Installation of the Target Fabrication Quality Management System

Contact *Donna.wyatt@stfc.ac.uk*

E. Barber

Micro and Nanotechnology Centre
Rutherford Appleton Laboratory, Science and Technology Facilities Council, Didcot, Oxon, OX11 0QX

D. Wyatt, C. Spindloe, I. East, H. Lowe, S. Serra and M. K. Tolley

Target Fabrication, Central Laser Facility, Rutherford Appleton Laboratory, Science and Technology Facilities Council, Didcot, Oxon, OX11 0QX

Introduction

With target complexity increasing and also with the introduction of high repetition rate laser, systems such as Astra Gemini, the demands on Target Fabrication to improve productivity and quality increase. It is essential to be able to trace, track and record target fabrication processes both during and after an experiment, to interrogate data and to understand the underlying science that is achieved. To deliver this service and to improve and streamline the processes from inception to delivery of a product the Target Fabrication Group has introduced a Quality Management System (QMS) into its experimental delivery procedures. This quality management process incorporates the full process of target fabrication from the initial conceptual design of a target, through the planning stage to manufacture and finally delivery to the experimental user group for their experimental shots.

What is a Quality Management System?

A QMS does not just focus on the quality of the product but also focuses on the means to achieve quality. It is made up of procedures, processes and resources which collectively monitor and improve the system. This reduces the risks involved whether financial, safety or consistency of work. A QMS provides the framework for continual improvement to increase the probability of enhancing customer satisfaction[1]. The principal concepts of the QMS are[2]

1. Achieve, maintain and seek to improve continuously the quality of its products in relationship to the requirement for quality.
2. Improve the quality of its own operations, so as to meet continually all customers and other stakeholders stated and implied needs.
3. Provide confidence to its internal management and other employees that the requirements for quality are being fulfilled and maintained, and that quality improvement is taking place.
4. Provide confidence to the customers and other stakeholders that the requirements for quality are being, or will be, achieved in the delivered product.
5. Provide confidence that the quality system requirements are fulfilled.

Benefits

Many of the systems used in a QMS occur in the natural development of any department – any business that has run for more than 3 years will already be 80% compliant, and Target Fabrication was no different. There were very few changes in procedures that were required to fully integrate a QMS into Target Fabrication, but the benefits have had a very high impact, not only to Target Fabrication, but also to the communities that interact with them.

Traceability of Targets There is now complete traceability of the materials used in each target. When an external supplied component or material is ordered it is recorded in a central order book that all of Target Fabrication staff can access giving all incoming materials a unique number. The numbers are recorded against each target identification number so every part of each target can be traced back to its source. (The order book is also used for tracking non-target related items as part of the QMS procedures). This small addition to the purchasing procedure gives a huge benefit to both Target Fabrication (in terms of tracking batches of parts) and also to users who have confidence that their targets (and parts) meet good quality requirements. Any anomalous results can be traced back, for example, to a possible supplier issue. The tracking also gives assurance the correct targets have been manufactured and delivered. The recording of targets and their components also means that it is easier for Target Fabrication to keep track of completed orders if a change of fabricator is required part way through an experiment. It is now much easier to share or delegate the fabrication of targets if the fabricator is off-site or required elsewhere. All procedures are now recorded and approved and this allows for more consistent fabrication as all fabricators now work to the same defined methods. Significant effort has been focused to ensure that although the QMS is thorough it incorporates the experimental nature of the department and has been designed to cope with the daily changes that are inherent in the work that is carried out while still maintaining accurate records.

Changes made to the Target Fabrication Structure

As part of the new system, two new roles were identified – a Laboratory Quality Manager (QM), who oversees the system and makes sure that the procedures are helpful rather than a hindrance; and an internal auditor, someone to inspect how well the system is being followed. The QM monitors the results of all processes such as on-time-delivery, and the number of non-conforming (defective) targets produced. All changes are reviewed and, where possible, procedures are put in place to improve results. The QM also monitors results from the coating plants, customer feedback, and internal audits.

