Development of thin bond lines for high power laser experiment targets

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Introduction

The assembly of microtargets for high power laser experiments is a complex and challenging discipline. It typically requires precision (depending on the target design) to a few microns, and in some cases to less than a micron. Some target components have surface roughness and features in the sub-micron scale, and assembly using adhesives can drastically affect the performance of the targets. For example, when taking VISAR (Velocity Interferometer System for Any Reflector) measurements from shock experiments, an adhesion layer in the target can cause the shock to ring in this layer, leading to difficulties in interpreting the data. Such targets would benefit from either having no adhesion layer or, if this is not possible, an adhesion layer that is of sub-micron thickness. There is, therefore, significant motivation to pursue thin adhesion layers for these and many other target designs.

This paper describes the steps taken to develop a micron-thick adhesion layer to assemble a target for AWE to field on the Orion Laser System [1]. The multilayer target is shown schematically in Figure 1, and consists of: a tungsten washer with an inner aperture of 1.5 mm diameter, to act as a target mount and diagnostic shield; a single crystal diamond (SCD), 100 µm thick, attached to the washer with two-part epoxy glue; and a 5 µm thick Cu foil placed on top of the thin adhesion layer.

The target specification required the grain orientation on the 5 µm thick Cu foil to be random. To fulfil this request a commercially available Cu foil was purchased and characterised prior to being adhered to the SCD.

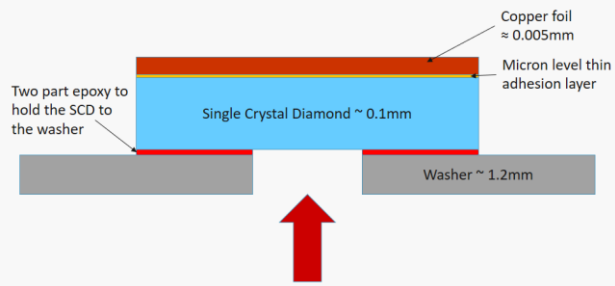


Figure 1: Schematic of the assembled target

Sample Manufacture

All the testing and fabrication was carried out in a Class 10000 clean room, with an average humidity of 35 - 45%.

The preliminary testing mentioned in this section was carried out on microscope glass slides.

One method to produce a consistent thickness coating is to employ spin coating [2]. In spin coating a sample is isolated at (very) high speeds for a specific amount of time to spread a solution evenly across a substrate.

The process has many applications including the deposition of anti-reflective coatings on glass, for example, and applying photoresist for lithographic processes. In these processes either the spinner is programmed to run until the solvent evaporates from the solution (AR coatings) or the thin film is baked to ensure the solvent is removed (lithographic processes).

However to use a coated PMMA layer as an adhesion layer, the right conditions must be met, the conditions must allow for a thin PMMA layer while retaining its adhesive properties.

