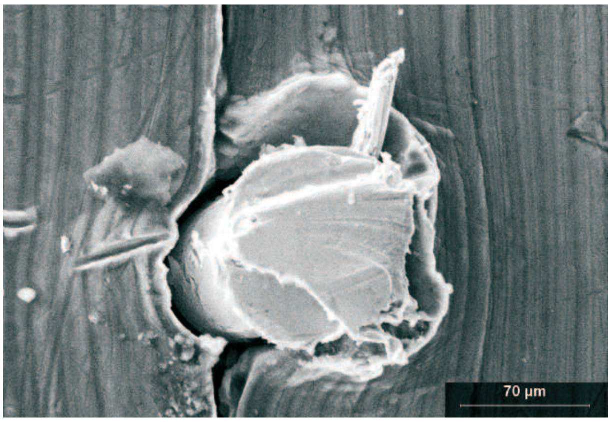

Figure 6(a). SEM (Secondary electron) image of 50 µm diameter iron wire embedded between two aluminium blocks.

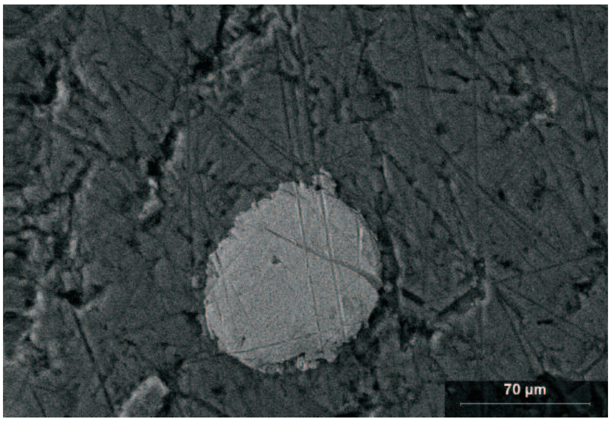

Figure 6(b). SEM (Backscattered electron) image of 50 µm diameter iron wire embedded between two aluminium blocks after lapping.

The aluminium block is then lapped down on both sides to improve quality of the aluminium/iron interface. The lapping of the target allows the top layers of the aluminium to be removed and exposes an area where there is contact between the iron and the aluminium. Figure 6 (b) shows the same 50 µm target as in figure 6 (a) after the surface has been lapped showing that as a result of the lapping process the join between the two blocks is no longer visible.

Conclusions

Embedded microdot targets are becoming of more interest to the High Power Laser community as a potential way of collimating the fast electrons that are produced in laser-matter interactions. Work is ongoing to model the optimum conditions that are required for the maximum energy transport and this has implications for Inertial Confinement Fusion (ICF) and especially for fast ignition.

The Target Fabrication Laboratory at RAL has produced and characterised a wide range of these targets and is working towards methods of optimising the target design and production with a wide variety of materials to allow further experiments to be carried out to inform future modelling.

We would like to acknowledge the work of the CLF Mechanical Workshop for the design and manufacture of the moulds.

References

1. A. P. L. Robinson and M. Sherlock, *'Magnetic collimation of fast elections produced by ultraintense laser irradiation by structuring the target composition'*, *Phys. Plasmas*, **14**, 083105 (2007).