Target Fabrication Workshop 5
St Andrews Scotland
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Abstract Book

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Target fabrication with two-photon-polymerisation

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In this talk I will introduce the process of two-photon-polymerisation (2PP) and its application to the field of micro-structured target fabrication for laser-driven ion acceleration. In order to exploit recent advances in the design of high power laser systems the fabrication of suitable targets is mandatory. This requires both careful selection of the material as well as customised target shapes.

In the scheme of target normal sheath acceleration (TNSA), in which ions are accelerated along the direction normal to the target surface, the target shape influences ion beam divergence. The aim of utilizing 2PP in target fabrication is to design and produce specifically shaped targets that allow for the production of collimated or even partly focused ion beams. With 2PP it is possible to build almost arbitrary 3D freeform structures with a resolution up to 100 nm[1].

2PP is a nonlinear photolithography process with a photoresist as source material. In order to prepare a sample the resist has to be applied onto a glass layer by the process of spin coating. In classical lithography the whole sample is then exposed to an extensive UV light source. Parts of the resist which should not be exposed are covered by a mask. The unexposed resist can then be removed during the so called development. This process delivers a 2D structure.

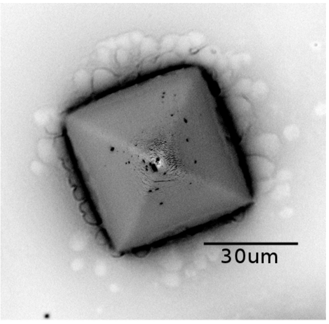

Figure 1: Two-photon-polymerisation produced pyramid with a base length of 37µm.

In contrast to the classical scheme the 2PP process uses a tightly focused laser with a wavelength of 800 nm. Since the 2PP process is a 3rd order nonlinear two-photon-absorption process the polymerisation is only triggered if the number of simultaneous photons is sufficiently high, i.e. if the sample is in focus of the laser. This requirement can be used to minimize the volume in which the polymerisation takes place, the so called volumetric pixel or voxel. By scanning the laser focus through the resist, a 3D free form structure can be fabricated point by point (voxel by voxel).

In our setup we use high precision motor stages in x, y, and z direction to move the sample relative to the fixed laser focus. This enables us to generate arbitrary forms, e.g. pyramids (see fig. 1), with a length scale on the order of 10 µm.

The use of micro-structured 3D patterns with a high resolution is not limited to the field of laser-ion-acceleration but can also be applied to biology and chemistry.

[1] V. Paz, M. Emons and K. Obata et al., *Journal of Laser Applications,* 2012, **24**, 042004

Batch Production of Micron-scale Backlighter Targets.

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Abstract.

The generation of x-ray probe beams for diagnostic use in high power laser science is well known and is often achieved by the irradiation of a high-Z wire target adjacent to the primary target. These backlighter targets have had typical dimensions of a few 10's of microns in diameter. However the source size from these is large due to the non-constrained nature of the sample. The resolution of the x-ray probe beam is limited by the size of the source and so there is a drive to fabricate micro-wire backlighter targets with significantly smaller dimensions to create probe beams with greater resolution.

This paper will describe the mass production of micron scale micro-wire backlighter targets using Micro-Electro-Mechanical System (MEMS) fabrication techniques. These techniques are a development of the fabrication methods using in the semiconductor industry and use industry standard silicon wafers as the basic substrate. In the same way that integrated circuits (ICs) are manufactured in large numbers, micro-wire backlighter targets can be batch produced on individual silicon wafers.

By the use of optical and e-beam lithography, thermal and sputter deposition and plasma etching, large numbers of targets can be fabricated on a single silicon wafer. In the example described here, the smallest micro-wires manufactured had a cross-section measuring 1um x 1um and approximately 250 were parallel-processed on each 100mm diameter wafer with the mount for the target also produced in the fabrication process. These mounts are, designed to be "snapped-out" from the remaining wafer and mounted on a simple target stalk, alongside the primary target, before being positioned in the laser target chamber. To aid location and laser alignment, the fabrication processes include steps which create alignment arrows on the supporting CH membrane which indicate the tip of the micro-wire and its orientation.

Production of a thin diamond target by LASER for HESR at FAIR

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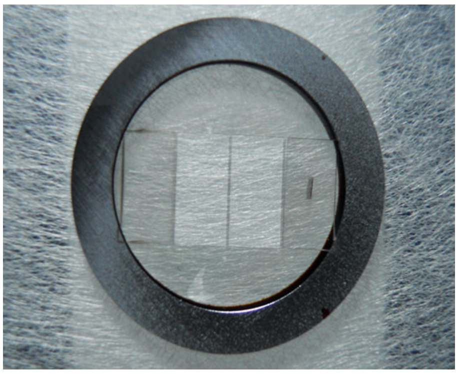
In the future hadron facility FAIR the HESR ring will supply antiprotons in the momentum range 1.5-15 GeV/c as projectiles for charm, strangeness and Form Factor physics.
For all the reactions it will be necessary to use internal targets and in particular, for the double strangeness production, the most fruitful target nucleus is ^{12}C[1].



Inserting a solid target inside an antiproton ring creates two main problems: a large background on the detectors due to the overwhelming amount of annihilations and a strong depletion of the beam due to all the hadronic and Coulomb interactions of the antiprotons with the ^{12}C nuclei. The width of the target plays a crucial role in minimizing these unwanted effects.
Two prototypes of wire-shaped targets, 100 μm wide, 3 μm thick and 11 mm high, have been already realized. One of them is shown in the figure. Starting from a thin diamond disk, produced by CVD technique, the wire shape has been obtained by cutting the diamond using a FEMTO-EDGE LASER of 1064 nm wavelength.
One prototype has been submitted to irradiation by protons of 1.5 MeV and simultaneously controlled by Proton Back-Scattering technique, in order to test:

a) the impurity level,
b) the surface ^{12}C density,
c) the radiation hardness and
d) eventual phase modifications during irradiation.

Moreover, it has been submitted to Micro-Raman spectroscopy in order to scan the carbon phases along the width.
The results show performances which satisfy the requirements of mechanical resistance and thermal and electrical conductivity. They will be illustrated in details in the talk.

References

[1] F.Ferro et al., *Nucl. Phys.*, 2007, **A789**, 209

Novel Route to Adhesive Free Single Crystal Layered Targets Through Laser Machining and Micro Grinding Techniques.

Dr N..J. Bazin, C.A.Macqueen, S. Gooding, S. Chima and I. McGowan.

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Dynamic strength campaigns fielded on the OMEGA Laser platform at the Laboratory for Light Energetics (LLE), Rochester, New York USA have typically been based on crystalline foils bonded to pin holes and characterised through a combination of Laue x-ray diffraction and VISAR data (velocity inerferometery of surfaces at any reflectivity). These experiments however, have always suffered from interference for an adhesion layer (required to bond the foil to a support) which blur the VISAR data yielding inaccuracies in the velocity of the crystal foil under loading and spatial non uniformities in the adhesion layer further complicate the data. This paper discusses a novel approach to resolving the adhesion issue through laser machining and subsequent micro polishing of the foil substrate material which had previously not been thought possible. The overall concept of the target and components is discussed along with relevant design modifications required to support the manufacture and metrology of the target. The steps and learning curves in the machining of the substrate materials are also addressed. The target itself consisted of a tantalum single crystal (5μm thick) sandwiched between an ablator and a tamper. This was supported between a Hevimet (tungsten alloy) circular washer (diagnostic side) and a rectangular Hevimet washer (drive side). The full target assembly was housed in a broad band x-ray camera. The x-rays were generated from the implosion of a capsule in the target chamber using 44 of the Omega laser beams and the target was shocked by a further 12 laser beams.

X-ray Microtomograph Skyscan 1074 for Laser Target Characterization

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Our studies begun with Skyscan 1072 are at present continued on the new device by the Bruker company, SkyScan 1074. The laser target characterization is in particular focused on the possibility to obtain, control and measure precisely the gradient density samples and targets.

Among them we should mention the stepped density layer profiles, one-step smooth density profiles in plastic foams, metal nano-composites and nano-snow layers. Some of them are already reported to find application in laser experiments.

Robotic assisted machining and assembly of targets

L. Carlson[1], J. Bousquet[1], D. Kaczala[1], Katrin Clark[1], S. Woods[1], M. Mauldin[1] and P. Fitzsimmons[1]

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General Atomics has integrated robot arms into machining, assembly and characterization processes to improve process control and efficiency. GA's general approach to robotic machining and assembly will be outlined followed by two detailed examples. Integrating a robot arm with a traditional CNC lathe has enabled GA to increase fabrication of hohlraum mandrels, paving the way for this technology to be integrated with diamond turning processes. Using robot arms for planar assembly has also increased assembly throughput. It has been demonstrated that characterization activities can be reduced due to increased process control.