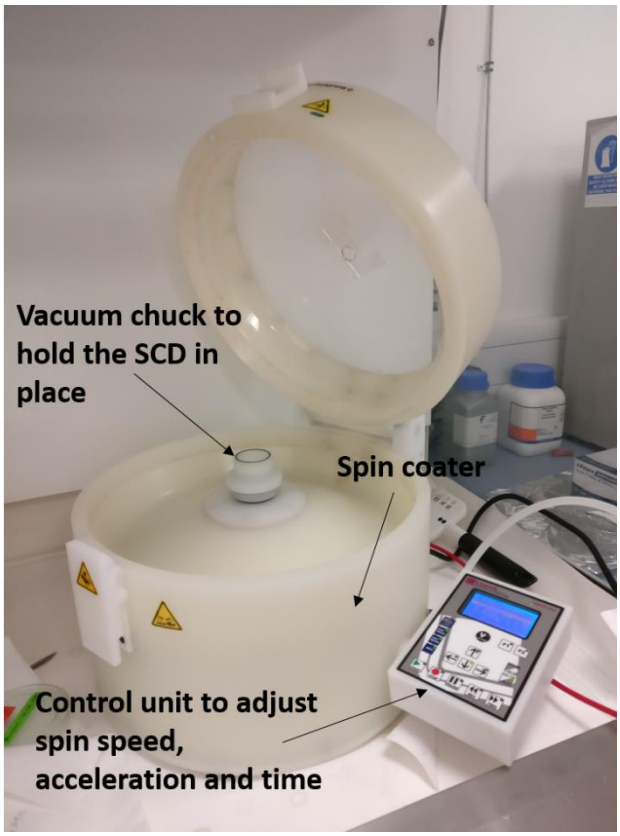


Figure 2: Spin coater (Laurell WS-650Hz-15NPBB) used in the manufacture of the thin glue targets.

Figure 2 shows the spin coater (Laurell WS-650Hz-15NPBB) used for depositing the adhesive layers. The maximum speed at which the spinner can operate is 8000 RPM. The central vacuum chuck holds the sample in place. For the spinner there is an acceleration time, which is the time taken to reach the set speed. Initially the acceleration was set to 5 seconds. For example, if the sample was being spun at 5000 RPM, the spinner would take 5 seconds to reach the rotation speed. Furthermore the same time is taken for the spinner to slow down to zero after the cycle finishes.

The overall spin time when coating a sample includes the acceleration and deceleration times. However, all the times stated throughout this paper exclude the acceleration and deceleration times unless stated otherwise. For example for a stated spin time of, say, 20 seconds the actual spin time would be 20 seconds plus the acceleration and deceleration times.

Polymethylmethacrylate (PMMA) was the chosen solution for the adhesion layer as it is known to produce uniform thin films [3].

The tests began with 100% PMMA solution without any mixing. A small amount ~0.005g of PMMA was deposited on to the test glass slide which was dispensed using a precision syringe (Terumo 1ml syringe with a Neolus sterile needle, 23 gauge 25mm long). The basic test set up for the first trial is shown in figure 3.

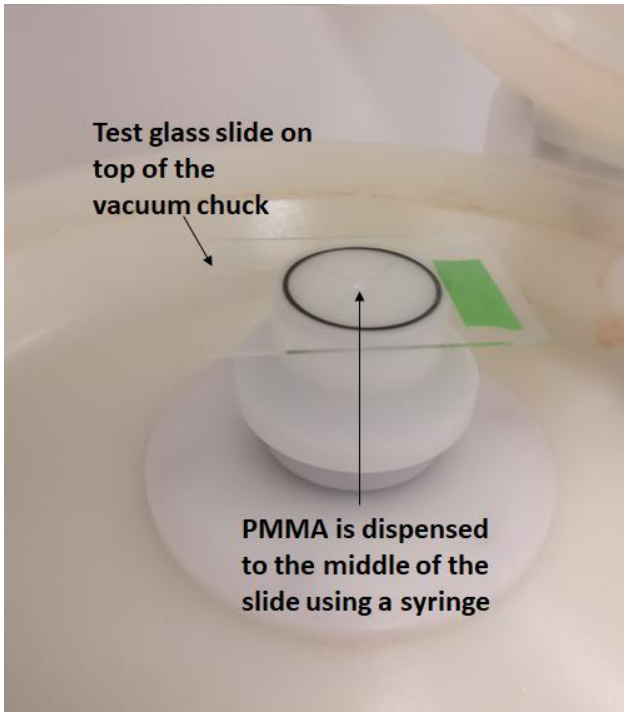


Figure 3: Experimental set up used to spin coat PMMA

The two main factors that affect the adhesion film thickness are the spin speed and the spin time. Faster spin speeds result in thinner adhesion layers. However, at a high rotation speeds the deposited film will dry quicker.
Spin times lead to variation in thickness as well. With a reduced spin time corresponding to wet thin film. The aim of the first experimental run was to estimate the appropriate parameters for depositing a thin film that could be used for an adhesion layer.

