Advanced X-ray collimator micro-fabrication for warm dense matter studies

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Introduction

This article describes some of the recent target fabrication activities at the Vulcan laser facility at the Rutherford Appleton Laboratory (UK) and at the LULI2000 facility at the Laboratoire pour l'Utilisation de Lasers Intenses (LULI, France). Advanced micro-fabrication capabilities are becoming necessary for the success of current X-ray scattering experiments to probe the microscopic dynamics of shock compressed targets. By laser driven compression of ordinary solids a new state of matter known as warm dense matter (WDM) is generated. This state is characterized by solid and super-solid densities with temperatures of few tenths of an electronvolt which results in the appearance of both long-range order (as in regular solids) and short-range order (as in the liquid state). WDM is of particular interest for both astrophysics and inertial confinement fusion research [1,2] and it provides an experimental platform to benchmark theoretical modelling of such systems.

Recent target production

Targets are the main factor determining the success of an X-ray scattering experiment. They contain the sample material, the backlighter foil for the production of the X-ray source and, at the same time, define the scattering geometry in terms of relatively well collimated X-ray probe beam as well as scattering line-of-sight to the recording instrument (see e.g. Ref. [3]). There have been a number of experiments [3-7] that have used X-ray scattering as a diagnostic for warm dense matter and, due to the different experimental goals and laser beam configurations, these have all used a slightly different target design. In this paper we will describe a number of such targets and the related manufacturing issues. The first of these targets consisted of commercially produced, relatively inexpensive machined copper squares 6 mm × 6 mm × 3 mm with a 2 mm diameter central hole and commercially sourced photo etched silver pinholes 150 μm thick with a 250 μm diameter central hole with alignment marks. These parts are shown in figure 1 and were assembled together to provide the necessary X-ray collimation. The small hole machined into the top of the Cu block is to allow air to escape consequently permitting the whole assembly to be held under vacuum without it being destroyed due to the pressure of trapped air inside the full assembly during pump down inside the interaction chamber. The drawing of a fully assembled target is shown in figure 2.

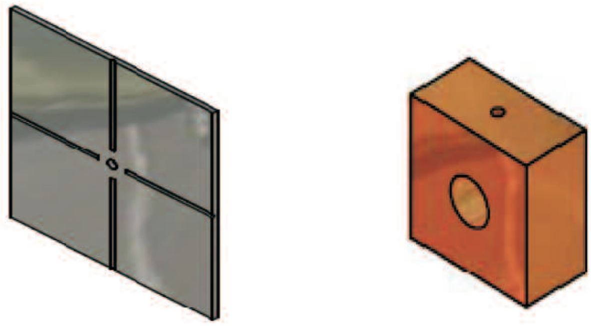

Figure 1. The Cu and Ag parts.

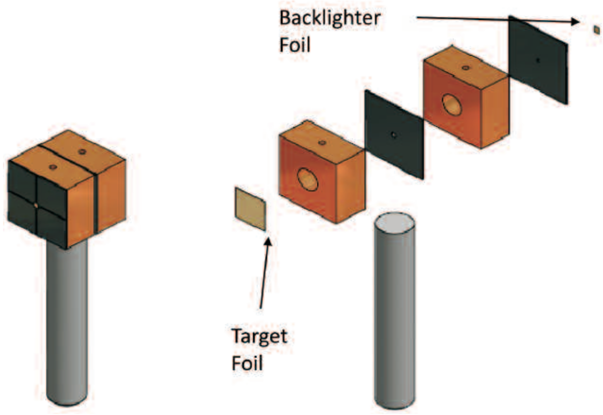

Figure 2. The complete target assembly and components prior to assembly.

The probe X-rays were produced by the interaction of a laser pulse with a 5 μm titanium foil, placed on one side of the assembly (see figure 2), and the X-rays were then collimated through the pinhole assembly. The X-rays were then incident onto a second thin foil of CH/Al/CH (produced using thin film coating techniques) which was placed on the opposite side of the assembly, and that had been simultaneously shocked with an intense laser. The X-rays were then used to diagnose the characteristics of this shocked foil, as described in detail in Refs. [8,9].

