Development of a multi- heated target assembly for heavy ion experiments

R J Clarke, B Fell, P Holligan, D Neville, C Spindloe, M K Tolley

CCLRC Rutherford Appleton Laboratory, Chilton, Didcot, Oxon., OX11 OQX, UK

P McKenna

University of Strathclyde, Glasgow, G1 1XQ, Scotland, UK

Main contact email address: *r.j.clarke@rl.ac.uk*

Introduction

The study of heavy ion reactions has been of interest in the field of high-intensity laser induced nuclear physics for some time[1-6]. The ions are accelerated from the target, close to the surface, where a very high electric field (sheath field) is generated by high energy (MeV) electrons passing through the target. This acceleration mechanism is be damped by the simultaneous acceleration of protons from surface contaminants on the target. In order to determine the exact conditions for optimum acceleration of the heavy ions, it is necessary to remove the surface contaminants from the targets before the laser-target interaction. With interaction chamber pressures of ~ 10^{-5} mBar, surface contaminants can build up on the target quickly, hence either ultra-high vacuum (UHV) or an in-chamber method for removing the surface contaminants during a shot is required. The ability to provide UHV systems where a laser is able to propagate to target is complex, hence the latter technique of cleaning the target pre-shot is more favourable. Several experiments have used target heating to attempt to reduce the contaminant proton signal[2,3,7,8], and the most common techniques are by close proximity heating elements or resistive heating of the target. This paper outlines the development of a multi- heated target assembly using resistive heating techniques to reach temperatures in the order of 1000°C, removing surface contaminants and reducing proton emission from target foils.

Power Constraints

To achieve the exceptional current control required for resistive heating, the power supply used must offer a high resolution of voltage control. At high temperatures, very small changes in the current cause rapid changes in temperature and an almost immediate melting of the target. As a result, a high resolution power supply is required, also capable of delivering the high currents (up to 100A) required for the heating of target foils up to 100µm in thickness. The power supply chosen was an Agilent/HP 6672A, 20V/100A 1 kW unit. The current and voltage requirements vary substantially between different target specifications, dominated by the cross sectional area and resistivity of the target. The resistivity values of the targets tested are shown in Table 1. As the target resistivity is increased, the electrical current required for heating decreases. As the cross sectional area increases, the actual resistance of the target decreases, and the electrical current (and voltage) requirements to heat the target again increase. The power supply is operated in a voltage control mode, allowing the target to freely draw current up to the limit set.

Target Mount Design

The target mount has several requirements in order to be effective for laser-plasma and nuclear interactions. The first is the requirement to have the front and rear sides of the target clear. This opens the path for the laser to target and for the accelerated electrons and heavy ions to be emitted without constraints. Secondly, the ability to optically probe the target is required to allow the measurement of pre-plasma scale lengths to be made via shadowography and interferometry techniques. This requires the target plane in the horizontal direction to be clear. Finally, the ability to operate with multiple targets is favoured as this reduces the time between shots by alleviating the need to perform let-up and pump-down procedures. This final requirement is the most difficult to meet, as the electrical connections must be changed for each target. This is achieved using a rotational mount with silver-doped carbon brushes, which connect to different targets as the central wheel rotates.

Target material	Target resistivity (µΩ)
Copper	1.69
Gold	2.2
Tungsten	5.4
Iron	10.1
Palladium	10.8

Table 1. Target resistivity for tested materials.

A 3D view of the target mount is shown in Figure 1. The mount contains 4 removable target clamps, each of which is spring loaded to allow easy mounting of foils of varying thickness. These clamps are attached to the main rotational wheel and are automatically electrically connected to the body of the target mount.

