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Design and production of carbon microtargets for X-ray Thomson scattering on laser-accelerated proton heated warm dense matter

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Introduction

The aim of this experiment was to demonstrate X-ray Thomson Scattering from warm, dense, isochorically heated matter. An intense, ultrashort proton beam, generated by a high-intensity short-pulse laser pulse via Target Normal Sheath Acceleration was used to heat a carbon sample to a temperature of a few thousand Kelvin. A second short pulse laser was then used to generate a short-lived (several 10 ps) bright source of 4.75 keV Ti He-alpha radiation for X-ray scattering. A variable target geometry allowed the probing of the carbon sample in different depths relative to the front surface towards the proton beam.

Initial target design

The target design for this experiment was extremely complicated to allow the incorporation of a number of shielding features and pinhole collimators. The initial target design is shown in Figure 1.

The proton production foil was to be placed within a gold shielding cone of 1 mm diameter that is very similar to an AFI cone. A carbon rod of diameter 100 µm was to be placed in the tip of the cone so that the distance from the proton foil to the rod was 300 µm. The distance was chosen to ensure that the emergent proton beam would fully irradiate the whole of the diameter of the carbon rod. The carbon rod was to be probed by radiation (Ti He-alpha) from a secondary backlighter foil that had passed through a pinhole to limit the source size. The backlighter foil was mounted from the side of the gold cone to ensure the distance was consistent. A small region on the rod 10-20 µm wide was to be probed. The rest of the rod was gold coated to shield it from the backlighting. The uncoated region could then be adjusted and moved in the coating/assembly process to enable probing of different areas of the rod.

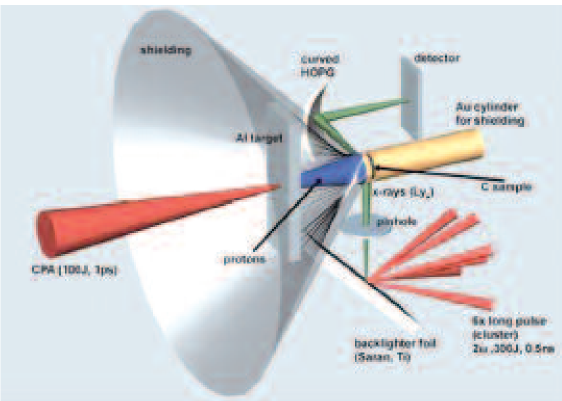

Figure 1. Initial target design incorporating a gold shielding cone and a partially gold coated carbon rod.

During the experimental planning stage, issues with the production of the gold coating to leave the 10-20 µm uncoated area on the carbon rod led to a radical redesign of the targets. This new design enabled the experimental aims to be achieved while reducing the assembly and the coating problems of the original design.

Final target design

The revised target design was based on the use of two precision machined aluminium blocks to create a slit to replace the pinhole in the previous design. The slit also serves the purpose of shielding the carbon bar from the backlighting radiation replacing the need for

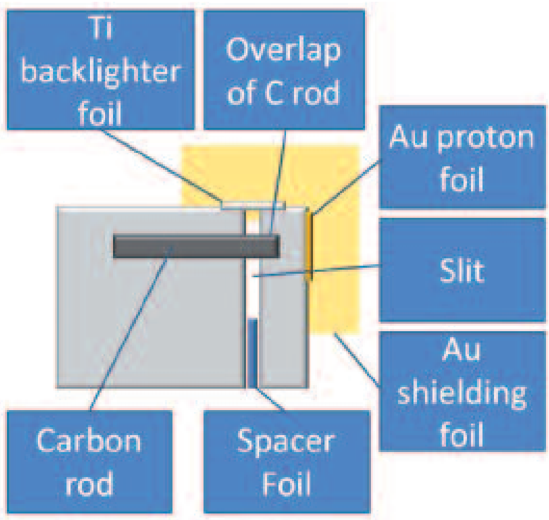

Figure 2a. Diagram of carbon bar target showing positions of the slit, carbon bar, backlighter foil and proton production foil.