Internal Audits

Whilst the procedures that have been defined in the QMS are fixed, the department itself is constantly changing. The task of an internal audit is primarily to ensure that the procedures still meet the requirements of the department. Target Fabrication activity has been split into 12 different areas; each area is audited annually by the internal auditor. Changes that have been made already include the move to using Shared Services for purchasing, and the need for enhanced documentation during the planning phases of experiments.

External Audits

To be granted accreditation the Target Fabrication QMS has to be inspected by an external ISO9001:2008 certified auditor. This inspection is split into 2 parts. The documentation audit was carried out in March 2010 and there were found to be no Major problems. The final certification audit will be in August 2010.

References

1. Quality management systems – Fundamentals and vocabulary. BS EN ISO 9000:2005
2. Quality management and quality assurance standards. Part 1: guidelines for use. BS EN ISO 9000-1:1994

Electroplating of gold and palladium for high power laser target fabrication

Contact *Sam.Serra@stfc.ac.uk*

Sam Serra, Chris Spindloe, Hazel Lowe and Martin Tolley

Rutherford Appleton Laboratory
Chilton, Didcot
Oxfordshire, UK
OX11 0QX

Introduction

This article describes the setting up of gold and palladium electroplating processes in the Target Fabrication Laboratory. This will meet the needs of the user community for: thick metal layers (up to 30um), coating of complex intricate forms and different types of metal surface finish. In the past thick films were deposited using coating plants in a long and expensive process or subcontracted.

Electroplating process

Electroplating (also called electrodeposition) is the process of producing a coating on a prepared conductive surface by the action of an electric current. 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 (Fig. 1). The metallic ions of the salt (M^+) carry a positive charge and are thus attracted to the object. These metal ions receive electrons and are reduced to metallic form at the interface between the solution and the cathode, plating onto its surface [1, 2].

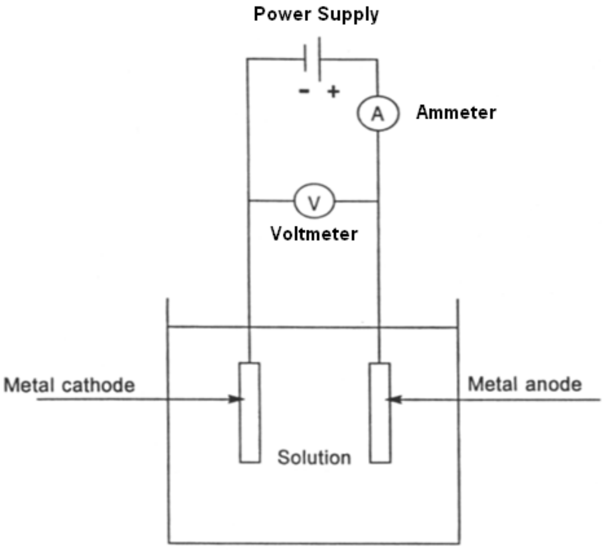


Fig 1: Schematic for electroplating.

Sophisticated plating electrolyte formulas have been developed and are being routinely employed providing greater control over the deposition process such as layer thickness, porosity, adhesion and surface finish. New developments enable greater plating speed and better throwing power (the ability of a plating solution to produce a relatively uniform distribution of metal on a cathode of irregular shape). In addition, electroplating of materials such as palladium, gold and copper are now broadly used in electronics for connectors, circuit boards, contacts, etc. Generally the more complex the ion the more efficient and smoother deposits occur compared to simple ions [3].

In aqueous solutions such complex ions dissociate slightly into simpler ions, and metal is deposited by direct discharge from the complex ion.