A second target design, which has the advantage of protecting one side (using a large copper cone) from seeing the emission from the blow-off plasma produced on the opposite side of the assembly, is shown in figure 3. These were fabricated from commercially available gold tube of 1mm diameter with 150 µm wall thickness that was diced using precision machining to form short tubes of 0.5mm length. Over these tubes were positioned a number (commercially sourced) chemically etched silver pinholes of varying diameter that had alignment markings to align the laser beams accurately in the interaction chamber. The assembly consisted of an end pinhole 100 µm diameter to act as a foil mount over which a 150 µm diameter, 8 µm thick Parylene-D ($C_8H_4Cl_2$) foil was placed. (The foil was produced by the polymerisation of a CH-D parylene dimer.) The X-rays produced by the laser interaction with the foil were collimated through a 170 µm Ag pinhole and then were incident onto a 250 µm thick lithium sample. The assembly for this target is shown in figure 3. Results from this work are discussed in Ref. [10].

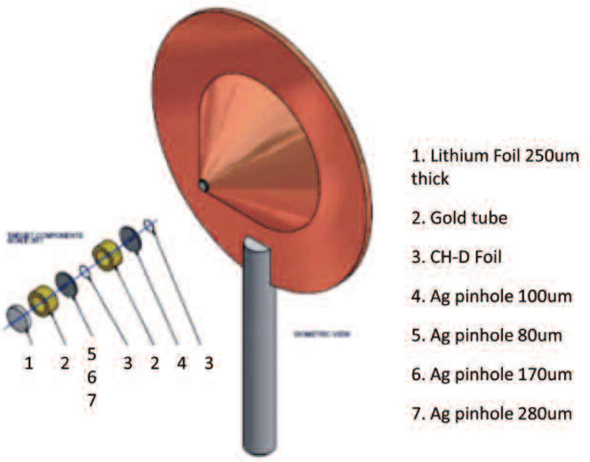

Figure 3. The Lithium target assembly.

High collimation X-ray micro-targets

While the previous examples of target manufacturing were primarily concerned on the production of a high throughput X-ray source, with moderate X-ray collimation, more recent experiments have aimed to spatially resolve the transit of a laser-driven shock wave across the observation volume, which then requires much more stringent constraints in the collimation. In this case, a single crystal diamond sample 1 mm × 1 mm × 500 µm had a sub-mm high precision micro-machined collimator attached to one side to enable shock probing (see figure 4). Again there was a need for shielding around the target to stop stray X-rays entering into the detector line-of-sight and to reduce the background noise. The specifications were for a collimator with a central pinhole of 80 µm with a counter bore on each side of 200 µm. The length was 400 µm its width 300 µm and height 1 mm. The assembled target is shown in figure 4 and the dimensions of the collimator are shown in figure 5.

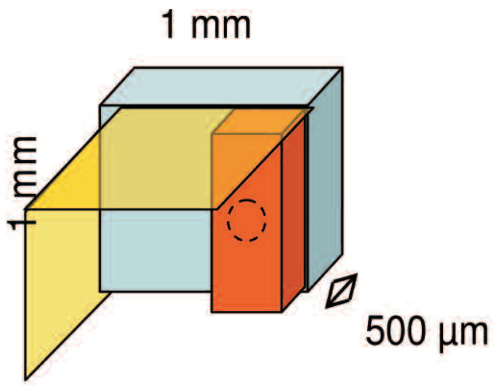

Figure 4. The complete assembly.

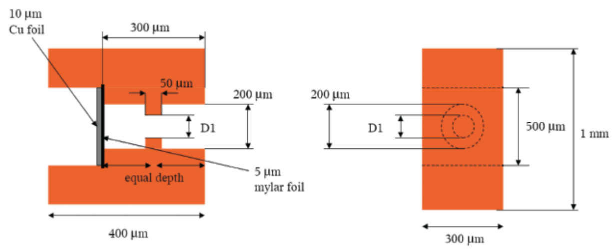

Figure 5. The collimator design.