Solid Hydrogen target for laser driven proton acceleration

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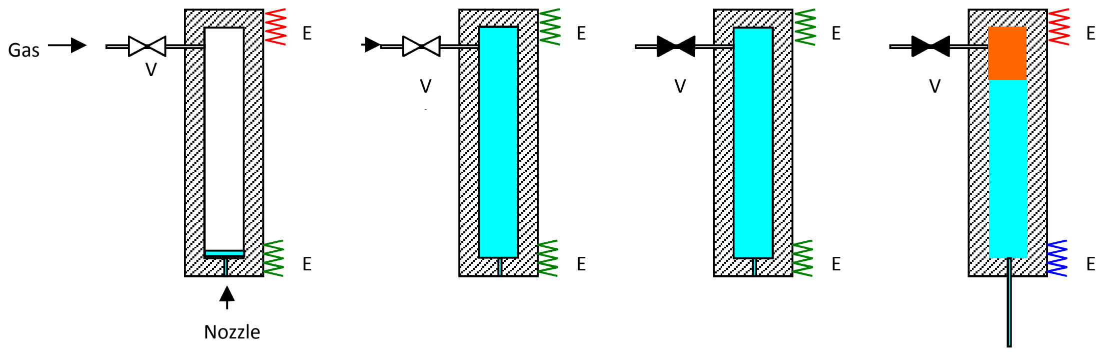
There is a great interest for fundamental research but also for applied research, in producing energetic protons. These protons can be used for example in the field of thermonuclear inertial confinement fusion research or in medical domains as proton therapy.

One mean to obtain a beam of energetic protons consists in focusing a high intensity laser on a target. Various physical mechanisms of laser-driven ion acceleration have been investigated to date. The mechanism most investigated experimentally is the Target Normal Sheath Acceleration (TNSA) when ions are accelerated at the rear side of thin target in a quasi-electrostatic sheath formed by fast electrons propagating from the target front side [3,4] . A suitable target for this application is a thin ribbon of solid H2.

In this context, the low temperature laboratory of the CEA developed a cryostat able to produce a continuous film of solid H2 of some tens of microns in thickness and one millimeter in width. A new extrusion technique is used, without any mobile part. Thermodynamic properties of the fluid are used to achieve this goal. The principle is as follow: Once the experimental cell is totally filled with solid H2, the inlet valve is closed and the top of the cell is heated up. The pressure increases and pushes the solid H2 placed at the bottom of the cell through a calibrated hole.



The construction of new high power laser facilities (e.g. high repetition rate petawatt-class lasers at ELI-Beamlines[5]) will clearly enable numerous prospective applications based on secondary sources of energetic particles. In particular the use of the proposed solid hydrogen cryogenic target along with these emerging laser technologies will allow demonstrating future medical applications such as hadron therapy [6,7]. In fact, in recent years pilot experiments of cancer cell irradiation have already been realized[8]. The possibility to use other gases than hydrogen suitable for different applications (e.g. deuteron for neutron) is also envisioned in the future.

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Ab initio aproximation: Target Hydrogen Isotopes in ICF initial compression

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The deuterium-tritium target used as fuel system inertial confinement fusion, must meet conditions of homogeneity in terms of roughness, thickness, crystal structure (no mixing phase), among others, that are directly related to efficiency ignition. Our interest is to analyze the conditions present in the early stages of compression target, studying how to control and reduce instabilities in these earliest moments that affect the propagation of the shock wave. Solid the molecular hydrogen is taken to approximate the study of its isotopes. The conditions which are manufactured allows us to model the target system from a hexagonal crystal structure. The simulations were performed using the SIESTA code. We have developed a methodology by which the phase transitions of solid molecular hydrogen are studied[1], presented the structure associated with each of these phases[2] in turn are determined mechanical properties of the solid system, in particular the change of bulk modulus for tritium and hydrogen to the pressure, compared with experimental measurements directly[3]. Furthermore we treat contamination or cover material segregation of the sphere covering the DT ice, analyzing as does the inclusion of beryllium within the solid molecular hydrogen, demonstrating that the elastic constants suffer of considerable magnitude change[4]. This work demonstrates the existence of discontinuities in the phase transitions that affect the speed of sound and consequently the propagation of the shock wave in solid molecular hydrogen[5]. The method allows to analyze systems of solid deuterium and tritium, as well as their mixtures and the inclusion of tantalum, gold and carbon in its structure, studying how they affect the mechanical properties. As prospects we are working on the construction of an equation of state to represent each of the phases and taking into consideration the above mentioned discontinuities.

[1]Carlo L. Guerrero C., S. Cuesta and JM Perlado. In book: First Workshop on Fusion Technologies and the Contribution of TECHNOFUSION, Chapter: 16, Editors: Seccion de Publicaciones de la ETSII (2011) pp.243-256, ISBN: 978-84-7484-239-5

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[5]Carlo L. Guerrero C., S. Cuesta and JM Perlado, sent to Europhysics Letters 2014.

Quantifying rupture forces for nanometre thick thin-foil window targets

David Haddock[1], David Armstrong[2], Colin Johnston[2], Chris Spindloe[1] and Martin Tolley[1]

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An analysis of stress testing nanometre thin films mounted across a window-like geometry is presented. The pressure at which an ultra-thin foil ruptures when mounted across a hole is currently poorly understood. This project offers insight into the forces involved in the realms of windows a few hundred atoms thick and tests material properties on a nanometre scale. Application of this knowledge could lead to improving yield across high-repetition rate arrays and give experimentalists the opportunity to compare rupture pressures to pre-pulse intensity in laser experiments.

References should be designated by a superscript number[1] in the text and the bibliography should use the following format (If you are using Endnote, the Output style to use is Chemical Communications).

[1] A. N. Author, B. C. Author, and D. F. Author, *Abbreviated Journal Name,* Year, **Volume number**, First Page

Production of Low Density Foam Targets for High Repetition Rate Laser Experiments

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With the recent developments in laser technology there are an increasing number of high repetition rate systems that are available for utilisation by the plasma physics community for experiments investigating topics such as ion acceleration. One of the most interesting types of targets in this field is a low density foam target that can be used to investigate hole boring[1]. It is however difficult to manufacture thin foams in the numbers that are required to carry out these experiments. Current manufacturing techniques rely on a manual fill of target geometries under a microscope with a syringe and then processing this using a critical point dryer. We report on a production method that is using a semi-automated dispensing and curing system and developments to maximise the output of the drying process to produce targets that are technically challenging and previously not possible to fabricate.

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Challenges using high internal phase emulsions as templates for polymers

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High Internal Phase Emulsion (HIPE) foams are widely used in the cosmetic and pharmaceutical industry. Here we report on the progress made on the development of these meso-porous materials with respect to High Energy Density Physics (HEDP) experiments. In particular this paper will focus on the challenges faced producing polystyrene polymers using HIPE foams as a template. Samples of polymers made using this template have been evaluated using a range of techniques including micro X-ray tomography, scanning electron microscopy and contact radiography. Recent research has focused on improving the homogeneity of the samples, allowing a reduction in density variation.

Mass-Limited Targets

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Mass-Limited Targets (MLT) represent an interesting option for many applications, based on laser-plasma interactions. Various theoretical studies investigated MLT's extensively. Experimental verification of these schemes is extremely demanding, due to the technological challenges on targetry and requirements on the laser system. In this talk, we present a target system for MLT. By the use of a Paul Trap we levitate targets of spherical geometries and position these targets with submicron precision. This system can handle a range of target masses from 0.5 femtogram to 5 nanogram, corresponding to plastic spheres with radii ranging from 500 nm to 50 μm. A short summary on acquired experimental results on particle acceleration on various laser systems (Max Born Institute, GSI Darmstadt, Texas Petawatt) and on planned further upgrades of this target system will be given

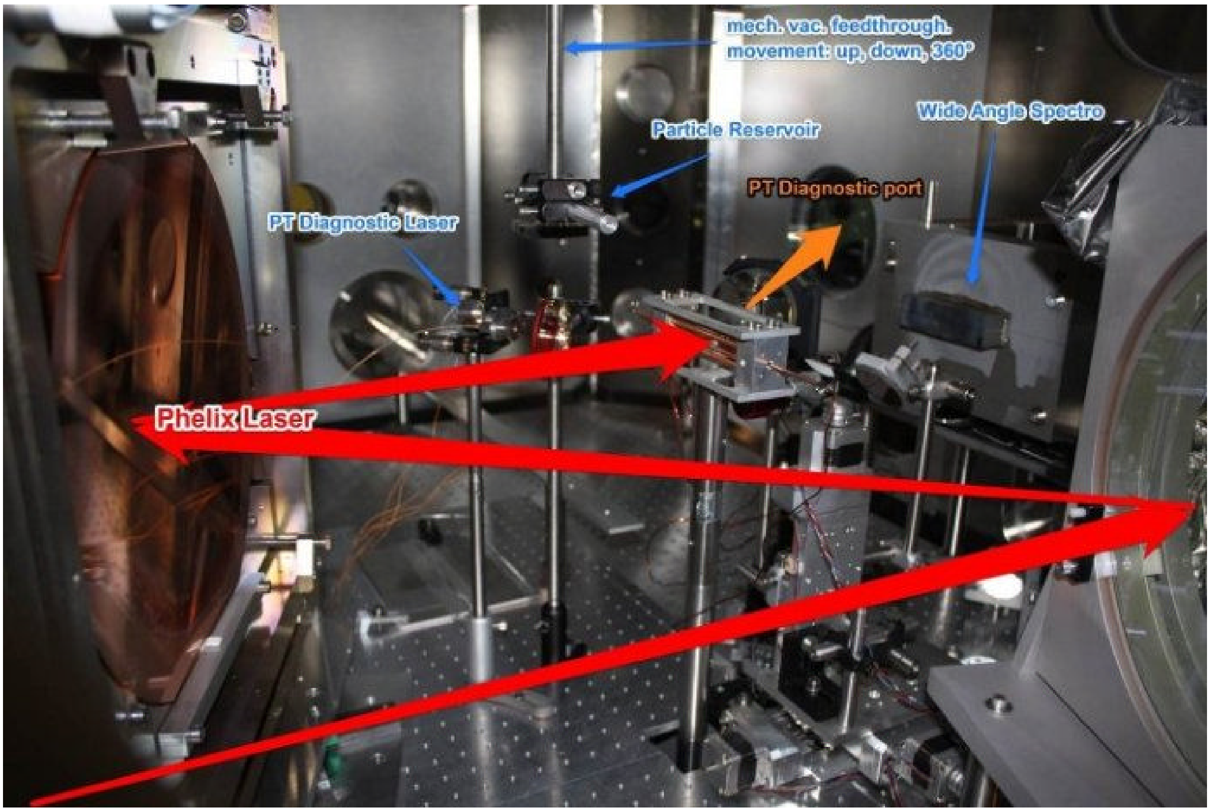

Figure 1: The Paul trap at the Phelix Laser system

A novel microfluidic system for the mass production of ICF shells

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Microfluidics involves the transport of one or more fluids, usually within duct systems, often planar in format and of dimensions in the order of micrometers to millimeters.