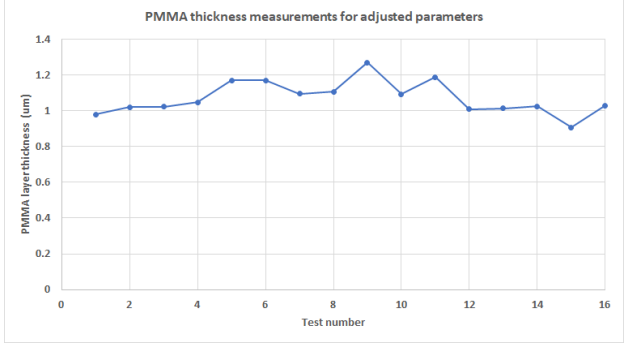


Figure 4: Graph showing test thickness values for the spin coated PMMA

Figure 4 shows the results for PMMA tests spun and dried at 353K for an hour. To measure the thickness of the film a small incision was made with a scalpel on the dried film. A touch probe (Tencor Alpha Step IQ) with a 5µm tip on the probe was used to measure the step height to find the thickness of the film. The results showed that approximately 1µm thickness is possible to achieve. However, at such thicknesses the adhesive properties were reduced so much that the Cu foil would not bond.
Consequently, the next step appeared to be to choose a spin speed that allows adhesion as well as a thickness of 1µm as specified. The spin time and spin speed were fine tuned to optimise the outcome.
More work was carried out to achieve thickness values in the region of interest. Both the spin time and spin speed values were recognised to give approximately 1µm thick adhesions layers. Further fine tuning was done within the picked spin time and spin speed to optimise the thickness as well as the wetness of the film.
The settings carried forward towards the target manufacture was as follow, spin speed was 3600RPM, spin time was 24 seconds and the acceleration was 3 seconds.
These parameters gave resulting adhesion layers of 1µm range being looked at, where the thin film layers remained suitable for bonding. These preliminary tests were carried out on glass microscopic slides. Using these results the spin coater parameters were set for applying the thin PMMA film to the SCD to be used as an adhesion layer.

Final target manufacture

The SCD was attached to the supplied support washer using standard two-part epoxy before any processes were carried out. The adhesion layer thickness between the two components was not important because the glue would be outside of the laser interaction area. A holder for the washer was 3D printed and glued to a glass microscope slide. The washer provided was too small to be kept in place solely by the vacuum chuck.
The 3D printed holder also prevented the SCD being exposed to the vacuum pressure through the washer aperture.
The printed holder was then used for all the testing on the SCD as well as for the final manufacture of the targets. The holder is shown in figure 5.

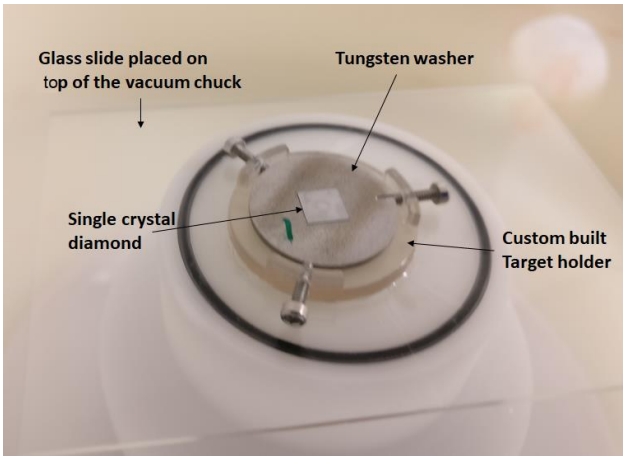


Figure 5: Photograph showing the placement of the 3D printed jig to hold the washer.