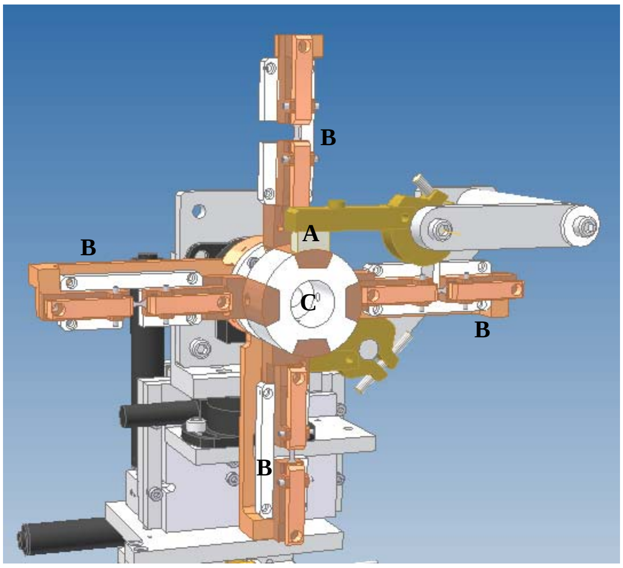

Figure 1. 3D view of the heated target mount. Specific items are: A – electrical contact brushes, B – Target clamps, C - Rotational wheel.

Two silver-doped carbon brushes provide electrical connections. The first, at the rear of the mount, is connected to all targets at all times. The second, at the front of the mount, connects to the top-most target via a copper contact on the front of the mount. As the rotational wheel moves, the front brush disconnects from the current target and reconnects as the next target reaches the top. Insulating material between the contacts ensures no two targets are connected at the same time. Figure 2 shows an image of the target mount in place in the Vulcan Petawatt target chamber, and Figure 3 shows a magnified image of one of the target clamps containing a palladium target.

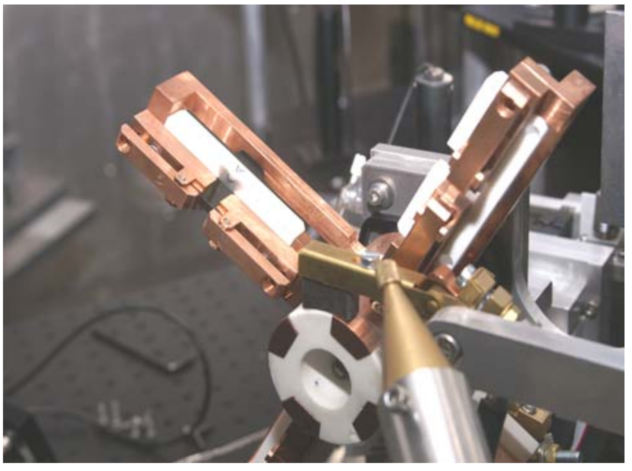

Figure 2. Heated target wheel (under rotation) in situ on a heavy ion experiment (P. McKenna *et al.*, University of Strathclyde) in the Vulcan Petawatt area.

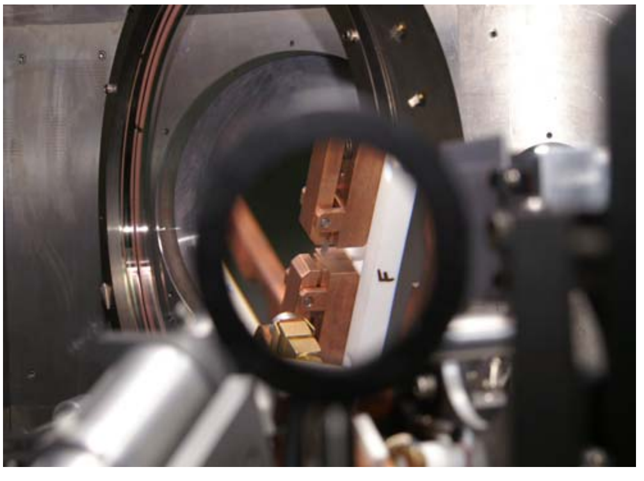

Figure 3. Magnified image of the target clamp containing a palladium foil target.

Test Results

The initial tests of the heated target mount were performed using a single stage mount, though testing of the multi-target mount showed no difference in heating or power requirements. Non-contact temperature measurements were made with a disappearing filament optical pyrometer, capable of manual temperature measurements between ~700°C and 2000°C. This device uses an adjustable heating filament to match the optical output of the target object at 633nm. The calibrated heating filament is then used to determine the temperature of the target for a specific optical emissivity. The accuracy of temperature measurements during tests was found to be better than 10°C. The optical emissivity values and melting temperatures of the various targets used are listed in Table 2. All targets were tested to destruction to determine a safe operating temperature where the targets can survive for an extended period. Heating tests showed target survivability for over 15 minutes with both palladium and gold targets at 1000°C. Tests with other targets, performed at higher temperatures showed dramatic reductions in the survivability time as the temperature was increased.

