Production of Novel Gaussian-Shaped Micro-bump Targets

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Introduction

There has been continuing research into producing Gaussian-shaped targets with a view to producing well collimated, higher energy and spectrally narrow beams of ions from laser target interactions. In order to achieve this ion acceleration by Radiation Pressure Acceleration (RPA) should be maximized. Therefore minimum target deformation is desirable to reduce ion acceleration from Target Normal Sheath Acceleration (TNSA). The laser has a Gaussian focal spot which means it's more intense at the centre of the focal spot and less intense in the wings. The aim of the experiment was to establish whether making the target thicker in the centre of the interaction point, as show in Figure 1, would compensate for the Gaussian shape of the laser beam and maximize ion production by RPA.

The user group requested Gaussian shaped metallic micro-bump targets with varying thickness and bump diameters. They requested aluminium targets on a backing foil between 0.2µm-0.5µm thick where the height of the micro-bump would be 1µm. The Target Fabrication Group used their experience and knowledge of metal coating processes to investigate options for the production of this novel target type using a thermal evaporation process.

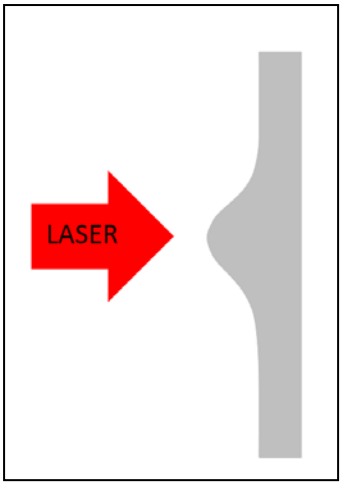

Figure 1: A schematic of the laser beam interacting with a Gaussian shaped micro-bump on the front surface of the target.

Target Production Tests

The first tests to create the profiled micro-bumps were carried out using a 100µm diameter platinum aperture bonded onto a glass microscope slide, coated with 500nm of aluminium. This was to see if it was possible for the coating to go directly through the pinhole onto the slide and characterise the shape it would produce.

This test produced a micro-bump that, when examined using the Wyko white light interferometer, had a 'top hat' distribution and not the Gaussian distribution that was required. The height of the 'top hat' shaped micro-bump was 300nm which was 60% of the full thickness coated (see fig 2a). The discrepancy between the thickness coated and the height of the micro-bump suggested there was a correlation between the hole size of the mask and the amount of material that coated through the aperture onto the substrate.

Figure 2a: 2D cross section of the 100µm diameter micro-bump tests.

The second test was similar only this time it was important to see if it was possible to create a micro-bump of the exact size required. To do this a 25µm diameter copper aperture was attached on onto the slide as shown in Figure 2b. 750nm of aluminium was coated which produced a micro-bump with a maximum height of around 300nm. This showed that when coating through a 25µm aperture the thickness of the bump is approximately 40% of the bulk coating thickness.

Figure 2b: The original setup of a 25µm Cu aperture glued on top of a microscope slide.

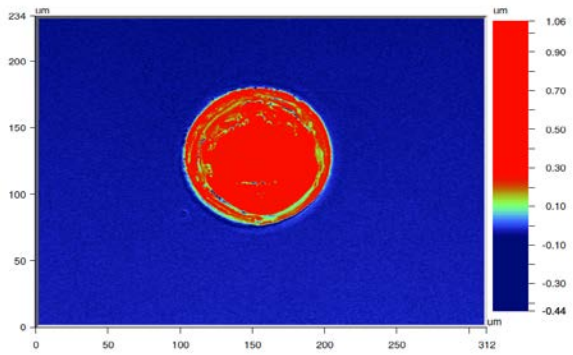

Figure 2c: Wyko interferometer scan of the original micro-bump tests with the top-hat distribution

All of the tests up to this time produced a 'top hat' profile. A novel coating mask was needed to meet the requirement for production of an approximately Gaussian-shaped micro-bump by metallic deposition. A scheme was devised to use a stand off mask as well as a pinhole. The schematic for this is shown below in Figure 3.

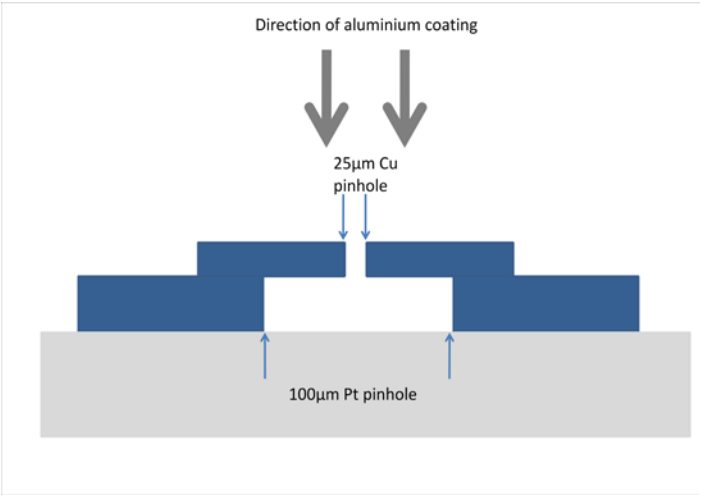

Figure 3: Schematic of the standoff mask and pinhole setup.

A copper pinhole array was fabricated with a selection of 100µm diameter holes on it. The 25µm apertures were attached to this grid and the grid was then attached to the glass slides. 1.7µm of aluminium was coated through the mask. This produced a micro-bump with a height of 1µm that was required. An approximately Gaussian-shaped aluminium micro dot was produced.