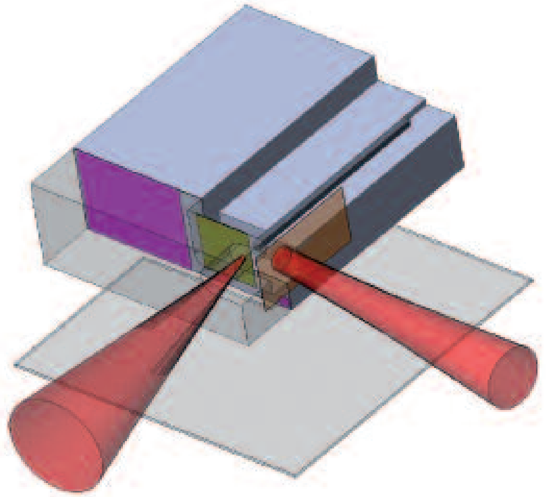

Figure 2b. Isometric drawing of a complete target showing incident laser beams on the proton production foil and backlighter foil.

the gold coating with the 10-20 µm uncoated region of the original design. The carbon bar would then be mounted so that it overlapped the slit as shown in Figures 2a and 2b.

A gold proton production foil was positioned adjacent to the end of the carbon bar and a titanium backlighter foil was mounted parallel to the bar. A gold shielding foil was attached to the base of the aluminium blocks to shield the diagnostics from X-rays coming directly from the titanium foil.

Target assembly

The assembly of the targets was a very complex procedure requiring characterisation of each target at several stages to ensure that it was within specification. The aluminium blocks were micro-machined by the Precision Development Facility (PDF) in SSTD and 125 µm thick carbon foil was diced into 100 µm, 150 µm, 200 µm and 300 µm wide bars by the Millimetre Wave Technology Group in SSTD. The spacer foils, backlighter foils, proton production foils and shielding foils were all cut out by hand in Target Fabrication.

The first stage of the assembly process was to precisely position the carbon bar relative to the aluminium block. This was achieved by using a precision assembly

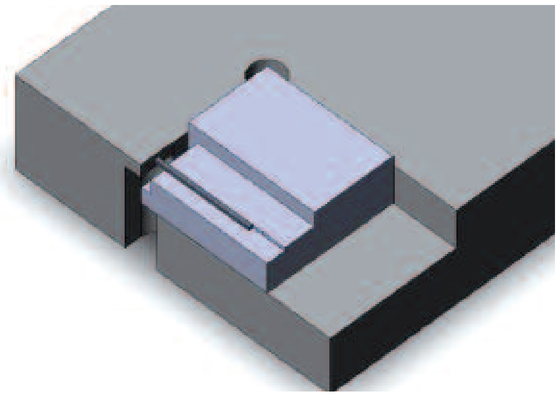

Figure 3a. Drawing of the aluminium block on the assembly jig used for positioning the carbon bar.

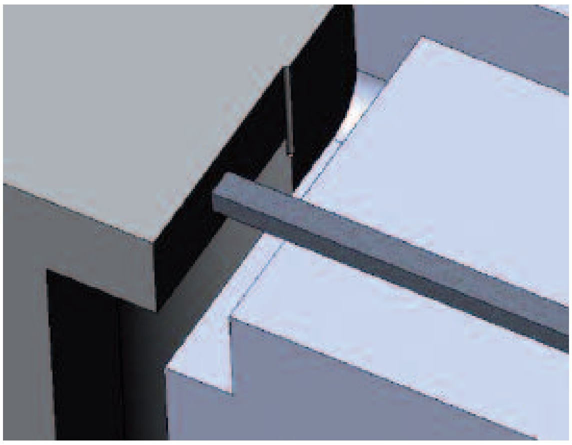

Figure 3b. Close up of the carbon bar in position up against the precision assembly jig. The 30-50 µm step used to set the overlap of the carbon bar can be seen on the assembly jig.

jig produced by the PDF. The use of a set of different jigs allowed the overlap to be varied. Figure 3a shows the aluminum block positioned on the assembly jig. On the edge of the assembly jig that lined up with the edge of the aluminium block, there was a precision machined step. The overlap of the carbon bar was set by pushing the carbon bar up against the step as shown in Figure 3b.

At the start of the experiment, the overlap of the carbon bar was set to 30 µm from the edge of the aluminium block resulting in a 20 µm overlap from the edge of the slit once the whole target was assembled. At this stage the position of the carbon bar was measured using a Coordinate Measuring Machine (CMM). It was possible to position the bar with an accuracy of ±5 µm.