A diverse range of thermal, kinetic and chemical phenomena can be exploited under such microfluidic conditions; benefiting from low Reynolds number flows, high surface-to-volume ratio and an increased dominance of forces such as inter-facial tension are a few examples.

When two or more immiscible fluids are employed to flow into a specific configuration, segmented flow conditions result with serial trains of alternating fluids. With this compound emulsions can be formed, consisting of a central inner fluid surrounded by an outer liquid, which, in turn, is suspended in a carrier fluid. Where a liquid monomer is used as outer fluid, this can be polymerised to form a hard and liquid-filled shell.

Critical to the operation of the configuration is the preference that one fluid will wet the duct's walls, acting as the carrier into which the other(s) are dispersed. Usually this requires altered duct-wall-wetting characteristics or use of surfactants in the fluids. However surface treatments change over time and a homogenous distribution of surfactant is hard to attain[1].

Two novel microfluidic configurations are presented which are specifically designed for the high-repetition-rate production of monodisperse shells. A low-Z monomer trimethylolpropane triacrylate (TMPTA) was used which can be photopolymerised[2] with a water solution forming the inner core and mineral oil as the carrier fluid (Figure 1). The configurations were machined in fluoropolymers which facilitate the production of stable emulsions without duct surface treatment or use of surfactants.

The flow stability delivered to the microfluidic system is essential for repeatable emulsion volumes. Several factors in the pump system have been identified which cause pressure variability of the flow. In turn this affects the natural cyclic pressure variations governing the mechanism of segmented flow and altering the time period between segmentation. A modified drive system removes some of this variability (Figure 2). Also discussed are microfluidics methods employed to improve the sphericity and concentricity of the emulsions.

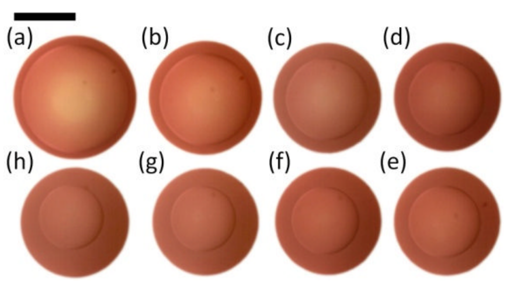

Figure 1 - Images depict individual static compound emulsions, which are suspended in mineral oil.
The diameter and wall thickness can be varied, depending on the flow rates into the configuration. Here the independent variable is the outer TMPTA flow. Scale bar is 1mm.
Flow rates (ml/h); Water solution= 1.5, TMPTA= a) 0.5, b) 1.0, c) 1.5, d) 2.0, e) 2.5, f) 3.0, g) 3.5, h) 4.0, Mineral oil= 24.0.

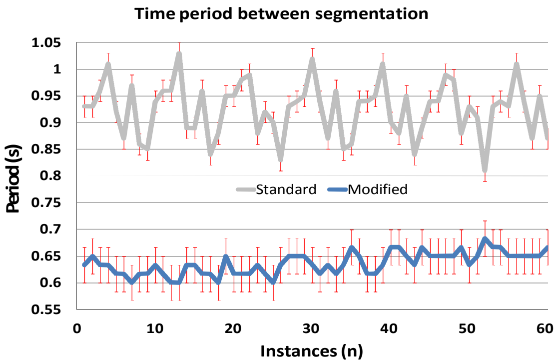

Figure 2 - Two 1ml SGE gastight syringes are used to deliver mineral oil and water into a microfluidic configuration where segmented flow occurs. The time period between the segmentation is extracted from video footage. Flow rate of each fluid is 7.91ml/h.
Standard drive; $\bar{X}$= 0.9248s, σ= 0.0508s, error= 0.02s.
Modified drive; $\bar{X}$= 0.6364s, σ= 0.0207s, error= 0.033s.

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The antiproton interaction with an internal ^{12}C target inside the HESR ring at FAIR

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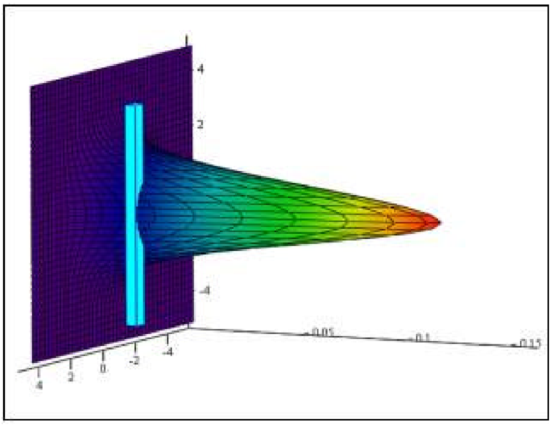
The advent of recent hadron facilities like FAIR and JPARC opened new perspectives for the investigation of the systems (particles and nuclei) containing strange quarks. In particular the antiproton ring HESR at FAIR will be used, among other, to produce doubly strange hyperons and nuclei.
A mandatory requirement for this project[1] is to insert a diamond target shaped as a thin wire 3 μm thick and 100 μm wide inside the antiproton ring. The presence of the solid target strongly affects the antiproton bunch which is strongly depleted at each round, due to the large amount of interactions between the antiprotons and the ^{12}C nuclei.
On the other hand, the strangeness physics needs high statistics[2]: this requires to optimize the time structure of the injection of the antiprotons into the ring. The processes that mostly contribute to consume the bunch in a cycle (hadronic interactions, Single Coulomb Scattering, Touschek effect…) have been calculated and the background on the detector estimated.
In order to fully exploit the antiproton production rate at FAIR, it has been planned to profit of the Gaussian shape of the radial distribution of the antiprotons inside the bunch. At the beginning of the cycle only the tail of the Gaussian will overlap the target as shown in the figure, then the beam will be slowly steered toward the center maintaining the interaction rate constant. All the parameters of the bunch evolution during a cycle have been calculated: positioning of the target, steering speed, rates of the beam-target interaction, energy loss inside the thin target and stress of the wire.



The results of these calculations and the final time structure of the beam-target interaction will be presented.

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Templated Nano/Microstructured Materials

- Can they have potential as target fabrication? -

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Microscopic template processes become important structural transcription has become an increasing powerful and universal processing to explore novel morphofunctional properties in materials science. Molecular recognition and steric effect in chemistry, supperlattice and confined effect in semiconductor engineering, morphofunction in biotaxis, and so forth should be merged to a superordinate concept that an identical substance can exhibit its shape-dependent properties in a microscopic scale. It spends long time and much effort to individually develop nano/microscopic structures of various kinds of substances. Structural transcription from a library of universal and reliable templates can accelerate exploratory research for novel morphofunctional concepts and materials. Along the concept on nano/microscopic structural transcription, we will introduce two examples: One is various functional nanomaterials from a single block copolymer[1-4] and the other is teraheltz electromagnetic response of metal microcoils dispersed materials from coiled algae, *Arthrospira platensis*, so-called spirulina[5]. To find possible application toward next generation target fabrication, various kinds of nano/microstructured materials, which our group could supply for collaboration, will be also introduced with their specifications.

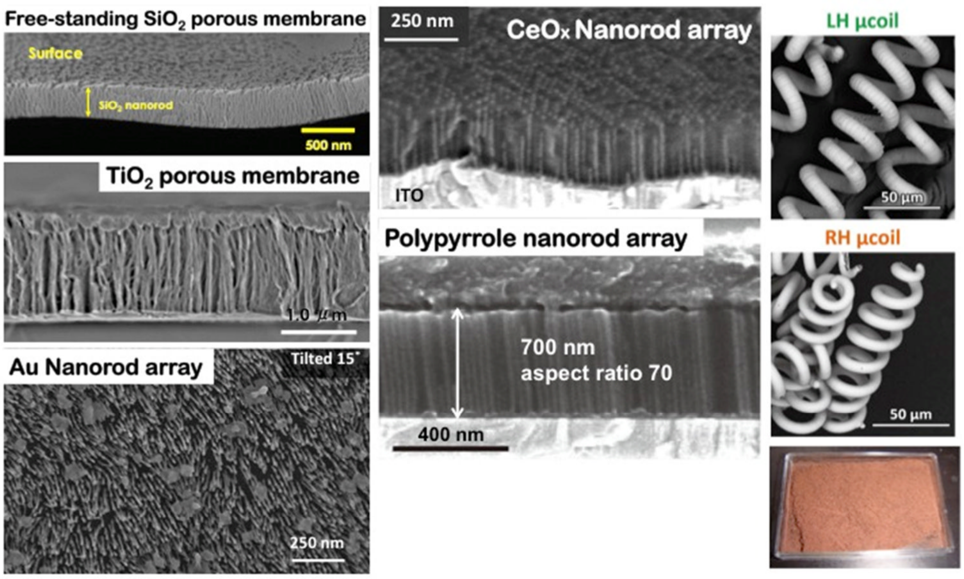

Fig. Various kinds of nanorod arrays and biotemplated microcoils dispersion

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Target Fabrication and Processing by Means of PE-CVD

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The Plasma-enhanced Chemical Vapour Deposition (PE-CVD) provides a versatile technique to synthesize and modify well-defined, thin layers. The deposited material depends on the applied process gases, the specific properties can be controlled by process parameters like pressure, mass flow rate, coupled power into the low-temperature plasma and substrate temperature.