Target material	Melting point	Emissivity
Copper	1083°C	0.02
Gold	1064°C	0.02
Tungsten	3410°C	0.3
Iron	1535°C	0.38
Palladium	1554°C	0.33

Table 2. Target melting temperatures and emissivity values used for non-contact temperature measurements.

The data collected during all test stages is shown in Figures 4 through 6. The first (Figure 4) highlights the non-linear increase in the current drawn by the target whilst operating in a voltage control mode. This highlights the need to accurately control the voltage applied rather than the current, as the extreme shift in temperature with only small current changes (when at high temperatures) can easily lead to the instantaneous melting of the target.

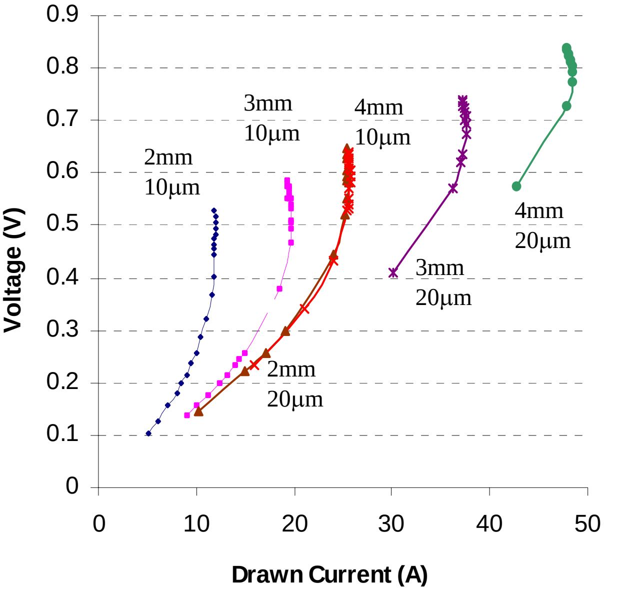

Figure 4. Current and Voltage parameters for copper target tests. Target widths and thickness are indicated. Data begins at ~700°C and ends at the melting point of the target (~1080°C).

Figure 4 also shows the relationship between the cross sectional area of the target and power requirements to maintain target temperatures. The increase in both applied voltage and current drawn to bring the target to a measurable temperature (~700°C), as well as to melt the target, increases as the cross sectional area of the target increases.

Figure 5 plots the target temperature against the current drawn by the target whilst operating in the fixed voltage mode. This emphasises the non-linear increase in the temperature of the target with respect to the current drawn and once again highlights the requirement to control the applied voltage rather than current.

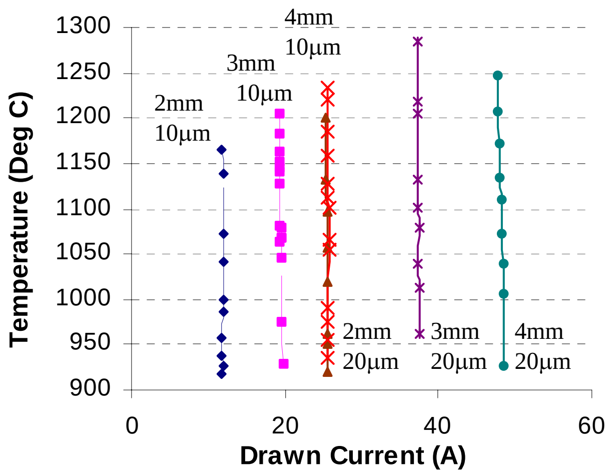

Figure 5. Temperature measurements plotted against drawn current for copper target tests. Target widths and thickness are indicated.

Figure 6 shows a complete data set containing all tested target materials at the different thickness. The figure shows the settings required to maintain a target temperature of 1000°C. Generally, the relationship between the electrical current and voltage required to maintain 1000°C corresponds well to the tabulated target resistivity at room temperature, with the curves for each target type moving to a higher voltage as the resistivity of the material increases.

