Novel micro-cone target geometries produced for experiments on the Vulcan Petawatt laser

Contact christopher.spindloe@stfc.ac.uk

C. Spindloe
Central Laser Facility, STFC, Rutherford Appleton Laboratory, HSIC, Didcot, Oxon OX11 0QX, UK

P. Hiscock and M. Beardsley
Precision Development Facility, SSTD, STFC, Rutherford Appleton Laboratory, HSIC, Didcot, Oxon OX11 0QX, UK

Introduction

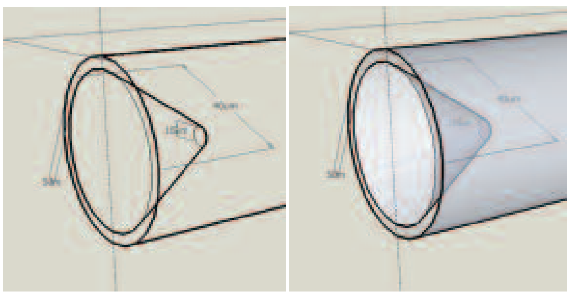
As part of the ongoing research into the Advanced Fast Ignition (AFI) approach to inertial confinement fusion a number of micro-cone targets have been produced at the Rutherford Appleton Laboratory in the last year to study the fast electron transport in targets. Previous AFI cone geometries have been fabricated [1] and these were sized at approximately 1mm long. A new type of target was proposed that included a design of cone that is considerably smaller and has dimensions of the order of 100 µm in height. As these were developmental targets they were made in low numbers and machining work was carried out by the Precision Development Facility using precision tooling and machining techniques.

The targets were for an experiment in the TAP experimental area and were to be diagnosed using a Ti K-α imager. Therefore the targets had to have a composition that included titanium for imaging purposes. Two specific geometries were created and the target designs are shown below.

Production

1. Cone machined into a thin wire.

The first design was a small micro-cone that was machined into the end of a thin wire 125 µm in diameter; this is larger than the initial specification in figures 1 and 2 to enable the target to be shot by the laser with higher confidence of focusing into the tip of the cone. Drilling the cone into the end of the wire means that any glue or material interface problems are removed and the wire geometry enables investigation of the electron transport along the wire.



Figures 1 & 2. The cone geometry required in wire and X-ray diagrams.

The design of this target was such that the cone could be machined directly into the end of the titanium wire. To do this a precision tool was ground that had the required side angle to fabricate the cone. The wire was then mounted and held in such a way that the tool could cut out the internal profile of the cone.

2. Micro-cone on a target foil.

The second geometry required was a cone mounted onto a thin two layered foil stack. The smallest diameter (20 µm) of the cone was at the foil packet and was comparable to the diameter of the end of a standard AFI cone tip. This target was then used freestanding, or embedded in a low Z medium to experimentally investigate changes to electron collimation. The aim of the target was to investigate the electron transport from the micro-cone into the foil packet and the effect that embedding the cone in a lower Z material would have on the electron collimation. Due to the novel design and the degree of difficulty in making such geometries the target was initially turned out of a copper foil due to its preferential machining properties. This was again done using a bespoke ground tool and a lathe. A number of step diameters were cut down into the foil and a central wire of 50 µm diameter was left. This wire was then profiled at the point where it joined the foil to leave the desired cone shape of a 50 µm top diameter

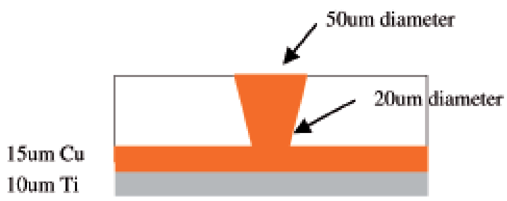


Figure 3. The embedded target design.

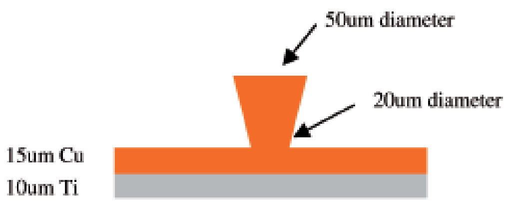


Figure 4. The plain target.