It was suspected that the PMMA might behave differently on the SCD to a glass slide. Therefore more tests were carried out before the final assembly. After the first spin coating run on the SCD it was noticed that the PMMA coating had not thinned out as much for the same parameters when used with the previous runs on glass slides.
The procedure was again optimised to investigate the correct spin speed and time to meet the 1µm adhesion layer specification.

Following this investigation, the necessary values were spin speed of 3600, acceleration of 800 and spin time of 26s. Reducing the acceleration from 1200 to 800 the PMMA thin film spread across the diamond more.
Four thickness measurements each were taken from four different SCD samples as shown in figure 6. The average thickness measured from all 16 sampling cuts was 1.07µm ±0.28µm

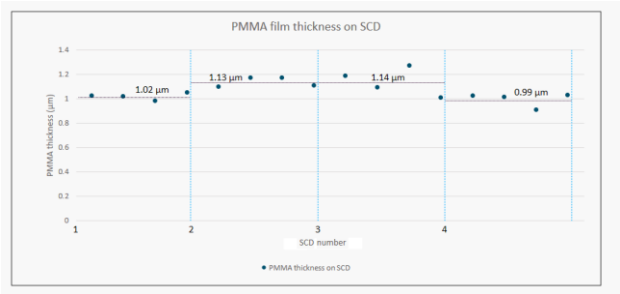


Figure 6: Graph showing 16 different measurements taken for thickness across 4 different SCDs. The average thickness for each SCD is shown in the graph. The spin speed was 3600RPM, spin time was 26 seconds with an acceleration of 5 seconds.

The thickness measurements on the SCD were taken using the same method as the preliminary tests on glass microscope slides. Using an alpha step profilometer.
Figure 7 is an image taken using a light microscope of the test SCD used to determine the adhesive layer thickness. The image shows the areas where the thin film removed using a scalpel in preparation for measurement on the Alpha Step. A line out on a SCD performed with the step probe which is shown in figure 8.

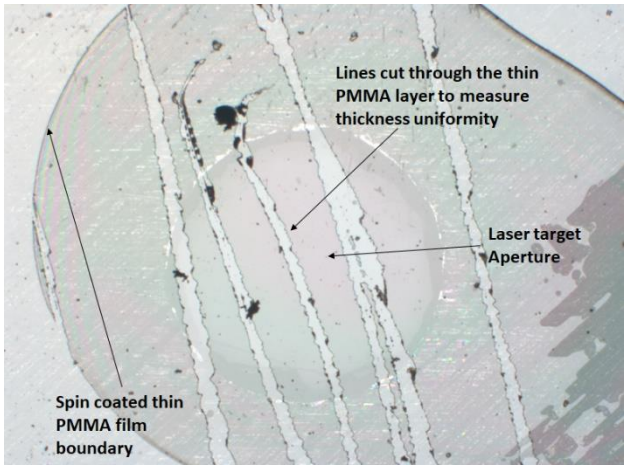


Figure 7: Optical micrograph of a SCD after a thin film of PMMA is coated. The cuts through the aperture are used for uniformity thickness measurements.

The thickness of the resulting adhesive layer was consistent across the SCD but as is visible from figure 9 the PMMA does not cover the whole SCD surface. It is essential to cover most of the SCD surface to allow the Cu foil to bond.

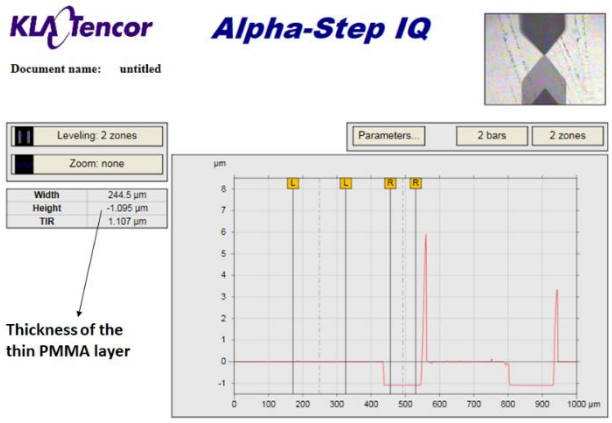


Figure 8: Data file from the step profiler showing the thickness for one example SCD for one cut through the aperture.