The target laboratory at TU Darmstadt is equipped with a PE-CVD system ***PlasmaTherm SLR770*** of which a schematic illustration is given in figure 1. Basically this system consists of an ECR microwave-powered plasma source which allows low-temperature deposition and even isotropic plasma etching (cleaning, stripping, etc.). The substrate plate can be powered with an RF generator (13.56 MHz), for instance to enable the preparation and treatment of substrates and layers by anisotropic Reactive Ion Etching (RIE). The substrate plate can be heated up to 400°C, and an upgrade for reaching temperatures up to 800°C is in development. Moreover, a comprehensive upgrade of this system was done by using National Instruments hardware components (digital and analog I/O) and a self-developed LabVIEW™ programme for controlling and monitoring.

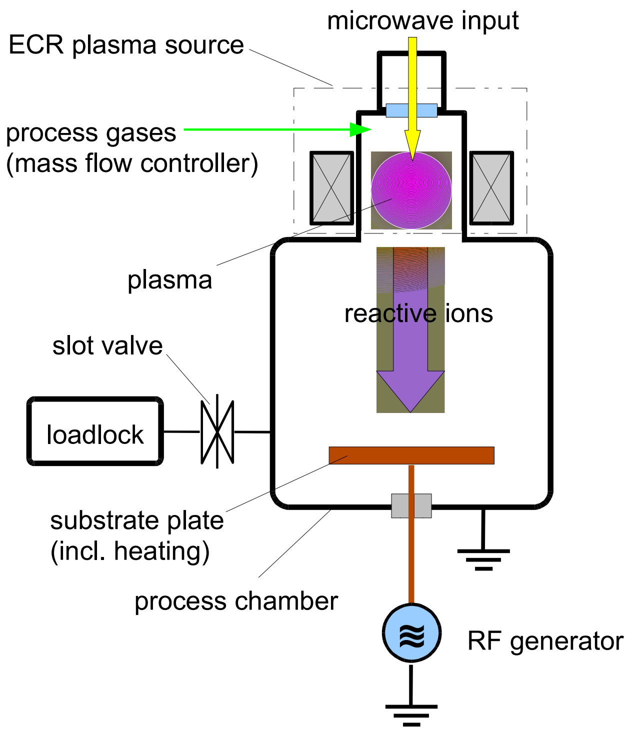

Figure 1: Schematic illustration of PE-CVD

Currently the PE-CVD (process gases) is configured for materials based on carbon. Diamond-like carbon (DLC, e.g. a-C:H) layers have already been fabricated in high-quality, and process optimization for vertically-aligned CNTs is in progress. Particularly structures based on such VA-CNT might be interesting for enhancing the conversion efficiency and yield of laser-driven targets due to their optically anisotropic properties. This can result in an effective source for fast ions (related to the so-called TNSA mechanism) or X-ray backlighters, for instance.

The surface properties of DLC films can be characterized by Atomic Force Microscopy (AFM) to get information about the roughness, etc. Furthermore, Scanning Electron Microscopy (JEOL6400 with LaB_6 cathode) is useful to investigate layers made of VA-CNT, too. Both methods are utilized to optimize and verify the deposition processes.

HTSC maglev systems for IFE target transport applications

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The Lebedev Physical Institute (LPI) is constantly growing in the development of the free-standing target supply system (FST-SS) for inertial fusion energy (IFE)[1,2]. The FST-SS must work in a high rep-rate regime of fabrication and delivery of cryogenic fusion targets at the center of a reaction chamber. Therefore, our research is grouped along the target mass-production using moving free-standing spherical capsules; fabrication of isotropic ultra-fine cryogenic layers with an increased mechanical strength and thermal stability; target acceleration and rep-rate injection; fast target characterization; survivability of a fuel core; interface issues related to elements assembly.

Recently, we have started the investigation into magnetic levitation as an alternative technology of non-contact manipulation, positioning and delivery of the finished cryogenic targets. In IFE applications, this direction attracts a significant interest due to maglev potential for almost frictionless motion.

In order to optimize target transport conditions, we proposed to use **h**igh-**t**emperature **s**uper**c**onductors (HTSC), and carefully examined samples from $YBa_2Cu_3O_{7-X}$ ceramics made at LPI (with Tc = 91-93 K and Bc ~ 5.7 Tesla at 0 K). An active guidance was achieved by using the $YBa_2Cu_3O_{7-X}$ samples and permanent magnet guideway (PMG), where an ordered motion was initiated by a special arrangement of the permanent magnets (with magnetic induction in the range of B = 0.1-to-0.6 Tesla). We also demonstrated a stable levitation of free-standing polymer shells coated outside by the HTSC layer. It is notable that at all temperatures varying in the experiments (6-to-80 K) we obtain similar results. This allows us to run the experiments mostly at 80 K (liquid nitrogen temperatures), which is less expensive than the experiments at 6-20 K (require expensive liquid helium).

Our near-term R&D program is aimed at developing maglev transport system for creation of a precise target injector. The program elements include the following:

- HTSC science and technology,
- Develop computational models of the response of IFE targets during their acceleration together with maglev sabots of different designs,
- Use the developed codes to plan experiments and study the key technical issues,
- Demonstrate the maglev sabot acceleration on laboratory scale tests,
- Study the target with an outer HTSC coating for
  1) demonstrating the target transport and trajectory correction in the magnetic field
  2) delicate assembly of spherical (e.g., hohlraum type) and cylindrical cryogenic targets

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Spin coated targets for filamentation studies

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In our presentation, we report on the experimental observation of spatially modulated proton beams emitted from micrometer thick Titanium foils spin coated with a thin layer of photo resist which were irradiated with ultrashort (30 fs) laser pulses of a peak intensity of $5 \cdot 10^{20}$W/cm^2. The net-like proton beam modulations were recorded using radiochromic film and the investigation of different target systems for a laser energy range of 0.9 to 2.9 J revealed a clear dependence on laser energy and target thickness for the onset and strength of the modulations. The surface structure was characterized with an atomic forcemicroscope and a scanning electron microscope.

Numerical simulations performed suggest filamentary instabilities, such as the parametric two plasmon decay and a Weibel-like instability, which occur in the laser-produced target front side plasma, as the source of the observed proton beam modulations.

We propose that these results on laser intensity dependent plasma instabilities may have implications for the scaling of present acceleration mechanisms, such as target normal sheath acceleration, to higher proton energies and hence higher laser powers. Furthermore, we comment on the potential influence of spatially modulated proton beams on the interpretability of spectra measured with common ion spectrometers featuring small entrance apertures.

J. Metzkes, T. Kluge, K. Zeil, M. Bussmann, S.D. Kraft, T.E. Cowan, and U. Schramm, *New Journal of Physics,* 2014, **16**, 023008

Microfluidic fabrication of inertial confinement fusion targets incorporating carbon nanotubes.

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Introduction: Microfluidics, can be used to generate double emulsions with consistent and controllable morphology, and is a promising method for the high-replication rate production of Inertial-Confinement-Fusion (ICF) targets for future fusion energy generation [1]. Capillary-based, triple-orifice generators [2], and planar, double T-junction, microfluidic chips [3] have been reported to produce trimethylolpropane trimethacrylate (TMPTA) and resorcinol formaldehyde (RF) microcapsules for ICF target fabrication, respectively. We demonstrate here the potentially, economical, microfluidic production of surfactant-free, photopolymerised, TMPTA capsules, as ICF target shells, incorporating functionalised, multi-walled, carbon nanotubes to increase the shell strength.

Material and Experiment: Water/organic/oil emulsions were formed on machnined PTFE microfluidic chips. TMPTA, with 5% v/v photoinitiator, and 0.1% functionalised (MWCNTs was formed as a double emulsion with density matched (63:37 v/v) water/glycerol inner phase and a 100% mineral oil carrier phase, by using double flow-focusing junctions. TMPTA capsule shells were solidified in a chip-based phtoreactor at 365nm. Young's modulus was measured using a TA Q800, Dynamic Mechanical Analyser, concentricity with a Nikon Microscope and sphericity with a GE X-ray computerised tomography tool.

Results: The diameter of the obtained microcapsules (Figure 1) could be varied between 500 and 1500 µm and shell thickness from 50-100µm, at 0.5-20 Hz production rates. The shells produced had a concentricity and sphericity of up to 99.63% and 99% respectively (Figure 2, 3). Whilst, non-functionalsied CNTs reduced the Young's Modulus of the TMPTA-CNT composite by 50% (1206Mpa -> 643MPa), functionalised CNTs increased it by ~32%. CNTs were found to be fairly evenly distributed after extensive sonification (insert, Figure 2).