Compared with other metals, pure gold is chemically least reactive, though it is attacked by aqua regia (1:4 volumetric ratios of nitric acid and hydrochloric acid solution) and can be dissolved in alkaline solutions of cyanide or sulphite. Most gold electrolytes are of the complex cyanide ion that efficiently creates smooth deposits. However, to avoid using cyanide, which is highly toxic, an electrolyte based on ammonium gold sulphite was used. Compared to cyanide electrolytes, the sulphite process produces more bright, hard and ductile deposits. Another advantage is the good throwing power of these electrolytes. The disadvantages are the limited life due to formation of free sulphite, leading to a rapid increase in solution density and precipitation. Another drawback is the higher commercial cost of the sulphite solution due to its complex preparation [4].

Palladium is a greyish white metal that is attacked by nitric acid. It has high corrosion resistance though it oxidizes fairly easy when heated. It is unaffected by most acids, alkalis or other corrosive agents with the exception of aqua regia [5]. For our palladium plating a virtually neutral solution based on palladium diammino-nitride complex was employed.

Electroplating experiments

In order to set up and optimize the plating processes for Au and Pd initial experiments were conducted on copper foils. Flat samples were chosen to facilitate area calculation, sample preparation and surface characterization.

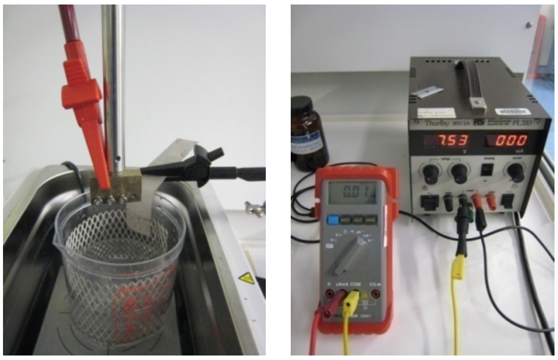


Fig. 2: Plating setup in Target Fabrication.

The influence of current density and surface cleanness on the adhesion and morphology of the plating deposit was studied. This was done while maintaining constant agitation, solution pH, temperature, anode type and distance between electrodes. After being optimized, the gold plating process produced a smooth deposit with good brightness and ductility (fig. 3). The coatings thickness, morphology and roughness were characterized by SEM and surface profilometry. A good throwing power was observed: the surface roughness tended to decrease as the plated deposits thickness increased.

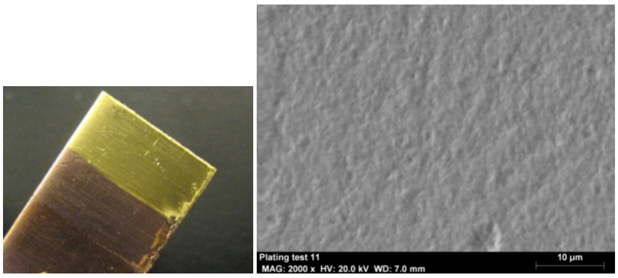


Fig. 3: Optical and SEM images of electroplated Au.

Electroplated palladium grew into more nodular coarse deposits and the throwing power was not as good as gold (fig. 4). However the roughness and adhesion of the deposit were good enough for our intended applications.

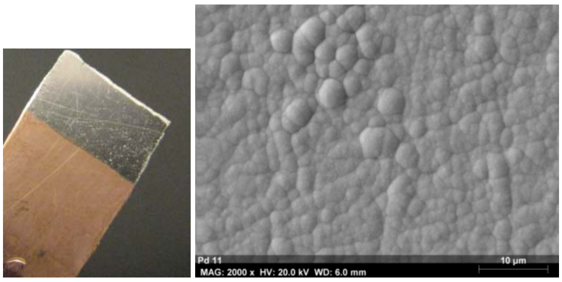
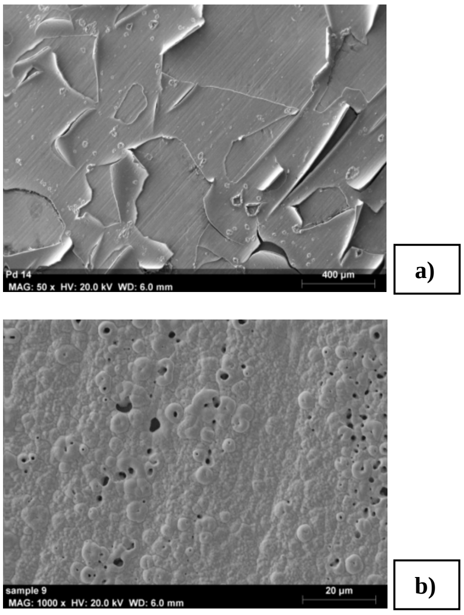