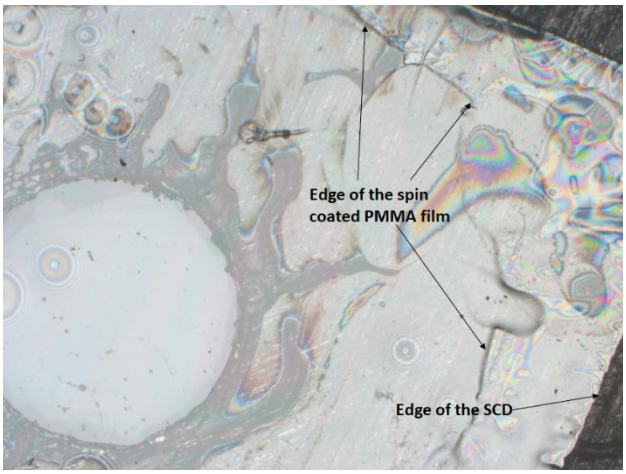
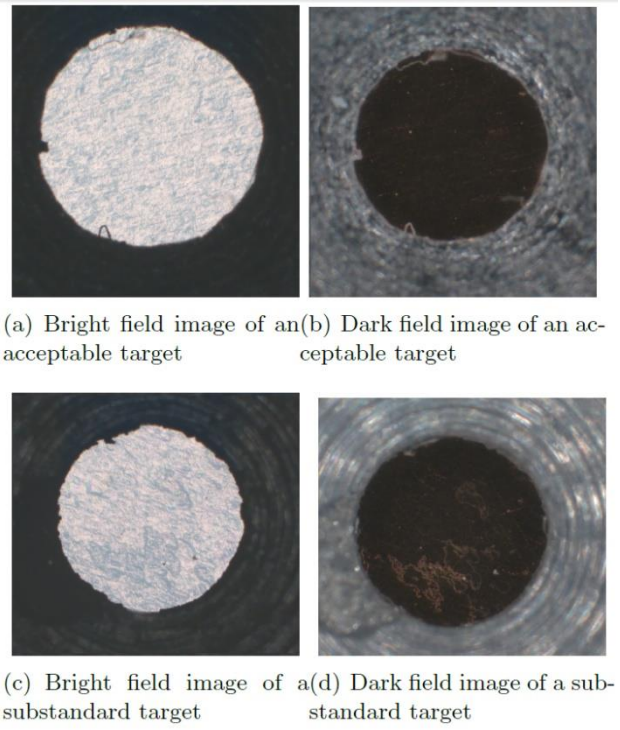


Figure 9: Optical micrograph showing how much the PMMA film spreads after a small weight is placed on it.

An experiment was performed in which a small piece of glass was placed on the freshly spun PMMA with a weight on top. This was to simulate what would happen when the Copper foil was placed on the SCD.
The SCD sample was dried in a 353K oven for an hour and then imaged using a high power microscope with contrast techniques to show the film layer in the sandwich. Figure 9 shows that the PMMA thin film does spread out across the diamond when force is applied. Although the PMMA spreads further than the initial position after the spin coating it does not spread all the way to the edge. However, it is spread sufficiently enough to keep the copper foil and the SCD in the interaction area as flat as possible.