Figure 4(a) shows a microscope slide after being coated with aluminium through the 100µm diameter copper pinhole array.

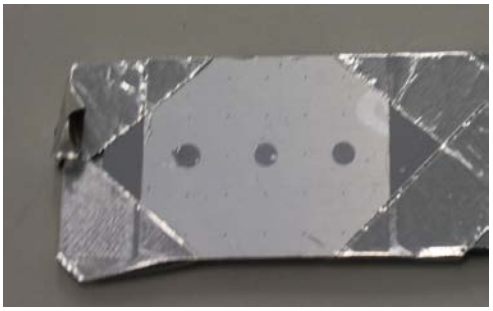

Figure 4(b) shows the final coated target setup with the 25µm Cu apertures stuck over the copper pinhole array.

Final Production Method

With the testing complete, a release layer was coated onto the slides. Once that was completed a layer of 200nm of aluminium was then coated onto it via thermal evaporation. Once those coatings were completed the pinhole array was taped down on top of the slides to create the mask for the micro-bumps. Again, via thermal evaporation the micro-bumps were created by coating 1.7µm of aluminium through the mask.

With the coatings all complete, the samples were then measured and checked under the Wyko interferometer which then showed successful approximately Gaussian shaped micro-bumps on the slides. The Wyko interferometer profile scan of the created micro-bumps shows very smooth profiles in both X+Y as shown in Figure 5.

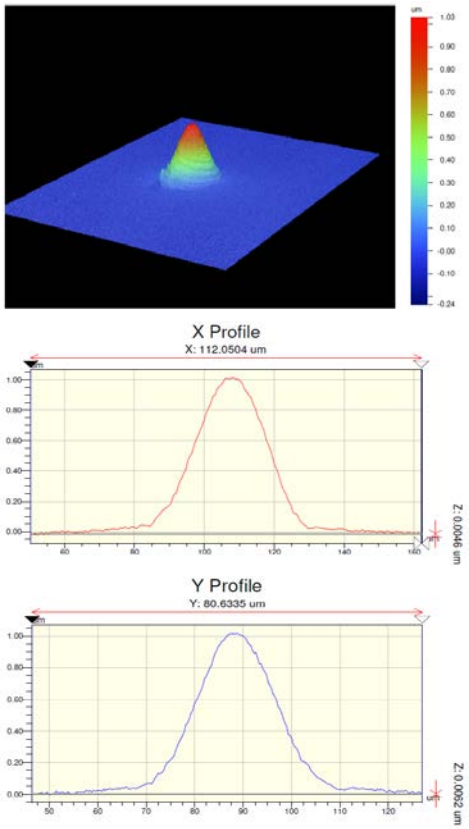

Figure 5: X+Y scanned profile of the approximately Gaussian shaped micro bumps showing a height of 1µm

Conclusion

The Target Fabrication Group successfully manufactured a novel approximately Gaussian-shaped metallic micro-bump target on a thin foil for an experiment on Vulcan. This is an extremely interesting topic and one where continued research is necessary. There is potential to continue research and development into these novel targets using different materials, thicknesses and sizes of micro-bumps.

Overview of the Target Fabrication new chemistry laboratory

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Introduction

The CLF Target Fabrication Group has recently commissioned a new chemistry laboratory to further expand the capabilities for the research, development and production of high power laser targets for internal delivery and also to the external high power laser community.

A brief overview of the facility will be presented with particular emphasis on electroplating, polymer thin film deposition, sample surface preparation (cleaning and lapping), chemical wet etching and an ongoing project to develop in house expertise in foam and aerogel production.

The Target Fabrication Chemistry Laboratory

Located on the ground floor of R1 the laboratory is located in an ideal situation to be close to the existing target fabrication laboratories allowing the transfer of components between the areas without damage.

There is significant space for numerous processes to be carried out, room for expansion and development of new capabilities.

The laboratory has good lighting, plenty of storage space and smooth functional worktop surfaces (fig. 1). There is also a large cupboard suitable for the storage of various chemicals.

Fig. 1: Pictures of the Chemistry Laboratory.

Equipment Available

A target assembly desk with a stereomicroscope, magnifying lamp and various hand assembly tools is also available (fig. 2).

A gas sensor system was installed to monitor the levels of oxygen and carbon dioxide. This will ensure the health and safety of staff while having N_2 and CO_2 gas supplies in the room.

Two extraction fumehoods were installed to provide a safe environment for various hazardous chemical processes using solvents, acids and bases.

Fig. 2: Assembly desk.

A Gallenkamp Hotbox Size 1 Oven allows temperatures up to 200°C while the Carbolite ELF 11/6B can heat up to 1100°C.

A MSE Centaur 2 Centrifuge is also available.

Electroplating

The chemistry laboratory provides a designated area for the electroplating of metals that had been conducted in the past at the Target Fabrication cleanroom [1].

This technique is used for the deposition of thick metal layers (up to 30μm) and allows the coating of complex intricate forms. The deposition of a metallic coating onto an object is achieved by putting a negative charge on the object to be coated and immersing it into a solution which contains a salt of the metal to be deposited. In other words, the object to be plated is made the cathode of an electrolytic cell [1].

The equipment used is a JB Aqua 5 Heated Bath from Grant, a Thurlby PL310 Power Supply and a fume cupboard with suitable ammonia filters (fig. 3).