Fig. 4: Optical and SEM images of electroplated Pd.

The palladium and gold electrolytes require regular maintenance by adding ammonia solution when the pH drops and filtering when solid particles are found in suspension. The maximum thickness obtained for Au deposits was 35um. The Pd processes allow us to obtain metal coatings that can go up to 25um thickness. However it may be possible to go beyond these thickness limits by using very low deposition rates.

As expected, the surface preparation had a strong influence on the quality of the plated deposits for both Au and Pd. Substrates that were only cleaned with detergents and solvents under ultra sonic agitation and heating yielded deposits that peeled off in some areas, especially under nitrogen clean or by pull out tests with adhesive tape (fig. 5a). It seems that although organic compounds such as grease or oil were removed during cleaning there was still surface oxide that weakly bonded with the metal deposit.



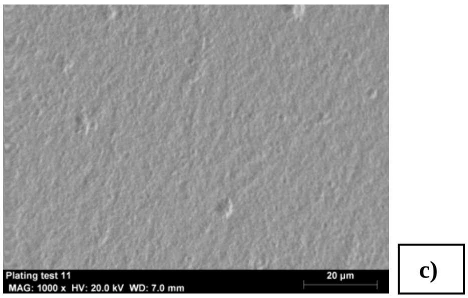


Fig. 5. SEM images of plated deposits: a) substrate cleaned with solvents and detergent, b) acid cleaned, c) acid cleaned and lapped.

By adding the step of cleaning the substrate with a diluted solution of sulphuric acid the deposit adhesion improved although some porosity, nodular growth and small areas of bad adhesion remained (Fig 5b). Finally, a third cleaning step of lapping was added where a more compact fine grained coating was plated. It is evident that a smooth lapped surface, free from scratches and pitting is more favorable for plating. It is also possible that the acid clean on its own was not totally effective at removing the oxide (Fig 5c).

Conclusions

Initial steps have been taken to develop a new deposition process at Target Fabrication. This process is quicker and more affordable for the deposition of thick metal films. However it is limited to conductive surfaces that are chemically resistant to the plating solutions. As a result, any incompatible surfaces should be coated with a thin conductive seed layer prior to plating.

Although only individual samples were plated this process can be adapted for mass production by making adjustments such as a larger plating vat or a suitable sample holder.
For the deposition on non conductive complex forms, such as polycarbonate spheres, more work must be carried out.
In the future, other metals such as Cu or Ag could be added to the Target Fabrication plating capability.

Acknowledgements

The authors would like to thank the support from John Spencer from the Space Science and Technology Department (SSTD) and also Gabriel Schauman from GSI Darmstadt. Also we aknowledge the contribution from the Laser for Science Facility (LSF) and the CLF Mechanical Workshop.

References

1. Electrochemistry Encyclopedia, http://electrochem.cwru.edu/encycl/art-e01-electroplat.htm
2. L. J. Durney, *“Electroplating engineering handbook”*, Chapman and Hall, 1996.
3. J. Poyner, *“Electroplating”*, Argus Books Ltd, 1987.
4. F. H. Reid, W. Goldie, *“Gold plating technology”*, Electrochemical Publications Ltd, 1974.
5. B. Tromans, D. Probert F. Essex, *“The Canning Handbook – Surface finishing technology”*, W. Caning plc, 1982.