The backlighting X-rays were to be produced from a copper foil as detailed in the drawings and a number of both metallic and plastic coatings were applied to various faces of the diamond to ensure that the shock propagated through the diamond as in the desired manner. The most challenging part of the assembly was the production of the collimators and these were manufactured using ultra precision micro-machining. The process involved numerous stages as the small diameter hole had to be drilled after the two counter bores. Also it was found advantageous to remove the front face of the collimators (labelled) therefore reducing the distance through which the small holes had to be drilled. Figure 6 shows the whole collimator after production and it can be seen that the dimensions are over specification at approximately 400 µm width with a hole size of 100 µm.

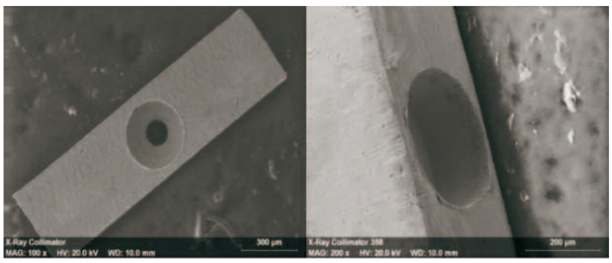

Figure 6. The micro-collimator and a magnified image of the holes.

It appears that in figure 6 that around the edges of the counter bore there seems to be some burring. Further investigation showed in the magnified image in figure 6 that there is only a small amount of burr that will have little or no effect on the target performance.

The final target assembly is shown in figure 7 and the picture in figure 8. This shows the assembly with the diamond, which is shocked by a laser pulse propagating from the bottom of the images, the collimator which is orientated so a pulse shooting from the right of the image creates X-rays which are collimated to probe through the diamond. Also shown more clearly in figure 9 are 2 gold shields (1 mm × 1 mm) that are to block stray X-rays. The targets were fielded in November 2007 at LULI in France and results are still being analysed [11].

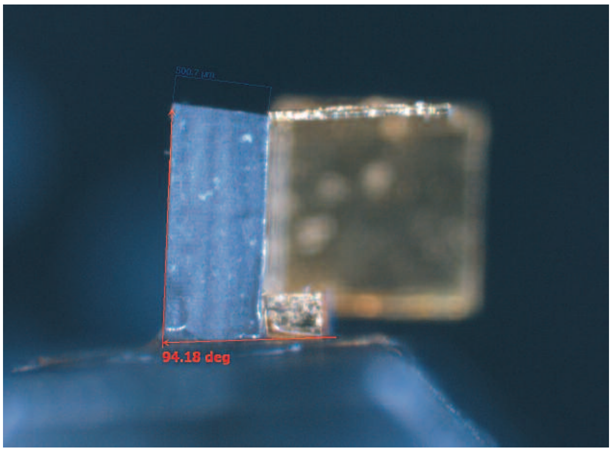

Figure 7. The completed assembly.

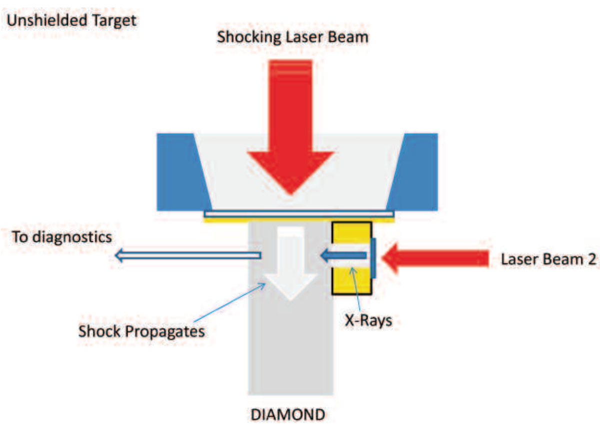

Figure 8. A sketch of the target (top view of figure 7).

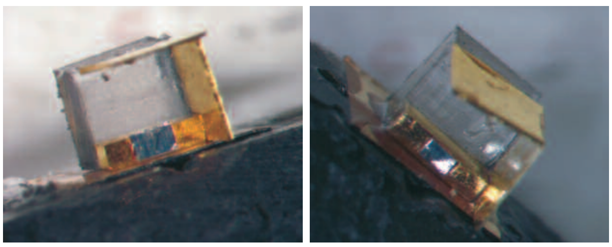

Figure 9. The completed target showing the gold shields.

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