After this test was completed PMMA was spun on all 15 targets. Once the spinner stops there is approximately 4-5 seconds to turn the vacuum chuck off, move the washer off to a stable base and place the Cu foil in a specific orientation (as defined by the characterisation of the grain structure). Afterwards, a weight (of about 10grams) is placed on top of the target. Then the sample is dried at 353K for an hour to allow the film to set and foils to adhere. By imaging the target through the SCD after the drying process it was possible to see if the Cu foil was in place.
Bright and dark field imaging were used to observe the adhesion layer coverage across the target interaction area. Seven of the fifteen targets did not have an even spread of the adhesion layer across the target area which may be due to a few reasons. Main reason could be that the flatness of the Cu foil not being consistent. Another being the movement of the Cu foil as its been placed to the correct position. This might

have dragged some PMMA across the surface creating areas of higher concentration. Also the pressure applied may have been insufficient to spread the adhesion layer further. The pressure used to spread the adhesion layer across the SCD was created by placing a few microscope slides on top of the target.
No more than 10g was applied to the target during the drying phase as the risk of damaging the SCD could have been greatly increased. Optical light microscopy was used to characterise the final targets.
The images in figure 10 show some examples of the final targets. Figure 10(a) and figure 10(b) shows an acceptable target and figure 10(c) and figure 10(d) shows a target with some adhesion irregularities.



(a) Bright field image of an acceptable target

(b) Dark field image of an acceptable target

(c) Bright field image of a substandard target

(d) Dark field image of a substandard target

Figure 10: 10(a) and figure 10(b) show bright and dark field images of a target that has achieved the thin adhesive layer which was specified. Bright and dark field images for 10(c) and figure 10(d) show a target with some adhesion irregularities.

It should be noted that the 1.07µm layer adhesion layer that is quoted in the paper is prior to the Cu foil being placed on top of the SCD. No measurements were done after the Cu foil was placed and pressed with weight as it was not possible to section the SCDs at the time. Likewise, a side on image could not be taken as the PMMA thin film did not cover the edges of the SCD.

Future developments

Sub-micron PMMA thin films were achieved to be used as adhesive layers by varying application parameters when applying the PMMA solution.
The main factors to control were spin speed and spin time. Acceleration effects also require further investigation because it was observed that the solution was pushed to one direction giving a teardrop shape to the spread. Also different substrates the PMMA spins on give a different spread.
Further work can include the study of adhesive PMMA thin films on different substrate as a clear difference in thickness and spread was noticed between glass and SCD for the same initial conditions.
Preliminary testing should be carried out for each new material used to establish the correct spin speed, time and acceleration to give the required layer thickness.
Another variable is the adhesive concentration. Dilution levels should be tested to investigate the effect on adhesive layer thickness.
Furthermore the choice of adhesive is an area of interest although this is an extensive area of investigation.
It would be beneficial to analyse a cross-section of a completed target to determine the thickness of the adhesive layer once the Cu foil was placed. Scanning electron microscopy might be used to achieve this if the target was diced.

Conclusion

A project from AWE required the micro-assembly of targets requiring adhesive layers of 1µm thickness or less in between two of the components. Through testing we have produced such layers to assemble the target as specified. The average adhesive layer quoted for the 15 targets was 1.07µm±0.28µm. Thin films of PMMA were spin coated on to the target SCD to be used as adhesion layers.
Throughout the project the thickness of the adhesive layers was measured using a touch probe (Tencor Alpha Step IQ). The thickness stated in the report is prior to placing a Cu foil on top the spin coated adhesive layer.
A (typically) 10g weight was placed on top of the Cu foil to spread the adhesion layer across the surface of the SCD.
Preliminary testing on glass microscope slides highlighted the significant effect substrate material has on the resultant adhesive layer thickness.
The adhesive layer was thicker on the SCD than on the glass when using the same formation parameters.
The main parameters investigated were spin speed and spin time of the spin coater. These were studied and optimised to achieve the sub-micron level adhesion layers.
Eight out of the fifteen targets were acceptable targets with no adhesion inconsistencies seen in the interaction area. The inconsistencies may have been caused mainly by the Cu foil as it was being placed in the correct position on top of the SCD.

Bibliography

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