Discussion & conclusion: Target shell mass-replication rates, at greater than 15Hz, and, concentricity values greater than 99% was best observed. Improvements to increase sphericity by a factor of 10-fold remains a challenge. Future work should seek to further improve both the TMPTA-CNT strength and its formation as a foam, inner phase removal, shell thickness refinement, on-the-fly shell characterisation and cryogenic fuel-filling.

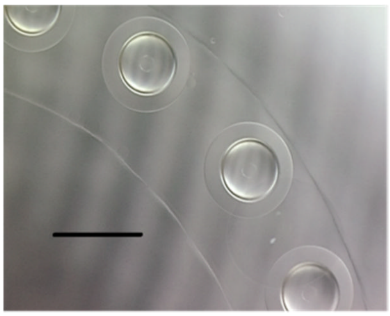

Figure 1. TMPTA shells centralising within a fluoropolymer UV photo-microreactor (bar=1000um).

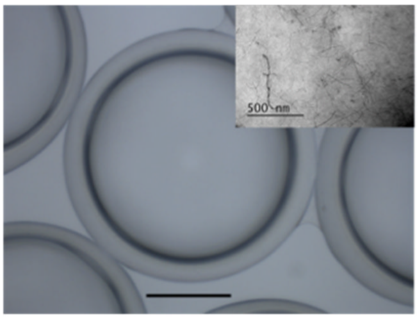

Figure 2. Photo-cured TMPTA shells with a concentricity of 99.63%. (bar=500um). Insert shows distribution of CNTs.

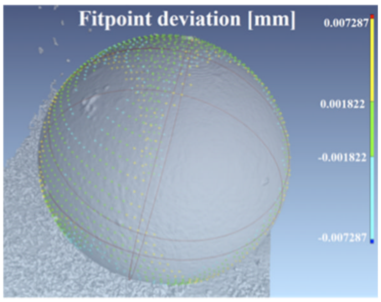

Figure 3. X-ray CT scan of ICF shell showing deviation (+/-7um) around mean dia. of 1.4mm, --> ~99% sphericity.

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New Organic Aerogels with Phenolic Resin Framework for Laser-Plasma Experiments

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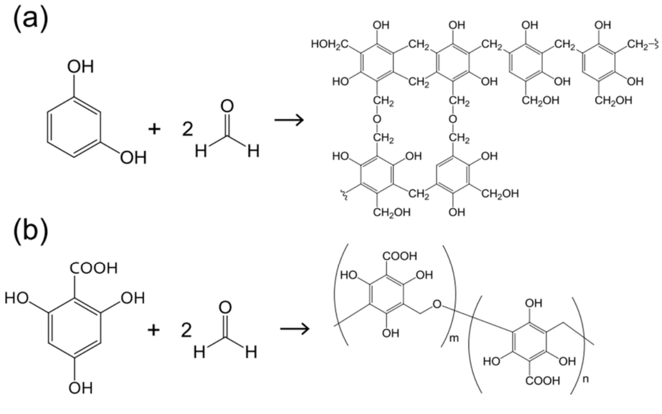

Fig. 1. Scheme of polymerization of the (a) resorcinol-formaldehyde (R-F) gel and (b) Phloroglucinol carboxylic acid-formaldehyde (PC-F) gel.

Low-density and porous materials have been used in laser-plasma experiments such as laser shock and coulomb explosion[1]. Resorcinol-formaldehyde (R-F)[2] and its derivative of low density plastics have been investigated based on their nanoscale structure and transparency. Control porous structure of aerogels is an important issue. The porous structure of aerogels can be significantly modified by changing precursors and solvents. It was reported that the surface area of the phloroglucinol carboxylic acid-formaldehyde (PC-F) aerogels[3], a precursor of carbon aerogels was twice as large as that of the R-F aerogel. In this study, we focused on an affinity between solvents and an R-F gel and a PC-F gel for control nanostructures of the aerogels. And it was discussed that the influences of the exchange solvents and the precursors on the porous structures of the aerogels.

Dynamic light scattering (DLS) techniques were used to evaluate the affinities between the gel clusters and the solvents. If the gel and solvents show low affinity, hydrodynamic radius measured by DLS techniques (rDLS) becomes larger due to the cluster aggregation. rDLS was decreased depend on dielectric constant (ε) until the ε of ethylene glycol (38.7). When ε were larger than this value, the rDLS were saturated around 2.8 nm. Molecular radius calculated from Molecular Weight (rMW) of the PC-F and the R-F gel were 2.45 nm and 3.07 nm, respectively. The saturated rDLS were consistent with the rMW, suggesting the gel cluster completely disperse in the higher polarity solvent than ethylene glycol.

It was suggested that higher polarity solvent shows higher affinity for the gel cluster than lower polarity solvent. And there is a possibility to control the nanostructure of the organic aerogels by using high affinity solvent as exchange solvent.

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Characterisation of low density porous materials using Time Domain Nuclear Magnetic Resonance (TD-NMR)

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Nuclear magnetic resonance (NMR) is a modern and increasingly essential polymer characterisation technique. NMR relaxation processes are dependent on molecular motion, hence structure, thus can be used for characterisation of materials. Measurements of spin-lattice (T_1) relaxation provide information on the fast motions of a material (MHz), whereas spin-lattice relaxation in the rotating frame ($T_{1\rho}$) provides information on slower chain motions (kHz).

Novel application of TD-NMR is presented, characterising styrene-co-divinyl benzene high internal phase emulsions (polyHIPEs). Probing multiple relaxation domains provided a new insight into these materials, which complements existing characterisation techniques. Furthermore, suggestions to resolve inhomogeneity issues with polyHIPEs are discussed.

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Form of Presentation: Oral
Preferred topics: Characterisation, Porous materials for laser targets, Synthesis of low density porous materials.

Host polymer and guest nanoparticles for the fabrication of metal doped targets

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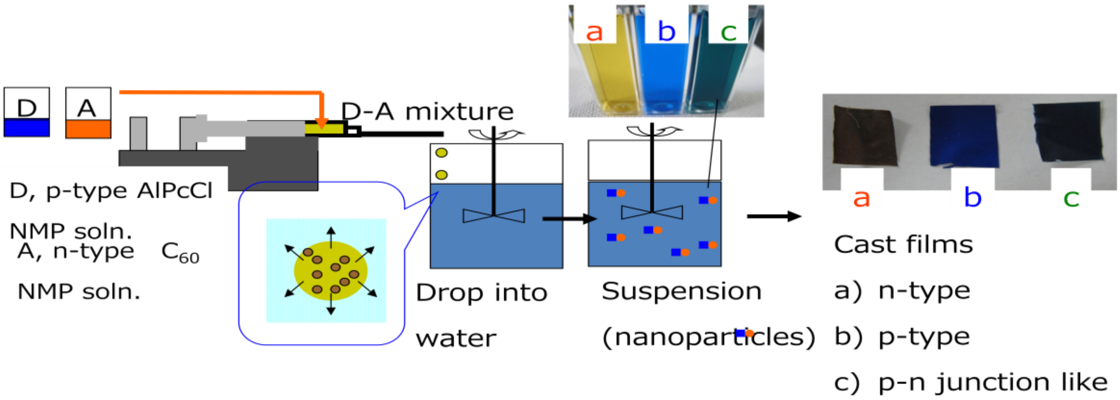
Low-density targets have been investigated for the laser-plasma quantum beam sources, inertial fusion energy (IFE) science and technology, and nanoparticles doping into host polymer is commonly used technique.
Polymer aerogel is sometimes used as host material and gives an ultralow density, while it is still difficult to prepare materials containing other elements. On the other hand, recent laser-plasma experiments require a wide range of composition of elements, thus a new technique to prepare low density targets is required for the wide range compositions and densities.
Organic nanoparticles composed of metal phthalocyanine (MPc) were synthesized using a reprecipitation method. Considering the high cost of a dry process (i.e., vapor deposition); it is essential to find an alternative process. A kind of wet process of a reprecipitation from a polar solvent gave biphasic nanocrystals of AlPc and fullerene, while previous reprecipitation invented gave a single component of organic crystals even whose size is controllable between nanometers to micrometers. The choice of N-methyl-2-pyrrolidone (NMP) as good solvent, a polar solvent is crucial issue to form biphase nanoparticles for example MPc -C_{60} combination. The composite's biphase structure was confirmed using scanning electron microscopy, scanning transmission electron microscopy, energy-dispersive X-ray spectroscopy, zeta potential, and dynamic light scattering, being 10 to 100 nm sized particle. The nanoparticles can be good dopant due to the easy control of particle size and well-controlled metal content.



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Synthesis and manipulation of Poly (methyl pentene) (TPX) foams Using Thermally Induced Phase separation

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Poly Methyl Pentene (TPX) foams is of interest to plasma physicists because of its empirical formula CH_2 which is of interest for opacity experiments. TPX can be produced by chemically induced phase separation (CIPS); solvent induced phase separation (SIPS) and thermally induced phase separation (TIPS).
In this paper a method for the production of thermally induced phase separation of TPX is described and procedures for controlling the pore size using thermal methods are reported. Structurally diverse and different pore sizes of TPX can be produced by temperature control.