Mass Production of AFI Cone Geometries for Fusion Target Studies

Contact *christopher.spindloe@stfc.ac.uk*

C. Spindloe, H.F. Lowe and M. K. Tolley

Target Fabrication, Central Laser Facility, Rutherford Appleton Laboratory, Science and Technology Facilities Council, Didcot, Oxon, Ox11 0QX,

P. Hiscock and M. Beardsley

Precision Development Facility, Space Science and Technology Department, Rutherford Appleton Laboratory, Science and Technology Facilities Council, Didcot, Oxon, Ox11 0QX

Introduction

The recently launched HiPER (**Hi**gh **P**ower laser **E**nergy **R**esearch facility)[1] project is a European initiative to open up Inertial Fusion Energy as a commercial process for energy generation. One of the baseline targets[2] for the HiPER project uses an innovation called AFI (Advanced Fast Ignition) in which a fuel sample is compressed using multiple laser beams around the end of a gold cone. An ‘ignition’ beam is then injected into the cone to induce a thermo-nuclear reaction. The HiPER facility is planned to run at a repetition rate of up to 10Hz and will require a large number of targets. If the baseline target selected is an AFI target then there will need to be a reliable supply line of high quality high specification target components at a low cost (a few cents per target). This report summarises the current capabilities of cone production in STFC and gives consideration to the scale up options that are available.

Standard AFI Cone Production

The first demonstration of the AFI concept was at the Rutherford Appleton Laboratory in 2000[3]. The cone targets for this experiment were produced in a ‘one-off’ fashion where they were turned on a lathe to profile the inside and outside features[4]. This production process supplied high quality targets but in low numbers and the cost of an individual target was upwards of £1000. While this was a feasible production method when experimental requirements were low, to carry out statistical studies and investigate a number of different parameters upwards of 50 targets are needed for an experiment. Therefore to increase the number of targets that are available the development of techniques for the mass production of cone targets was investigated.

Simple-geometry cone targets were produced using a high precision Kern CNC micro-milling machine that is capable of reproducing the geometries available on a lathe. The fully automated machine with online tool wear measurement and tool change capabilities produced a number of mandrels ranging in number from single cone geometries to arrays of up to 25 targets. This technology was scaled to be able to produce 50 cone targets in a production run opening up the way to statistical studies during experimental campaigns[5]. (See figure 1)

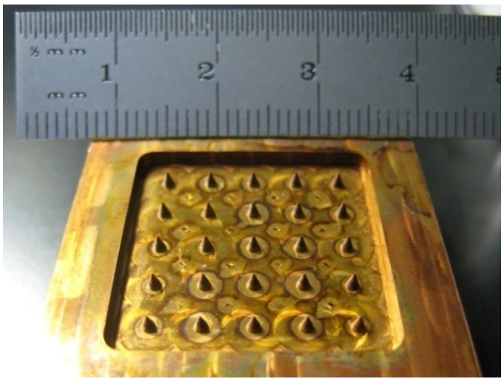


Figure 1: A 5 x 5 machined array of microcone mandrels

The targets that were produced in this way were shot on the Vulcan Laser system in November 2008 and exhibited a good performance [6]. The surface roughness of the internal walls of the cone was less than 1μm Ra. (See figure 2.)

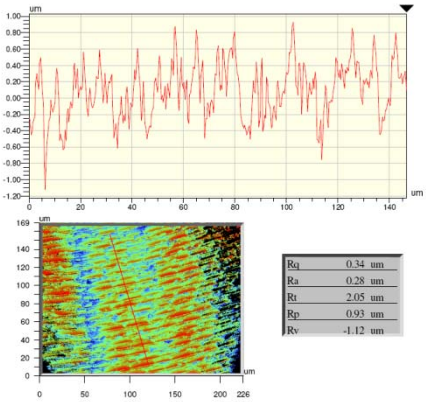


Figure 2: Lineout and 2D data showing the surface roughness on the internal wall of a mass-produced cone