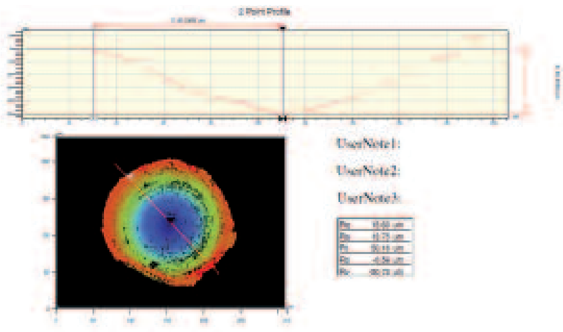


Figure 5. White light interferometric line measurement across the 2D cone profile.

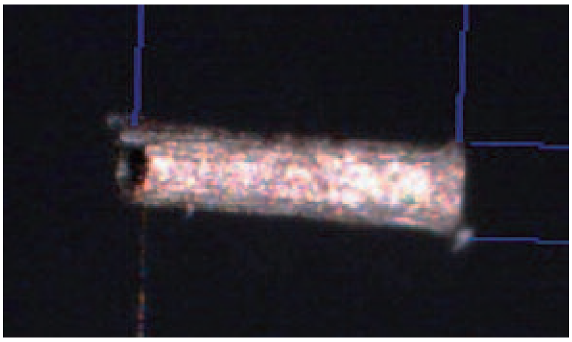


Figure 6. An optical image showing the end (right hand side) machined out to a larger diameter than that of the initial wire.

and a 20 µm diameter in contact with the foil. The machined targets were then processed in two different ways to investigate electron transport. One target was fully embedded in a plastic around the edges of the cone and was then re-machined to expose the top surface. The other target was left bare. Both targets were then coated on the reverse with 10 µm Ti that was deposited using an e-beam evaporator. Targets were fielded on the Vulcan Petawatt laser in February 2008.

Characterisation results

1. Cone machined into a wire

The cone drilled into the wire was characterised by a number of techniques to ensure that accurate measurements were taken and that any distortions due to the individual metrology processes could be accounted for. The target depth for the cone was initially 50 µm in a 40 µm diameter wire giving a half-angle of approximately 40 degrees. For a wire that was 125 µm diameter then assuming the cone was open to the full wire diameter then the half angle of the cone would be approximately 51 degrees.

The first measurements taken with a white light interferometer in figure 5 show a well defined cone of depth between 48-50 µm but with an open end diameter of about 160 µm. This gives an angle of 58 degrees. This larger open end of the cone is actually larger than the initial diameter of the wire but, this is due to the fact that the edges of the cone have been pushed out as part of the machining process. This can be seen in the optical image in figure 6.

A Confocal microscope scan of the wire shows similar results with a full angle of 116 degrees which is comparable to the 116 degrees full angle given by the interferometric measurement.

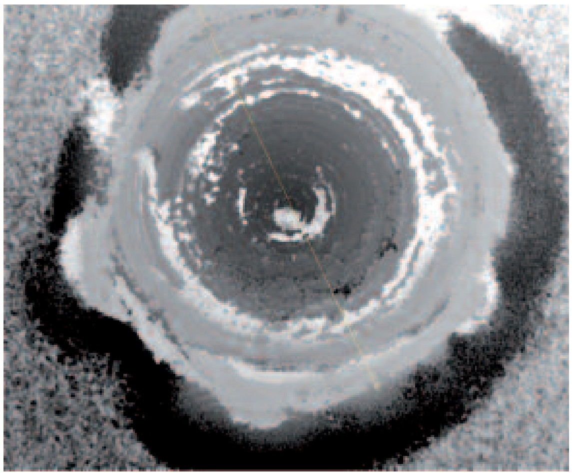


Figure 7. The Confocal measurement.