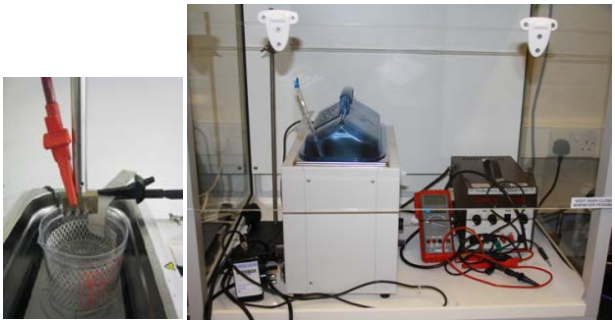


Fig. 3: Electroplating rig.

Gold and palladium have been plated (fig. 4) using electrolytes based on complex ions of ammonium gold sulphite and palladium diammino-nitride.

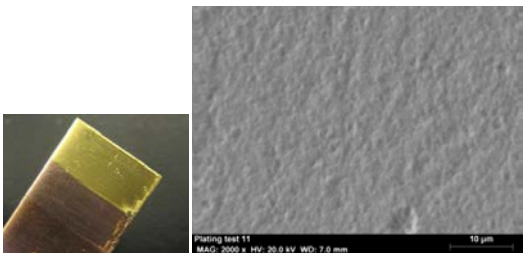


Fig. 4: Optical and SEM images of electroplated Au.

Copper and lead plating may be added to our capabilities in the future. The use of pulsed current for the metal plating of high aspect ratio structures is another area of interest.

Polymer thin film deposition

There is an increased need from the user community for polymer thin films that are CH pure or contain oxygen in their molecular structure [2], with polystyrene and formvar being the most commonly used. There is also an interest in deuterated polyethylene thin films.

The new laboratory provides an environment safer than the Target Fabrication Coating Room for the use of highly flammable solvents.

A cylindrical dropping funnel and a sample holder have been used for the dip coating process. Spin coating was performed with a SCS G3P-8 spin coater (Fig. 5).

Fig. 5: Glass cylinder for dip coating (left image). Spin coater (right image).

The spin coating and dip coating processes have different advantages and disadvantages as mentioned in table 1 and table 2.

The best polyethylene thin films were produced by dip coating while polystyrene had best results with spin coating.

Formvar can be coated with either process, although a higher risk of striations forming exists for higher film thickenesses when spin coated.

Advantages	Disadvantages
Very simple and inexpensive set up	Difficulty in reproducing results
Coating of intricate complex samples (e.g. cones)	vibrations and changing fluid speeds cause non-uniformities
Best results for high vapour pressure solvents	High amount of polymer solution needed

Table 1: Spin coating process comparison table.

Advantages	Disadvantages
Improved film uniformity	Can only be used in flat samples (e.g. slides, wafers)
Better reproducibility	Film striations with high vapour pressure solvents
Less polymer solution required	Non uniformities with high crystalinity polymers

Table 2: Dip coating process comparison table.

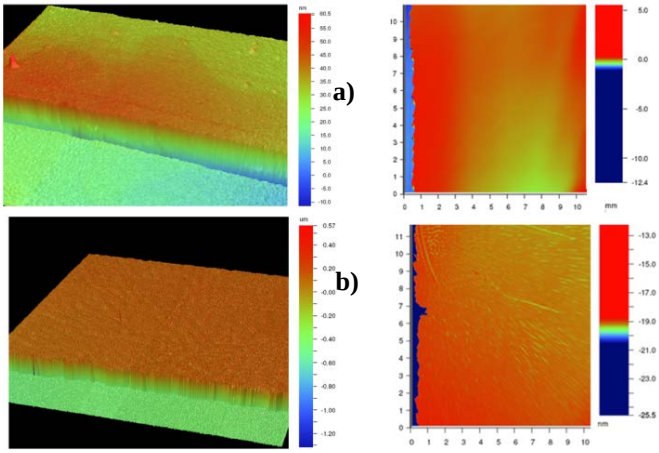


Fig. 6: 3D and 2D top view of polymer films: a) dip coated formvar and b) spin coated polystyrene.

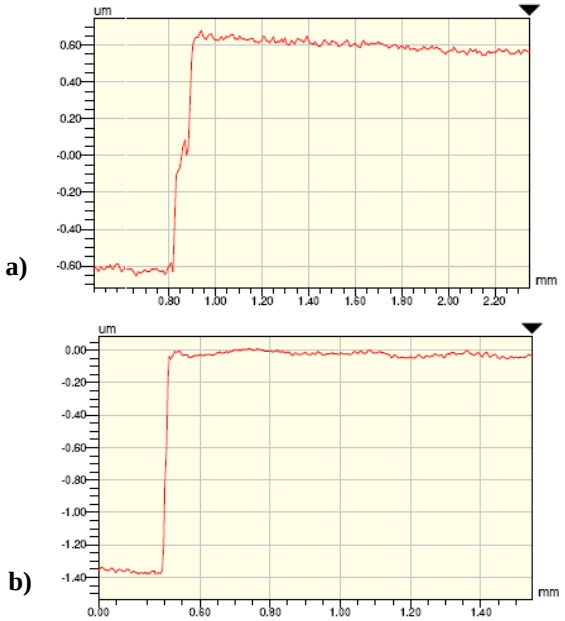


Fig. 7: Profilometry results for a) dip coated formvar and b) spin coated polystyrene.

Formvar films have been dip coated with thicknesses ranging between 10nm and 1.2µm (Fig 6a and 7a). The average variation along the whole slide was 35% while average roughness was 5.7nm.