The second step of the assembly process was to glue the two aluminium blocks together with a spacer foil in between to set the slit width. This was done by using the assembly jig shown in Figure 3b in combination with glass microscope slides to hold the two blocks in place while they were glued. The slit width could be varied by using different thickness spacer foils.

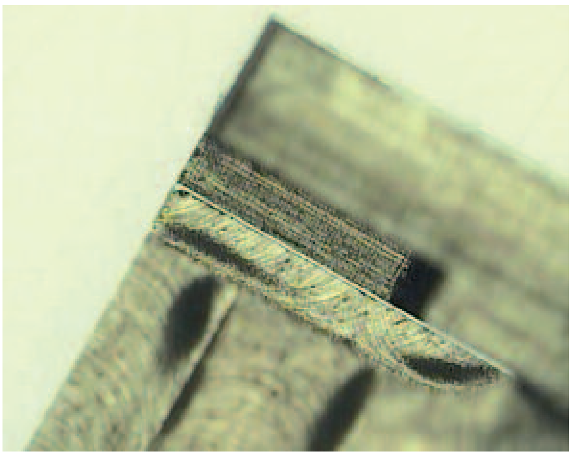

Figure 4. Image of aluminium blocks with 10 µm slit between the two pieces. (This picture was taken during the development stages of the assembly process so there is no carbon bar in place).

Each target was measured at this point using a very high performance optical microscope (Zeiss AxioImager m1M) under transmitted light to check that the slit width was within specification. In the early part of the experiment a slit width of 10 µm was required and it was possible to achieve this using a 6 µm spacer foil. Later in the experiment a slit width of 200 µm was required and this was achieved to an accuracy of ±15 µm using a 200 µm spacer foil. Figure 4 shows a 10 µm slit produced during the development stages of the assembly process.

The next stages were to glue the gold proton production foil and the titanium backlighter foil in place. The gold shielding foil was then glued in place so that when viewed through the slit the edge of the shielding foil was between the carbon bar and the titanium foil ensuring that the titanium foil was obscured from the diagnostics.

A completed target is shown in Figure 5.

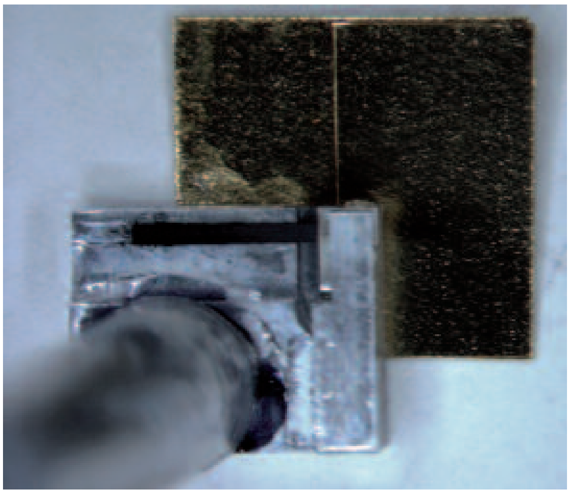

Figure 5. Photograph of a completed target mounted on an aluminum target post (out of plane, bottom left). The carbon bar and gold shielding foil are visible.

Conclusions

Target Fabrication effectively supported a very complex experiment and the target design was sufficiently flexible to accommodate changes to target specifications during the experiment. However, assembly of these targets was a very time consuming process also requiring a high level of skill to execute the various stages of the manual assembly process.

Limitations of the process were that glue residue built up on the assembly jigs requiring them to be cleaned regularly in order to maintain the level of precision required. Also, as the jigs were machined out of aluminium, they were soft and easily damaged and consequently they had a limited lifetime. The carbon bars were flexible making it difficult to position them precisely because when they were pushed up against the jig they tended to deform. However, despite these issues, 80% of the targets produced were within specification. 39 high specification targets were delivered to the user group contributing to a highly successful experiment.

Acknowledgements

We would like to acknowledge the work of Wayne Robins In the PDF in SSTD for the production of the aluminum blocks and precision assembly jigs and David Wilby from the Millimetre Wave Technology Group in SSTD for dicing the carbon bars.