Double hohlraum targets for heavy ion stopping experiments

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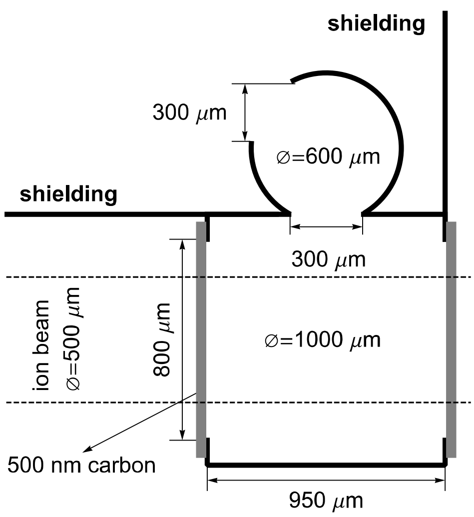
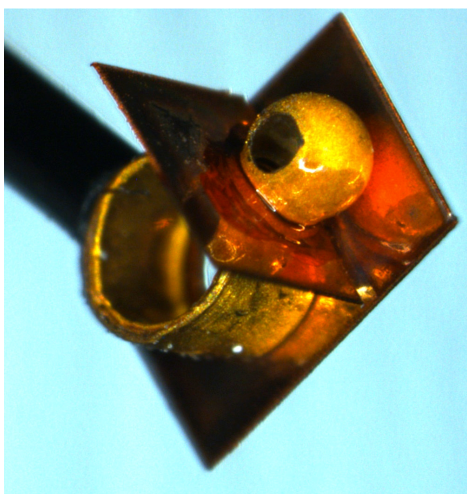
We present a novel double hohlraum target for the creation of a dense moderately coupled ($0.1 < \Gamma < 1$) carbon plasma.
A spherical cavity of 600 µm diameter is used to convert intense laser light into soft X-rays. For this purpose a high-energy laser beam of 150 J energy at 527 nm wavelength and with 1 ns pulse duration is focused into the sphere.
The generated quasi Planckian radiation has a temperature of T_r = 100 eV. These X-rays are then used to volumetrically heat two thin carbon foils in a secondary cylindrical hohlraum to a uniform and dense plasma state. An axisymmetric plasma column with a free electron density of up to $5\text{x}10^{21}$ cm^{-3}, a temperature of $T \approx 10$ eV and an ionization degree of $Z \approx 3$ is generated. This plasma stays in a dense and uniform state for about 5 ns. The aim is to use these targets in further experiments where a heavy ion beam probes the generated plasma and its energy loss and charge state distribution are measured.
The plasma conditions have been extensively studied by simulations and were verified by experimental measurements.
The target fabrication process has been optimized to allow an efficient batch production. They are produced using a variety of target manufacturing techniques like micro-chipping, electroplating and laser cutting.
Beyond the fabrication techniques, this talk presents the complex interplay of theoretical predictions, experimental characterizations together with the target fabrication possibilities.





Production and characterization of carbon foams for laser driven ion acceleration

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In this work we report on the production and characterization of low density carbon foams and on the results of first laser driven ion acceleration experiments on foam attached multilayer targets.
Low density materials can be exploited for the design of engineered targets for laser driven ion acceleration[1] as an attractive tool to control laser-matter interaction and to explore enhanced acceleration regimes in novel acceleration experiments. The production of a few mg/cm^3 dense carbon foams with controlled density and thickness and their characterization are not straightforward because of the extremely low density of such materials and request the use of advanced material science methods. The production of carbon foam layers with density down to 3 mg/cm^3 and thickness from 5 μm to 150 μm was achieved by Pulsed Laser Deposition (PLD)[2]. Foam morphology and structure were characterized through Scanning Electron Microscopy and Raman Spectroscopy. A new technique based on Energy Dispersive X-Ray Spectroscopy was introduced to evaluate foam density, as Quartz Crystal Microbalance, one of the most commonly employed density evaluation tools for physical vapour deposited films, is not reliable for densities below 20 mg/cm^3.
First acceleration tests[3] on multilayer targets composed by a near critical carbon foam layer (7 mg/cm^3) directly grown by PLD on a thin Al foil (1.5-10 μm) were carried on at the Saclay Laser Interaction Center Facility, with the UHI100 system, within the frame of Laserlab EU program (grant agreement no 228334, EC's Seventh Framework Programme). The results of these preliminary experiments show a systematic 2-3 fold enhancement of maximum proton energy with foam attached layers compared to the case of bare Al targets for laser intensities in the range $10^{16} – 10^{17}$ W/cm^2 both for low and ultrahigh contrast pulses.
Dedicated 2D Particle In Cell simulations were developed to support the interpretation of the experimental results. More generally, the results of a numerical analysis of a wide number of target-laser interaction conditions will be presented. Particular attention will be paid to the interaction of multilayer targets with pulses having the highest available intensities, with the aim of optimizing target design for acceleration experiments in this regime. Testing of such optimized targets in high-intensity ion acceleration experiments is foreseen in the next future.

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[3] M. Passoni, A. Zani, A. Sgattoni, D. Dellasega, A. Macchi, I. Prencipe, V. Floquet, P. Martin T. V. Liseykina and T. Ceccotti, *Plasma Phys. Control. Fusion,* 2014, **56**, 045001

Progress of Target Development in Hamamatsu Photonics K.K.

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The energy generation is the most important issue in the world. Hamamatsu Photonics K.K. (HPK) has been working to realize inertial fusion energy (IFE) as one of sustainable zero-emission energy source from more than 20 years ago. Some of our products, such as laser diodes, photo-multi-plier tubes for neutron detection, X-ray detectors and streak cameras, are key devices for IFE research. Mr. Teruo Hiruma, the chairman who was the former president of HPK, had mentioned that Japanese people need low-cost energy, so that he has conducted the establishment of the Industries Development Laboratory and started the feasibility study toward laser fusion power plant at Hamamatsu in 2008.

Our target development was started 5 years ago, when Dr. Takagi joined us. At first, deuterated poly-styrene shells for fuel pellets of IFE were fabricated by micro-encapsulation process, and the accuracy of diameter was 2% in 500μm shell fabrication. After that, it has become possible to reduce vacuoles and dimples of the shell wall. In the case of a batch of over 10,000 shells, it can be achieved that the shell diameter is fabricated within 0.7% of the accuracy, for the process improvement toward higher shape accuracy and mass production. Our fabricated beads are being used for repetitive target injection of our collaboration research [1]. Target fabrication technologies, such as multi-layer or low-density foam, and metrology have been developing for various requirements of IFE research and demonstration.

On the other side, the repetitive DD neutron generation has been demonstrated by the diode pumped solid state laser (DPSSL), which has been developed using our laser diodes. This power laser system with Ti-sapphere, which we called “MATSU” (800nm, 1.2J, 60fs, 20-TW), can be operated at 10Hz for high efficiency of electrical-to-optical conversion. Many deuterated poly-styrene nano-particles were spraying in target chamber, and high-intensity laser beam (560mJ, 59fs, 1.0E+18W/cm^2) was irradiated on targets at the timing of spraying. About 50,000 DD neutrons were generated at repetitive 100 shots of 1Hz operations. It is expected that the repetitive operation is lead to IFE demonstration.

Just now, annex irradiation room is being built for the demonstrations using higher power laser and radiation shield in our site. Many of our laser diodes will be stacked and optical components will be constructed in higher energy laser system. The target technologies, such as target injection, cryo-cooling and tritium handling, will be started developing on company work, and these developments will be continued for realizing large neutron energy generation by laser fusion.

We will present our target samples, for example novel multi-layer shell, and the neutron generation demonstration.

[1] O. Komeda et al., Nature, Scientific Reports 3, 2561, 6 Sep. 2013

Thin Cryogenic Hydrogen Targets for Laser-Driven Ion Acceleration: Fabrication & Characterisation

Gabriel Schaumann[1,] Stefan Bedacht[1], Sam Astbury[2], Steve Hook[2], Alex Ortner[1], Chris Spindloe[2], Alexandra Tebartz[1], Martin Tolley[2], Florian Wagner[1], Markus Roth[1]

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Target composition and geometry play a crucial role in laser-plasma interaction experiments. The temporal contrast ratio of high power short pulse laser systems has been considerably enhanced which allows for the use of ever-thinner targets. Depending on the target material and actual laser prepulses, targets as thin as a few nanometers can be successfully utilised, e.g. in ion acceleration experiments. Simulations of new laser-driven particle acceleration regimes exploiting these very thin targets (e.g. radiation pressure acceleration (RPA) [1] and laser breakout afterburner (BOA) [2]) predict particle energies in the GeV range in contrast to tens of MeV achievable in present target normal sheath acceleration (TNSA) experiments.

Suitable targets that are solid at ambient temperature, e.g. plastic foils (TPX or Parylene) and carbon targets (DLC), can be fabricated with thicknesses that allow for the BOA acceleration mechanism and these targets are used to explore the BOA regime and characterise the contrast ratio of a laser system. Nevertheless, these targets always deliver multiple ion species – namely carbon and hydrogen – from the bulk material and also suffer from additional contaminants that get adsorbed on the target surfaces from the residual gas inside the vacuum chamber.

In terms of the best charge to mass ratio for the acceleration process and maximum ion velocity a pure hydrogen target at solid density is ideal as no driver energy is used to accelerate heavier ions. Depending on the parameters of the laser system, BOA works best for a certain line density, which allows for a relatively “thick” hydrogen target of some micrometers in comparison to sub-micrometer CH-targets that performed best in previous experiments at the *Phelix* laser facility at GSI.

This presentation will give an overview on the growth procedure and experimental setup that allow for the fabrication and in situ characterisation of a thin, freestanding hydrogen membrane target. Possible applications of a high energy proton beam, that can be generated from such a thin, free standing hydrogen target at solid density, include proton driven fast ignition [3] and the production of secondary particle beams such as neutrons [4]. Cryogenic hydrogen targets could also be used in high energy density experiments with swift ions produced by either lasers or conventional accelerators [5].