Spin coated polystyrene films were produced with thicknesses between 27nm and 2.7µm and a variation of 15%. The average roughness was 2.6nm (Fig 6b and 7b).

To improve the current dip coating process a new mechanical dip coater will be developed, to ensure better coating uniformity and reproducibility. This system will be based on a linear stage actuated by a geared stepper motor and a controller unit. This system can be integrated with a hotplate to ensure the polymer solution can be heated while the process is running, allowing the coating of polyethylene thin films.

Surface preparation and wet etching

The wet etching of metals such as copper and aluminum is often required for the release of sacrificial layers from mandrels.

Polymer films, such as polystyrene and polyester also need to be etched for release layers and removal of support layers in commercial films.

Another commonly used etching process is the removal of Silicon with heated KOH (fig. 8).

All these processes involve the use of hazardous chemicals that require working areas segregated from incompatible chemicals and are carried out in fume extraction cupboards.

Fig. 8: Silicon wet etching with KOH at 80 C.

Hand surface lapping and polishing is used to change the roughness of samples, remove waviness as well as the cleaning of surface contamination. A Kemet 3 Lap Kit with diamond compound and various plates is available.

Some experiments need surfaces cleaned that cannot be processed using the usual techniques such as anionic surfactants, solvents and ultrasonic agitation. In these cases a more aggressive removal of contaminants is required, work has been carried out for experiments in Artemis that has involved the use of heated sulfuric acid solutions such as Piranha.

Foam production

The Target Fabrication Group is developing a capability to produce low density materials for laser targets and has been requested to produce polymer foams with pore sizes down to 1µm and Densities between 3 mg/cm^{-3} and 800 mg/cm^{-3}.

Sol-gel is commonly used to obtain such low density polymeric foams. In this process, solid nanoparticles are dispersed in a liquid (a sol) followed by agglomeration to form a continuous three-dimensional network extending throughout the liquid (a gel). A monomer in a solution is polymerized and the remaining solvent is replaced inside a high pressure chamber by liquid carbon dioxide (CO_2) (fig. 9).

Next, the temperature and pressure are raised above the critical point of CO_2 (fig. 10). This causes the liquid CO_2 to change to vapour without change of density and therefore without surface tension effects that would damage the delicate foam structure.

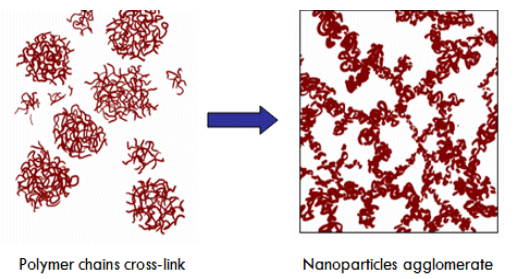


Fig. 9: Sol-gel process [4]

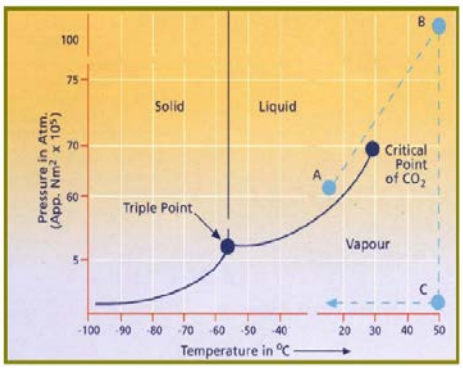
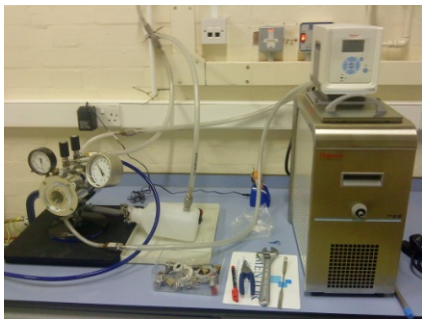


Fig. 10: Temperature vs. pressure during the supercritical point drying.

a)



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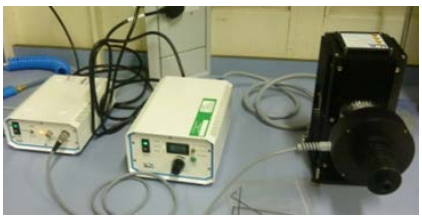

Fig. 11: a) supercritical point dryer, b) UV lamp system [5].

A Critical Point Dryer from Quorum Technologies Refrigerated and a Bath Circulator are used to control the temperature and pressure of the process (fig. 11a).

A UV System with flexible optic fibres was obtained from LOT to polymerize the foams (fig. 11b).

Tests will be carried out over the next 6 months and collaborations with St Andrews University will allow the CLF to produce foam targets in house.

Conclusion

The new chemistry laboratory has further extended the capabilities of the target fabrication group and will enable the development of new processes for laser targets production. The housing of the laboratory in a dedicated room will ensure a more suitable environment for the chemistry processes that are sensitive to environmental factors.

References

[1] S. Serra, C. Spindloe, H. Lowe and M. Tolley, **Electroplating of gold and palladium for high power laser target fabrication**, CLF Annual Report, 2010.

[2] S. Serra, C. Spindloe, H. Lowe and M. Tolley, **New capabilities at RAL Target Fabrication for high power lasers targets.** High Power Lasers Annual Meeting Poster 2010.