Other Materials

Using the above production method it is also possible to produce cone targets in copper. By machining an aluminium mandrel and plating with copper it is possible to mass produce copper cones in batch numbers of 50. (See figure 3)

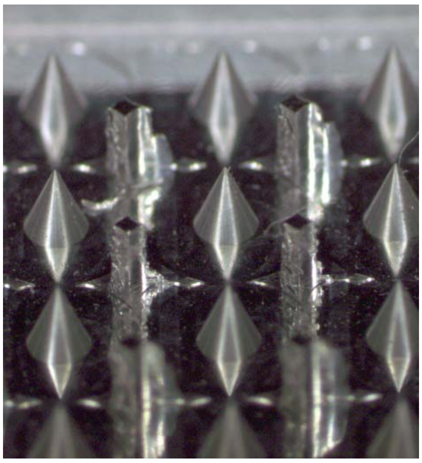


Figure 3: An array machined in aluminium for copper plating

Advanced Geometries

Using similar techniques to the production of standard cone targets it was possible to mass produce cones with novel geometries. A formula for a parabolic shape was used to create a number of machining points which were input into the Kern machine. (See figure 4)

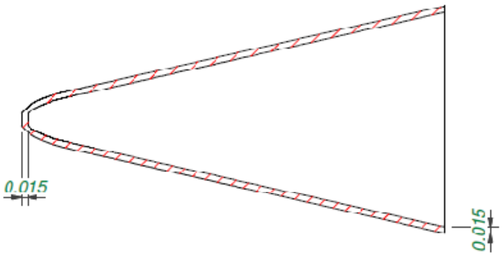


Figure 4: The design for the parabolic cone targets

Using a tool path that stepped every 2µm a mandrel was created in aluminium the replicated the internal profile of the cone. This was then plated in copper and re-machined using a number of datum points to ensure that the wall thicknesses were constant. For a number of cones the tip was removed to leave an open ended cone.

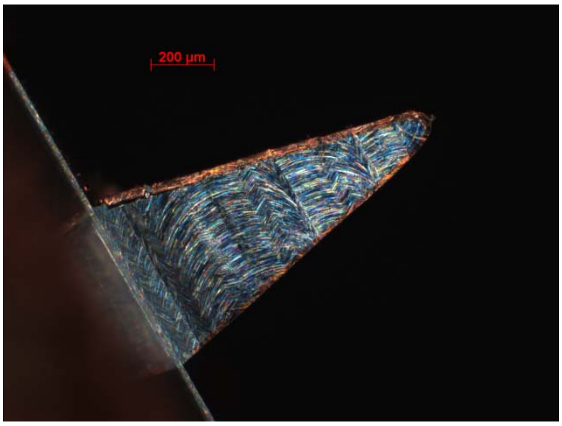


Figure 5: The sectioned copper cone on the sectioned aluminium mandrel

Figure 5 shows the reproduction of the parabolic shape on a cone that has been sectioned. To remove the aluminium mandrel from the rest of the cone the samples were placed in sodium hydroxide to etch the aluminium.

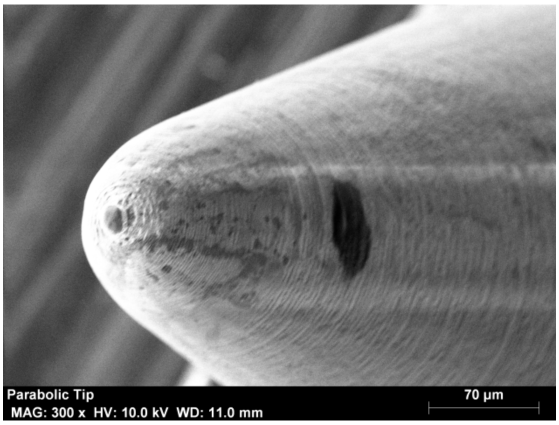


Figure 6: A SEM image of the parabolic shape of the tip.