[1] T. Esirkepov et al. , *Highly efficient relativistic-ion generation in the laser-piston regime*, Phys. Rev. Lett. 92, Vol. 17, 175003 (2004)

[2] L. Yin et al., *GeV laser ion acceleration from ultrathin targets: The laser break-out afterburner*, Laser Part. Beams 24, 291 (2006)

[3] M. Roth et al., *Fast Ignition by Intense Laser-Accelerated Proton Beams*, Phys. Rev. Lett. 3, Vol. 86, pp. 436–439 (2001)

[4] M. Roth et al., *Bright Laser-Driven Neutron Source Based on the Relativistic Transparency of Solids*, Phys. Rev. Lett. 110, Vol. 4, 044802 (2013)

[5] D. H. H. Hoffmann et al., *Present and future perspectives for high energy density physics with intense heavy ion and laser beams*, Laser and Particle Beams 23.01, pp. 47–53 (2005)

Manufacturing of multi-component assemblies for large-scale physics experiments

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The high-energy density target fabrication group at Lawrence Livermore National Laboratory uses a variety of micromanufacturing techniques and metrology tools to fabricate millimeter-scale assemblies with micrometer-scale features. These assemblies are used for physics experiments to study the properties of materials at high temperatures, pressures, and strain rates using large-scale laser facilities, such as the National Ignition Facility. In this presentation, we will provide an overview of our part requirements and current micromanufacturing and metrology processes, with the goal of sharing our technologies while investigating emerging technologies that may enhance our manufacturing capabilities. Typically, requirements for these assemblies include surface finish ≤ 50 nm Ra and feature form error ≤ 1 µm. We utilize a combination of micromanufacturing techniques, including single-point diamond turning (SPDT), micro-milling, physical vapor deposition, and precision tooling, to allow for in situ assembly and metrology. As examples of our fabrication processes, we will show how micromilling was used in combination with SPDT and kinematic tooling to manufacture integrated SiO_2 (30 mg/cc) and Ta_2O_5 (125 mg/cc) subassemblies.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

A Review of High Volume Fabrication of Laser Targets using MEMS Techniques

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[4]Department of Physics and Astronomy, Old Physics Building F013, Queen's University Belfast, Belfast, BT7 1NN, U.K.
[5]University of Oxford, Clarendon Laboratory, Oxford, OX1 3PU, UK

The latest techniques for the fabrication of high power laser targets, using processes previously used for the manufacture of Micro-Electro-Mechanical System (MEMS) devices, are presented. These laser targets are designed to meet the needs of the increased shot numbers that are available in the latest design of laser facilities. Traditionally laser targets have been fabricated using conventional machining or coarse etching processes and have been produced in quantities of 10s to low 100s. Such targets can be used for high complexity experiments such as Inertial Fusion Experiment (IFE) studies and can have many complex components that need assembling and characterisation with high precision.

Recent laser developments have led to the possibility of switching from experimental based laser facilities to application based facilities with PW level systems becoming more common and, with the ability to operate at rates of approximately 1Hz, these systems are no longer shot limited. Application based facilities require large volumes of relatively simple, high specification targets but conventional techniques are not equipped to deal with this demand. Using the techniques that are common to MEMS devices and integrating these with an existing target fabrication facility we are able to manufacture and deliver targets to these systems. It also enables us to manufacture novel targets that it has not been possible to fabricate in any other way.

Thin Polymer Targets for Laser-Driven Ion Acceleration

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High power laser systems allow for investigation of laser-plasma interactions and laser-driven ion acceleration for which several mechanisms have been presented in the past. While *Target Normal Sheath Acceleration* (TNSA) takes place in overdense plasma created from a solid-state target, laser intensities around 10^{21} W/cm^2 enable relativistic transparency for which the ion acceleration mechanism *Laser Breakout Afterburner* (BOA) was presented[1].

To be used as targets for ion acceleration, thin polymer foils with thicknesses from 200 to 1200 nm were produced by the process of spin coating. The organic polymer polymethylpentene (commercially available as TPX) can be solved in cyclohexane. The centrifugal force on a spinning substrate spreads the solution outwards while the solvent evaporates, leaving behind a thin film of solid polymer.

Interferometric measurements were used for characterization concerning surface quality and thickness. In addition, independent thickness measurements were conducted by letting alpha particles traverse the foil and measuring their energy loss. The amount of energy loss can be converted to a thickness using simulations with the software *Stopping and Range of Ions in Matter* (SRIM). Comparison of results yields good agreement between thickness measurements obtained from both methods and shows a linear correlation between concentration of the polymer solution and resulting foil thickness.

The foils were subsequently used as targets and as substrate for cryogenic hydrogen targets in experiments on laser-driven ion acceleration at the *Petawatt Laser for Heavy Ion Experiments* (PHELIX) at *GSI Helmholtzzentrum für Schwerionenforschung* in Darmstadt. Proton energies up to 60 MeV could be reached. By tilting the target with respect to the axis of laser propagation, features of two separate ion beams could be obtained. These indicate that, in addition to the TNSA mechanism, the BOA acceleration scheme could be exploited.

[1] L. Yin et al., *Laser and Particle Beams,* 2006, **24**, 291

In-situ formation of solidified hydrogen films using a pulse tube cryocooler

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Central Laser Facility, Science & Technology Facilities Council, Harwell Oxford, OX11 0QX, UK

In order to better understand the mechanism for Radiation Pressure Acceleration (RPA) for proton acceleration on Petawatt level systems there is a need to develop low atomic number, thin film targets. The low electron density of hydrogen is ideal because a relatively larger target thickness can be employed although producing solidified hydrogen in-situ poses many significant issues.

A team at the Rutherford Appleton Laboratory have developed a pulse tube cryocooler system and successfully grown hydrogen ice within the laser chamber on the Vulcan laser in the UK. One significant motivation is to generate MeV ions through RPA particularly the Breakout Afterburner (BOA) mechanism.[1]

This talk discusses the design of CLF's cryogenic targetry system, the recent advancements which have been made on the design and the future applications of the system.

[1] L. Yin, B. J. Albright, B. M. Hegelich, K. J. Bowers, K. A. Flippo, T. J. T. Kwan, and J. C. Fernández, *Phys. Plasmas,* 2007, **14**

Developments in the production of copper foams

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Metallic porous materials and meso-porous structures are widely used in fields such as catalysis, purification and electrochemical processes. Here we report on the progress made on the development of these meso-porous materials with respect to High Energy Density Physics (HEDP) experiments. This paper will focus on the challenges faced with producing copper foams of specified density that fulfil the strict criteria required for HEDP experiments.

Direct Drive Implosion of a Deuterium Filled Capsule Using the Orion Laser.

Dr N..J. Bazin, S. Gooding, S. Chima, M, Lightfoot and I. McGowan.

Target Fabrication, AWE, Aldermaston, Reading Berkshire RG7 4PR UK

This direct drive implosion campaign, the first experiment of its kind to be carried out on the Orion Laser, used defocused laser energy to ablate the outside of a pressurised capsule thus compressing the gas (deuterium) contained within the capsule. The target design required the bonding of a capsule onto a 9 micron carbon fibre with no more than a 20 micron spread of adhesive to aid the uniformity of the implosion. The experiment comprised of two elements, initially, the uniformity of the laser beams were assessed using a large 2.2 mm diameter gold coated plastic sphere. The subsequent targets, deuterium filled (10 atms) 500 micron diameter capsules were then inserted, aligned and fired. The success of the compression was determined by the yield of neutrons generated from the experiment. Novel concepts of this campaign included the use of a universal base plate for the mounting of the target components and alignment aids, uniform coating of large capsules using evaporation combined with bi-axial rotation of the samples and controlled bonding of the pressurised capsules to the mounting fibres. Further improvements to these designs are being considered for future campaigns and these are discussed in this paper.

Molding Of Organic And Inorganic Gelated Polymers To Aid Target Manufacture.

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1. Target Fabrication, AWE, Aldermaston, Reading Berkshire RG7 4PR UK
2. School of Chemistry, University of St Andrews, North Haugh, St Andrews, Fife, KY16 9ST, Scotland.

When manufacturing multi-component plasma physics targets the intimacy of the interfaces is as important as the component shape, composition and density. Conventionally a two component low density foam target would be made by separately machining each component and bringing them into contact using dedicated assembly jigs. This is both time and labour intensive. This paper discusses the potential for silica aerogel to be used as both a cast for shaped components for plasma physics experiments and a mold for casting of other materials. Initial investigations show silica wet gels can be cast into fundamental shapes and organic monomer solutions have been cast and polymerised in these fundamental cavities thus taking up the shape of the silica gel. Subsequent simultaneous critical point drying of these foams has shown the original shape to be retained and an intimate interface between the two materials formed with no machining.

Orion Laser Hohlraum Heating Plasma Physics Campaign, Design and Manufacture

Dr N..J. Bazin, S. Gooding, S. Chima M, Lightfoot and I. McGowan.