[3] J. W. Falconer, W. Nazarov, C. J. Horsfield, **In situ production of very low density microporous polymeric foams,** J. Vac. Sci. Technol. A 13(4), Jul/Aug 1995.

[4] http://www.aerogel.org/

[5] **E3000 Series Critical Point Drying Apparatus Operating Manual**, Document Number OM-E3000, Issue 3 (09/07), Quorum Technologies Ltd.

Novel Micro-Focusing Cone Target Fabrication

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Introduction

Significant work is being carried out in the field of high power laser research into the areas of Inertial Fusion Energy (IFE) and also the medical and security applications of high power laser interactions. A number of laboratories across the world are developing facilities and fundamental research projects to exploit these fields, with the most high profile being the National Ignition Facility (NIF) at the Lawrence Livermore National Laboratory (LLNL) in the USA. This facility aims to use the IFE concept to show a net gain of energy from the fusion reaction and is on track to demonstrate this within two years.

Such experiments depend on the availability of large amounts of laser energy (with the NIF project costing upwards of $3 billion). This cost is mainly due to the fact that high energy laser technology is very expensive and to increase the energy of such a laser system by even 10% would cost $100 millions. The proposed STFC 10PW and EU ELI laser facilities are also planned to come online over the next decade.

It has been shown that typically 30% of laser energy is absorbed by a target in a high power laser interaction [1] with the rest being specularly reflected and usually lost from the system. Therefore it can be seen that if the laser target interaction could be increased in efficiency this would lead to a highly cost effective way of increasing the energy that is coupled into a target. It has been suggested that micro-cone geometries integrated into a target design have the potential to increase the laser absorption. This target design is such that the reflected pulse interacts with another part of the target, a short time after the main pulse has interacted with it.

While modern laser systems that use optical parametric chirped pulse amplification can be designed to deliver the bulk of their energy on timescales of the order of tens of femtoseconds, typically the pulse has a characteristic profile including amplified spontaneous emission ($\sim 10^{-8}$ of the main pulse intensity on the nanosecond timescale), and prepulses, commonly cited as a problem due to leakage from Pockel's cells ($\sim 10^{-5}$ at ~50ps). With intensities of 10^{13} W/cm^2 being sufficient to ionise target material these features can result in unwanted plasma formation, and it is possible with a front surface plasma expansion of around 3 µm/ns [2] that the cone target could become filled with plasma before the main pulse arrives. This would mean that the concept of the target cannot be tested with such a laser pulse where intensities of 10^{21} W/cm^2 are reached.

Therefore to experimentally examine such cone targets in this intensity regime, a plasma mirror must be introduced [3] to eliminate ASE effects on the large timescales and reduce prepulse intensities by a factor of $\sim 10^3$ to allow the concept to be investigated.

It has been shown in experiment that the conversion efficiency of laser energy to fast protons can be increased by a factor of 3.3, as well as increasing the maximum proton energy [4] by the introduction of a high intensity prepulse a short time before the main pulse. This is attributed to the increase in laser energy absorption by the plasma due to its increased scale length by the prepulse. The proposed microcone targets will increase plasma absorption by both this mechanism and by the multiple reflections inside the cone, being better absorbed after each reflection, although this increase in scale length must be limited for the reasons already discussed. Nonlinear optical effects will also occur on the scale of the laser pulse spot size approaching the cone diameter which will cause the laser to have an increased intensity as the laser and reflections approach this region.

Target Design

The Astra Gemini laser has a focal spot size that is limited to approximately 1.26 times the diffraction limit of the laser beam. At this point it is very difficult to focus the laser beam any further using conventional techniques. The limit for the Astra Gemini system is about 2µm full width half maximum. It is suggested that if a micro cone is produced in a thin foil that is of the order of 5µm at its opening diameter the effects discussed above will increase the absorption of the laser energy.

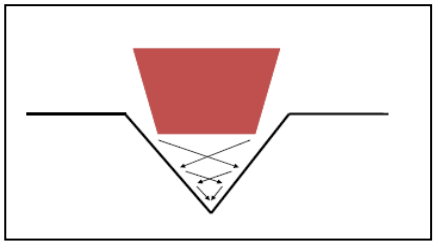

Figure 1: The target design

Production

The CLF Target Fabrication Group in collaboration with the Micro and Nanotechnology Centre at RAL have produced targets that have been developed using technology first used as medical devices for the injection of vaccines [5]. These micro-projection (MP) arrays are fabricated in silicon by Deep Reactive Ion Etching (DRIE).

To tailor the technology to be useful for high power laser targetry the silicon needles were used as moulds (or formers) to allow a secondary material to be deposited onto the needles. The etching of the initial silicon needle then leaves the inverse profile in a foil target (a microcone). For the purposes of high power laser target fabrication the array of features were spread out to ensure that when irradiated targets that are adjacent were outside the area of laser damage due to laser shock or material redeposition. These targets are spread out at a spacing of approximately 500µm to allow for each one to be used as a laser target for a high rep-rate laser system.

A protective SU8 layer was deposited onto a silicon wafer and a mask was used to selectively remove some parts leaving a number of different features sizes on the surface. A combination of plasma isotropic etching and an oxidization sharpening process produces the needles. Different ratios of gas were used to vary the size and the height of the cones and also the cone angle. This resulted in a wide range of micro-needle heights and sizes being formed with some needles being fully etched and

others having a top hat profile at the tip. The needles are shown in figures 2 and 3.