Figure 6 is an SEM scan of the parabolic tip that shows the form and also gives an indication of surface roughness. The wall roughness is similar to that on a standard cone but as the step size is constant, the parabolic tip shows a smoothing effect since the tool interaction is different when machining the changing angle at the tip of the cone. There is also a small feature at the tip of the cone where the material has not been fully removed.

In figure 7 the tip of the cone has been removed while the mandrel is still in place. In this instance it can be seen that the hole size that will be left when the mandrel is removed will be in the order of 40-50um diameter.

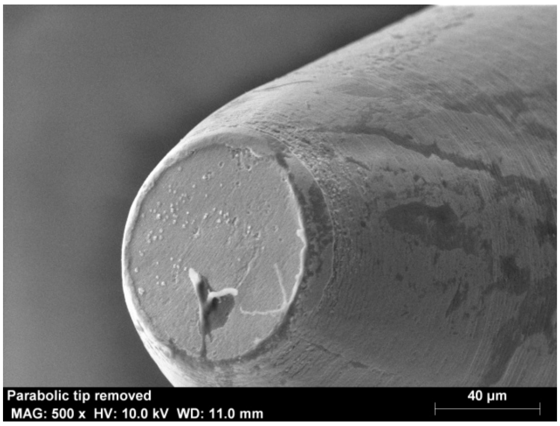


Figure 7: SEM image of a parabolic cone with the tip removed (mandrel still present).

Further Work

The next generation of cones will included a number of different material layers and locating features to aid assembly. Three layer cones will be made from chrome, aluminium and gold and are formed on a novel material for the mandrel. The targets are due to be fielded in late 2010.

Conclusions - Scale-Up to High Rep Rate Systems

While a significant step change has been introduced in moving to mass production in batches of 50 this cannot be scaled to the numbers required for a HiPER style reactor. The reported technology clearly opens the way to 100-1000's of shots but another step change in the manufacturing is needed to deliver to a reactor. Such technologies could include hot pressing or wafer based production but whichever technology is chosen will clearly need to be fully integrated with an assembly station and also cryogenic filling and layering stations and, eventually, a full injector system to give an integrated target solution.

Acknowledgements

The author would like to acknowledge Dr Pasley from York University for discussions on the target performance of the initial mass produced cones, Dr A MacPhee for the design input and discussions on the parabolic cones and Prof P Norreys for the specifications of the next generation multi-layered cones.

References

1. HiPER Project – www.hiper-laser.org
2. S. ATZENI, A. SCHIAVI, J. J. HONRUBIA, X. RIBEYRE, G. SCHURTZ, PH. NICOLAЇ, M. OLAZABAL-LOUMÉ, C. BELLEI, R. G. EVANS, AND J. R. DAVIES, Fast ignitor target studies for the HiPER project, Phys. Plasmas **15**, 056311 (2008);
3. P. A. NORREYS, R. ALLOT, R. J. CLARKE, J. COLLIER, D. NEELY, S. J. ROSE, M. ZEPF. M. SANTALA, A. R. BELL, K. KRUSHELNICK, A. E. DANGOR, N. C. WOOLSEY, R. G. EVANS, H. HABARA, T. NORIMATSU AND R. KODAMA, Phys. Plasmas **7**, 3721 (2000)
4. M. BEARDSLEY, J. SPENCER, M. K. TOLLEY AND C. SPINDLOE, Rutherford Appleton Laboratory, Central Laser Facility Annual Report 2005-2006, 221-222
5. C. SPINDLOE, M. K. TOLLEY, P. HISCOCK, M. BEARDSLEY AND J. SPENCER, An Update of Target Fabrication Techniques for the Mass Production of Advanced Fast Ignition Cone Targets, accepted Journal of Fusion Science and Technology June 2010.
6. I. BUSH *et al*, Rutherford Appleton Laboratory, Central Laser Facility Annual Report 2008/2009, 17-20