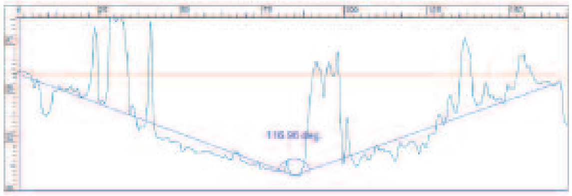
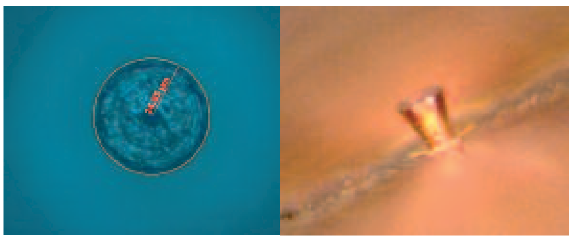


Figure 8. The line out across figure 8.

2. Micro-cone on a target foil

The micro-cone was characterised using optical techniques to give an indication of the profile of the cone and also to measure the diameter of the largest end of the cone. Measurements in figure 9 indicated that the diameter at the top was 50 µm and the image in figure 10 show the profile of the cone. When the cone was embedded in a glue layer backscattered SEM analysis (with a negative detector bias showing high Z elements as dark areas) showed how the top of the cone behaved in relation to the embedding material (which in this case was a two part epoxy mix). It can be seen in figure 11 that there is an area around the cone where the epoxy seems at a lower height than the surrounding areas but this is misleading as in this area the glue is not lower than the cone tip. Although there is a small lip from the epoxy to the cone of about 5 µm the dark area in the epoxy can be attributed to local conduction effects of the cone allowing the glue to discharge locally in the vicinity of the copper cone.

Further work was carried out to produce cones made of iron. These cones were 50 µm diameter at the base in contact with the foil and 100 µm diameter at the top. A range of targets were produced of which the cone lengths were 250 and 350 µm. SEM characterisation results using backscattered electrons as seen in figure 12 showed interesting contamination of the targets and machining lines along the length of the cone.



Figures 9 and 10. Optical images of the cone profile and top size.

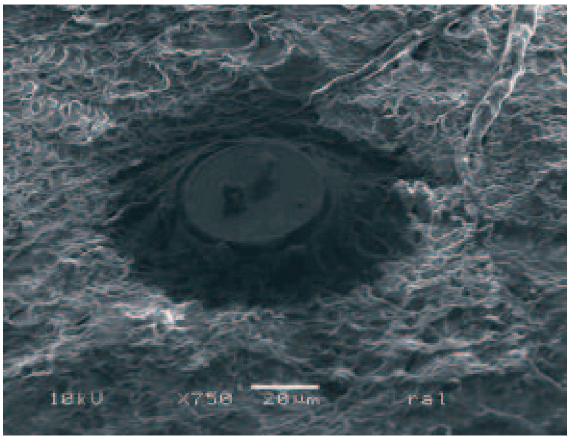


Figure 11. SEM image of the embedded cone.

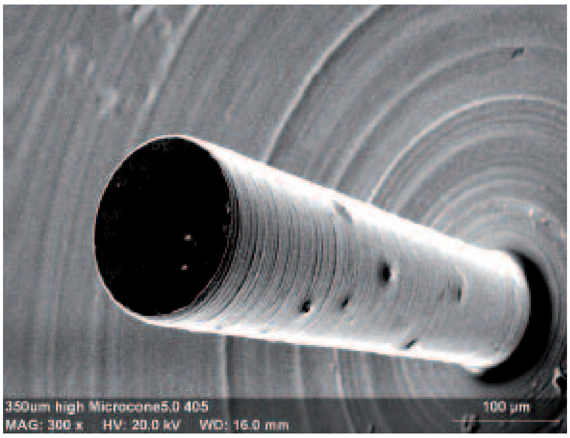


Figure 12. A backscattered SEM image of the 350 μm high cone.

Conclusions
Cone structures can be fabricated not only in the 1mm scale lengths but also in the 100 μm scale. However these geometries and sizes have significant challenges associated with them, with material properties becoming increasingly important at these sizes. Mass production of such targets would require a large amount of R&D effort to enable them to be produced and used on high rep rate systems such as Astra Gemini.

References
1. M. Beardsley, J. Spencer, M. K. Tolley and C.Spindloe, *'Devoloping and Manufacturing Cone Targets for the CLF'*. CLF Annual Report 2004-2005.