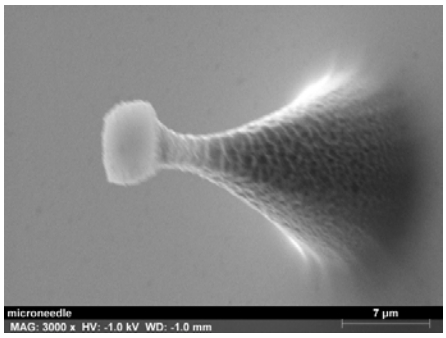

Figure 2: A micro-needle not fully etched.

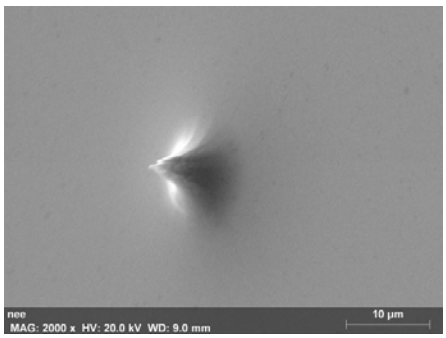

Figure 3: A fully etched needle.

Electroplating and Etching

The silicon mould was electroplated in the Target Fabrication Chemistry Laboratory. The wafer was first coated with a thin gold conduction layer to allow the target to be plated and then was diced into a chip that was of a size useful to become a laser target and electroplated with gold as described in [6].

A 30µm layer was deposited using a low current density ($0.2A/dm^2$) to ensure a highly uniform and compact film. Due to the heating and long electroplating time, regular monitoring and ammonia additions were required to maintain the electrolyte pH above 8.

SEM analysis showed that the needles were fully coated and also showed interesting features around where the needles were. These areas of locally higher electric field preferentially coated to provide a thicker layer at these points. This is useful to note because when shooting the target a thicker foil will be seen by the laser than the bulk plated material. This is shown in figure 4. Also shown in figure 5 is a range of needles that have been plated showing differing amounts of over-plating. This is due to the varying heights and etching amounts of the needles as the chip contains a variety of needles.

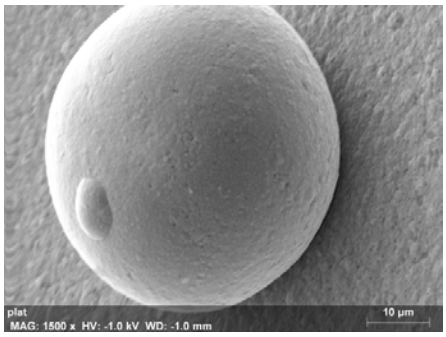

Figure 4: Over-plated micro-needle structure

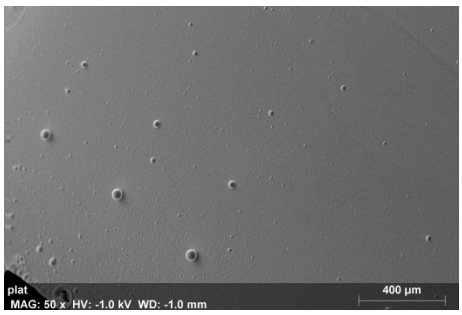

Figure 5: The variation of over-plating across a needle array

The silicon mould was then etched away in a heated solution of potassium hydroxide to release the gold plated foil from the silicon mould. This is a lengthy process but when fully etched the resultant foil is a micro patterned thin foil target.

Characterisation of Micro-Target

The gold foil was characterized under an optical microscope and also with an SEM. Optical microscopy shows the spacing of the targets in a regular array and gives an indication of the opening hole size. This will be useful for alignment of the target in the interaction chamber. Figure 6 shows an image taken using polarised light. The spacing of the targets is 500µm in the vertical direction and 300µm in the horizontal direction.

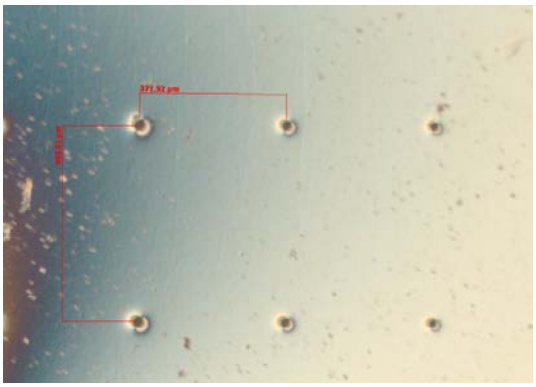

Figure 6: A polarised light image of the micro-cones.

The SEM analysis in figures 7 and 8 shows further detail of the micro-cones and details the size and structures on the internal wall where surface structure and some small debris can be seen. The equipment cannot image the bottom of the holes due to the high aspect ratio of the walls. Further work will be carried out to fully characterize the internal walls of the cones and to determine tip sizes.

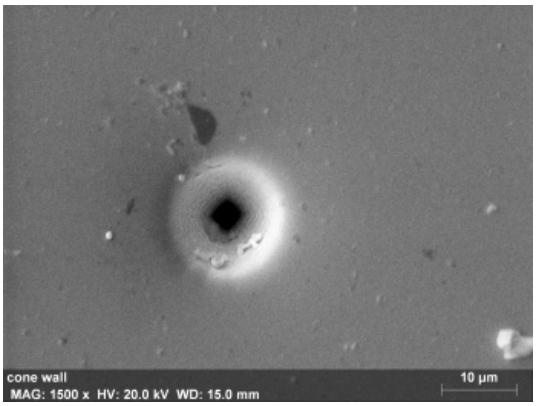

Figure 7: SEM image of the microcone at low magnification.