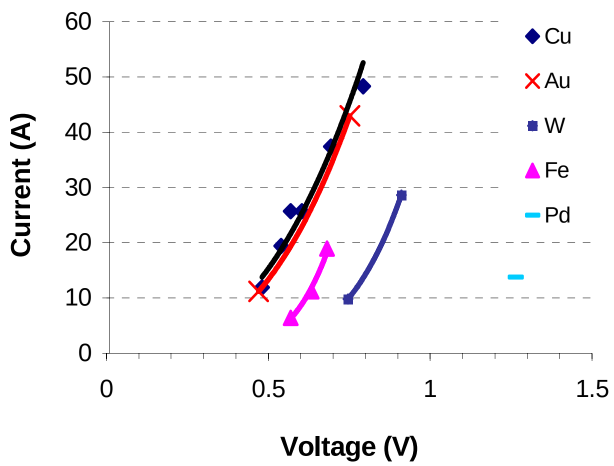

Figure 6. Settings required to maintain target temperatures of 1000°C for different target parameters.

Experimental results

A group from the University of Strathclyde used the heated target on a heavy ion acceleration experiment in the Vulcan Petawatt target area. The data from this experiment will be presented at a later date once complete analysis has taken place. Initial analyses from Thompson spectrometer CR39 traces show a dramatic decrease in the proton emission between cold and hot targets. The data in Figure 7, typical of a heated target shot shows the trace from one of the Thompson spectrometers. The red dotted line indicates where the non-heated proton trace would occur. Strong heavy ion traces are also observed only when heating the target. Those with significant improvement for the shot shown are carbon, copper and gold. The reduction in proton emission is also evident from the reduced activation of the target mount and surrounding chamber furniture.

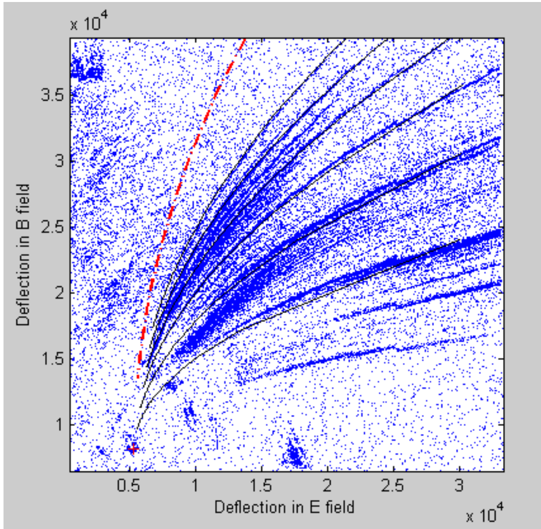

Figure 7. Thompson spectrometer signals on CR39 track detector for a gold / copper layered target at 1000°C. The red line indicates the position of the cold target proton signal.

Conclusion

The development of the heated target mount has enabled new heavy ion experiments to be possible within the CLF. The multi-target capability of the mount enables much larger data sets to be gathered than the previous single target systems and the design enhancements made allow its operation at much higher temperatures than previously achievable. The target mount has maintained excellent performance throughout the 4 experimental weeks and will continue to be developed to further its capabilities.

References

1. Badziak, J, Parys, P, Wolowski, J, *et al.*, OPT APPL 35 (1): 5-22 2005
2. McKenna, P, Ledingham, KWD, McCanny, T, *et al.*, APPL PHYS LETT 83 (14): 2763-2765 OCT 6 2003
3. McKenna, P, Ledingham, KWD, Yang, JM, *et al.*, PHYS REV E 70 (3): art. no.-036405 Part 2 SEP 2004
4. McKenna, P, Ledingham, KWD, McCanny, T, *et al.*, PHYS REV LETT 91 (7): art. no.-075006 AUG 15 2003.
5. Roth, M, Allen, M, Audebert, P, *et al.*, AIP CONF PROC 634: 35-42 2002
6. Krushelnick, K, Clark, EL, Allott, R, *et al.*, IEEE T PLASMA SCI 28 (4): 1184-1189 AUG 2000
7. Zepf, M, Clark, EL, Beg, FN, *et al.*, PHYS REV LETT 90 (6): art. no.-064801 FEB 14 2003
8. EL Clark, FN Beg, AE Dangor, *et al.*, CLF Annual Report 2000-2001: 35