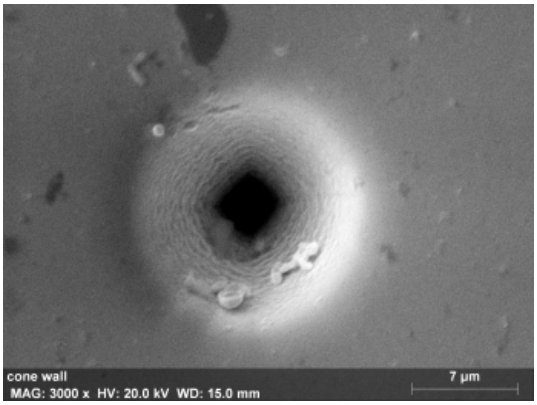

Figure 8: SEM image of the microcone at higher magnification.

Conclusions

We have shown that micro-conical designs can be fabricated using known technologies and that these can be adapted and tailored for use on high power laser facilities. The use of the micro-needles as moulds to pattern a thin foil target can produce micro-cone geometries that can be controlled by the variation of the original production parameters. More work is needed to fully characterise the cones and to understand the tip geometries as these are challenging to image with standard techniques. These targets also need to be tested experimentally and will be fielded in upcoming LIBRA experiments at RAL.

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Production of Novel Thin-Walled Cone Micro Targets for an Astrophysical Jet Experiment

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Introduction

The Target Fabrication Group was requested to supply a number of thin walled cones with an opening angle of 140 degrees. These targets were made with a gold wall that was a thickness of 3um or less. 20 Cones were required for the TAW experiment in June 2010.

The aim of this type of experiment is to simulate in laboratory conditions the formation of jets from young stellar objects and in particular investigate the effects of radiative cooling on plasma jets. Thin cones are irradiated around their apex with an intense laser, driving jets with velocities >100km s^{-1}. The plasma formed by the interaction of the laser with a target is focused on axis due to the conical shape of the target and forms a jet. This can then be studied with a variety of diagnostics [1].

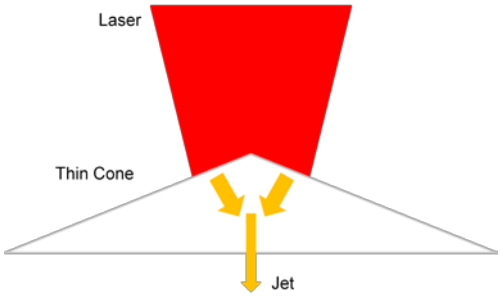

Figure 1: The formation of plasma jets.

Previous Micro-Cone Fabrication

Targets have been previously fabricated by the Target Fabrication Group that were thin walled aluminium cones that had a similar opening angle, a diameter at the open end of ~1mm and with wall thicknesses of approximately 3µm. These targets were fabricated using a coating process to deposit 3µm of aluminium onto a copper cone and then etching the mandrel material away to leave a free standing thin walled cone. These targets were fragile and there was a low yield from each batch due to the thinness of the aluminium and to the etching processes destroying the foils.

Production Process

Initial tests to produce the new batch of targets focused on techniques that have been used to produce other thin foil structures. This consists of coating onto a mandrel and then etching the material away to leave a free-standing target of the required geometry.

The Precision Development Facility (PDF) in RAL Space machined twenty mandrels, as specified in figure 2a, out of 0.5mm thick copper using a precision lathe. The finished mandrel is shown in figure 2b.

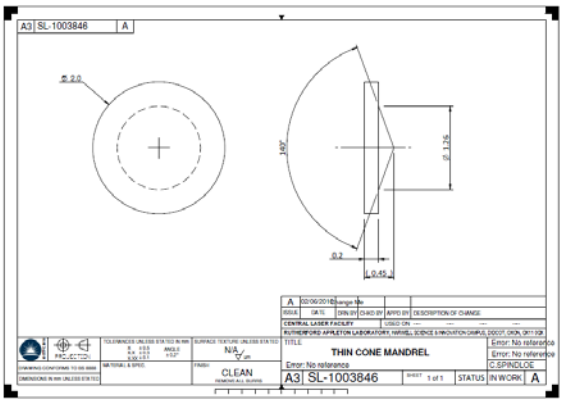

Figure 2a: Engineering drawing of thin cone mandrel.

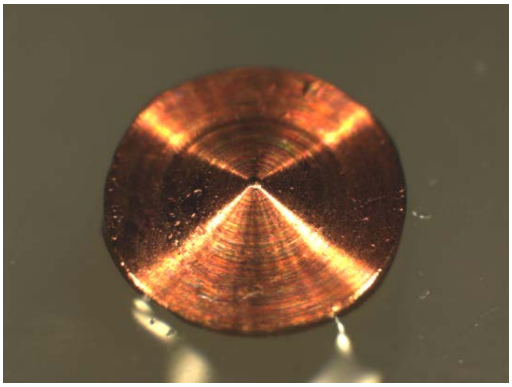

Figure 2b: Optical image of thin cone mandrel

Once the mandrels had been cleaned in ethanol in an ultrasonic bath they were ready for characterization. They were scanned using a white light interferometer, as shown in figure 3a, to look at (surface roughness and) the angle of the cone. As shown in figure 3b the angle achieved during the machining of the mandrels was 145° which was within specification.

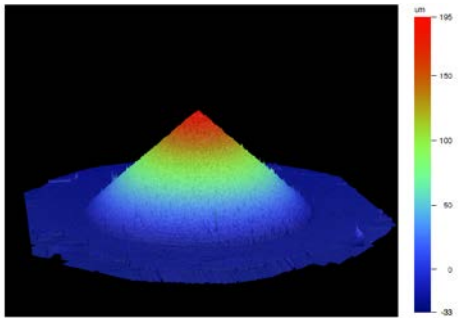

Figure 3a: White light interferometer scan of thin cone mandrel (z –axis stretched showing artificial apex angle).

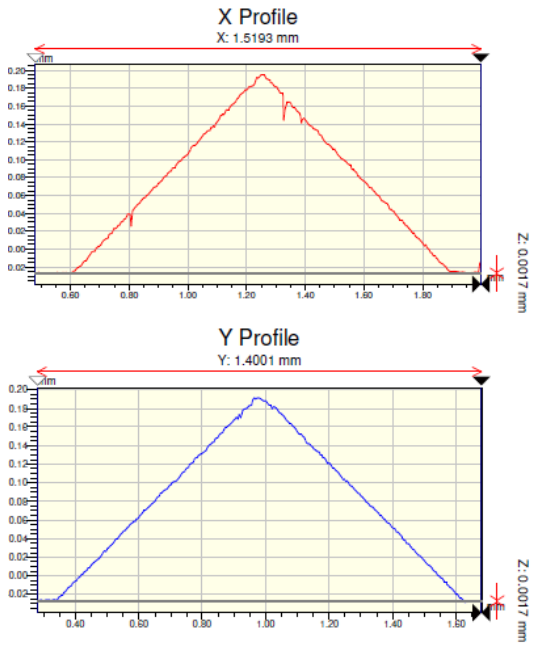

Figure 3b: Lineout of white light interferometer scan of thin cone mandrel

The mandrels were mounted on a glass microscope slide and placed inside the coating chamber. They were then coated with gold using a physical vapor deposition process, in this case electron beam evaporation, to a thickness of 1.5µm

This is the optimal process for coatings up to 2-3µm. However if a coating needs to be thicker then research and development coating plants available to the group in house are not able to coat to these thicknesses. Sub-contracting of thicker coatings is available but also electroplating processes have been developed to coat materials of greater thicknesses [2]

To measure the coating thickness, a witness slide was coated at the same time as the cone mandrels and the thickness was verified by using a contact profilometry system and was found to be 1.5µm± 0.1µm.

Etching process

The etching process is carried out using a diluted nitric acid solution to etch the copper. The mandrels are demounted from the glass slide and submerged in the nitric acid solution, where it is left for approximately 10 minutes to allow the acid to etch away the copper mandrel and ensure that the gold cone is free of any copper contamination. The cones are then removed from the solution and repeatedly rinsed in de-ionised water to ensure all traces of the nitrate solution are removed. The cones are then checked under a optical microscope for any remaining copper that might be left in the cone tip. If some is apparent the process is repeated until all the copper has been etched.

Characterisation

The finished targets were characterised for form and size on both an optical microscope and a white light interferometer. The images showed that a good replication of the mandrel was achieved in the target and witness plates confirmed that the thickness coated was as specified. The form replication of the mandrel into the target was interesting as 3µm thin foils are not usually free standing but the geometry of the targets made this possible.

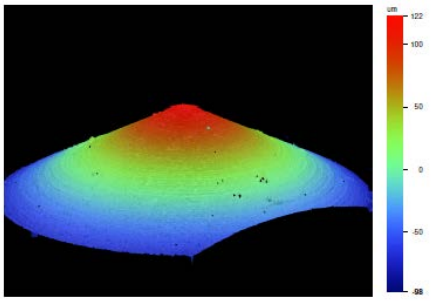

Figure 4: 3D scan of the outside profile of a fully competed cone (z – axis stretched showing artificial apex angle).

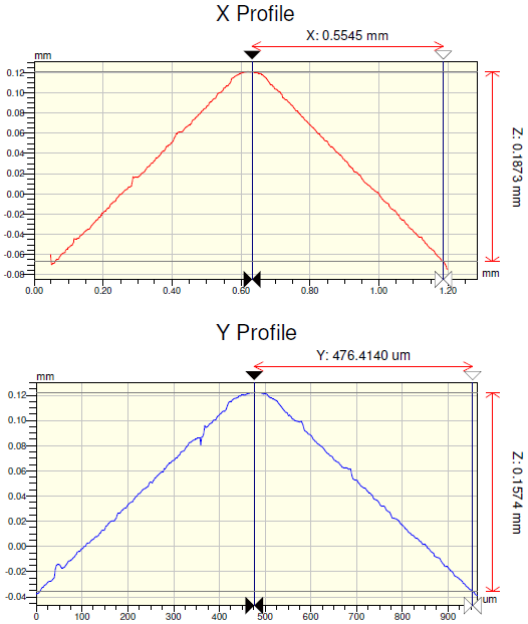

Figure 5: Line out of the external profile of a free standing cone

Mounting Process

The targets were mounted onto a holder that was photo-etched with a specifically dimensioned hole so that the cone would sit with its tip and its entrance protruding respectively above and below the mount to allow for probing of the interactions. 20 targets were delivered for an experiment in TAW in June 2010

Conclusions

Using micro-machining and thin film coating techniques thin walled micro cones can be fabricated with precise dimensions and thicknesses. Further work will be needed to expand this technique to batch production to deliver to the high rep-rate laser systems that are coming online across the world.

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