Target Fabrication, AWE, Aldermaston, Reading Berkshire RG7 4PR UK

This paper discusses the manufacturing challenges posed, and the techniques adopted to build a series of hohlraum based targets for one of the first ever experimental campaigns on the Orion Laser at AWE in the United Kingdom. The campaign, designed as both a calibration of the hohlraum geometries and the new laser system it self was split into a series of 5 target designs, building on each other culminating in the indirect symmetrical implosion of a formvar supported capsule enclosed in a Hohlraum. The first design was a thin walled hohlraum used as an alignment tool for the laser beams, here, the gold wall is designed to be thin enough for the generated x-rays to travel through the gold hohlraum so indicating where the beams hit inside the hohlraum. The next two designs were simple empty hohlraums differing in the laser entry hole (LEH) diameter aimed to determine the significance of this diameter. The first of the complex targets involved a halfraum bonded to an aluminised silica wafer with a large conical shield on one end to infer the uniformity of illumination of the hohlraum (hot spots etc.) The final design involved a capsule mounted in a formvar tent between two halfraums with diagnostic holes equatorially aligned with the sphere. This target also contained two back lighters to aid illumination of the target. Issues encountered and techniques developed to navigate manufacture and assembly of these targets are discussed along with proposed solutions for future campaigns.

Thickness Assessment of Ultra Thin Films From Contact and Non-Contact Profiling

Dr N..J. Bazin and T. Jewell.

Target Fabrication, AWE, Aldermaston, Reading Berkshire RG7 4PR UK

Thin films are routinely made at AWE for the preparation of plasma physics targets from a variety of techniques including dip, spin and evaporation coating. When a film is deposited on to a substrate there are a number or methods available for measuring its thickness. Each technique assesses a different parameter of the film and derives the thickness from it. This paper covers an introduction and principles of the measurement of thin films using contact profilometery and interference spectroscopy and the merits of each. Contact profilometery requires a physical edge or step to the film and can have a resolution in the order of a few nano meters. UV-Vis spectroscopy assesses the interference pattern from the surface of the film and the substrate. Whilst this concept can operate in both the transmission and reflectance mode it does require the film to be optically transmitting and ideally have a known refractive index. The wavelength used in UV-Vis spectroscopy is usually 200nm-1100nm with the shorter wavelength used for assessing thinner films. A standard plastic film (parylene) was assessed at three different thicknesses to cover the typical range used in plasma physics targets and the results are compared to an industrial standard technique of white light interferometery in assessing the films thickness.

Copper-based Aerogels and lanthanide Aerogels: Synthesis and characterization

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Aerogels are materials used as target for laser experiences. These materials are high specific surface and low density materials. To elaborate aerogels, the sol-gel method is mainly used for high valence element (>2). But this method is not appropriate for elaborate low valence like CuO. Nevertheless, thanks to a complexant agent such as a polymeric acid[1,2], a three–dimensional structure is obtained and finally a gelation occurs. After a drying in CO_2 supercritical conditions, an aerogel is synthesized. The drying allows replacing the solvent located on the pores by air keeping initial structure. In this study, only the epoxide addition method is described. The second method, called alkoxide addition method, is known to be more expansive synthesis than epoxide method, in view of alkoxide precursor use (frequently unavailable, difficult to obtain). The protocol of synthesis is optimized according to molar ratios (H_2O/precursor; epoxide/precursor; complexant/precursor), type of epoxide, type of solvent, the nature of inorganic salt and more precisely the counter anion, and the gel time. Tests of synthesis were carried out on bivalent (Cu^{2+}) and trivalent (Yb^{3+}, Tb^{3+}, Nd^{3+}) elements. Different cycles of drying are tested in order to bring about some change in the final aerogel. These materials are characterized using elemental analysis, nitrogen adsorption/desorption analysis, microscopy, and profilometry. To understand the gelation mechanism via the epoxide addition method, difference of reactivity of some parameters is discussed.

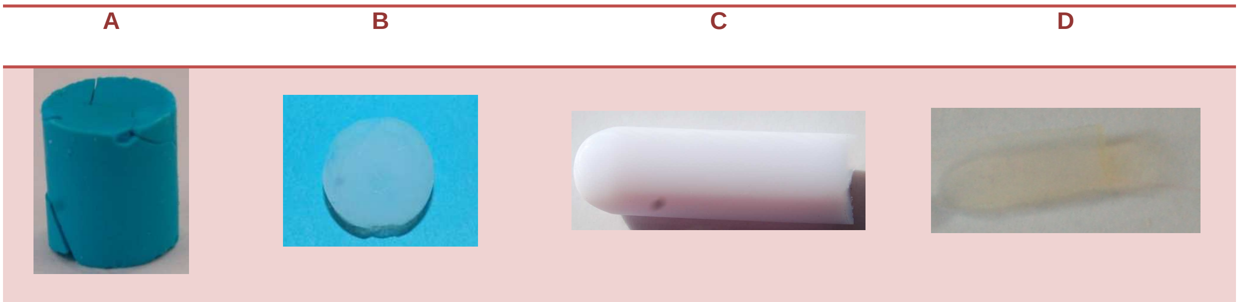

Figure 1: Photographs of copper-based aerogel (A) and lanthanide aerogels: (B) Yb_2O_3, (C) Nd_2O_3, (D) Tb_2O_3.

[1] Y. Bi, R. Ren, B. Chen, G. Chen, Y. Mei and L. Zhang, *J. Sol-gel Sci. Technol.,* 2012, **63**, 140

[2] Y. Bi, R. Ren and L. Zhang, *J. Sol-gel Sci. Technol.,* 2011, **217**, 1165

Achieving Thin Bond Lines

B.A. Chivers[1], B. Foote[1] and J. Foster[1]

[1] *AWE plc, Aldermaston, Reading, RG7 4PR, UK*

The use of adhesive to join together target components is a common approach when assembling targets. However the presence of a layer of adhesive between components can adversely affect the performance of the target – especially when the experiment relies upon the propagation of shock waves from one component to another.

This poster highlights the work undertaken at AWE plc into reducing the thickness of the adhesive bond line through reduced viscosity of adhesive and applied pressure during the process. Within this presentation we highlight the processes we have evaluated for reducing adhesive thickness and present preliminary results on the thicknesses that can be obtained through changing the parameters above.

Target Fabrication at the University of Michigan

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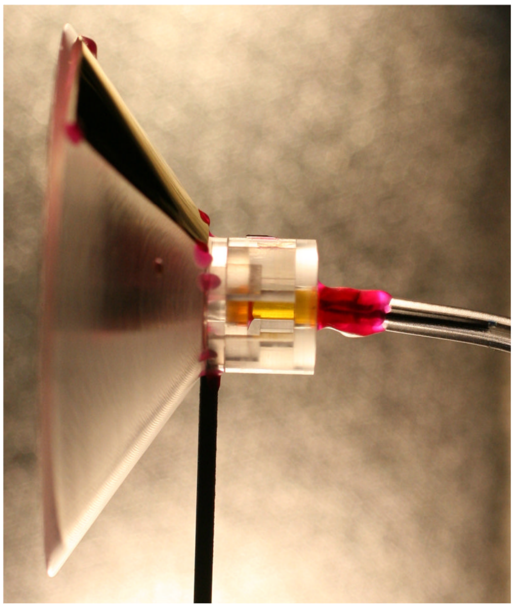
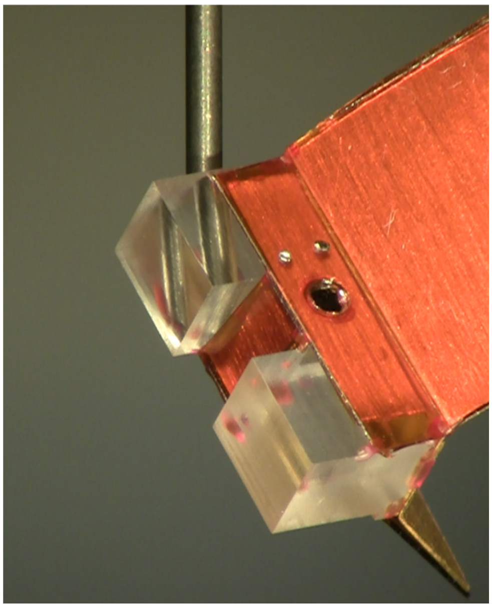
The University of Michigan has been fabricating targets for high-energy-density experiments for the past decade. We utilize the technique of machined acrylic bodies and mating components, acting as constraints, to build repeatable targets. We invest in engineering the target upfront when designing the target body. Our designs ensure that components are well constrained, including our stalk angle. A stalk hole is machined into the target body itself, so that even stalking the target at the time of assembly needs no special equipment. Stalk angles of targets are then very consistent from target to target. Having the stalk embedded into the target body also makes the target itself very robust to travel from where it is assembled to where it is shot. For lengthy campaigns requiring large quantities of targets, we combine 3D printing with traditional machining, therefore taking advantage of the very best part of both aspects of manufacturing. Here we present several campaigns to act as showcase of our techniques and how our methods have born success.





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Counter laser beam's engagement of 1-Hz-injected flying pellets

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Pellet injection and repetitive laser illumination are key technologies for realizing inertial fusion energy[1]. Numerous studies have been conducted on target suppliers, injectors, and tracking systems for flying pellet engagement. Here we for the first time demonstrate the pellet injection, counter laser beams' engagement and neutron generation. Deuterated polystyrene (CD) bead pellets, after free-falling for a distance of 18 cm at 1 Hz, are successfully engaged by two counter laser beams from a diode-pumped, ultra-intense laser HAMA[2]. The laser energy, pulse duration, wavelength, and the intensity are 0.63 J per beam, 104 fs, and 811 nm, 4.7×10^{18} W/cm^2, respectively. The irradiated pellets produce D(d,n)^3*He*-reacted neutrons with a maximum yield of 9.5×10^4 /4π sr/shot. Moreover, the laser is found out to bore a straight channel with 10μm-diameter through the 1-mm-diameter beads.

The results indicate potentially useful technologies and findings for the next step in realizing inertial fusion energy.

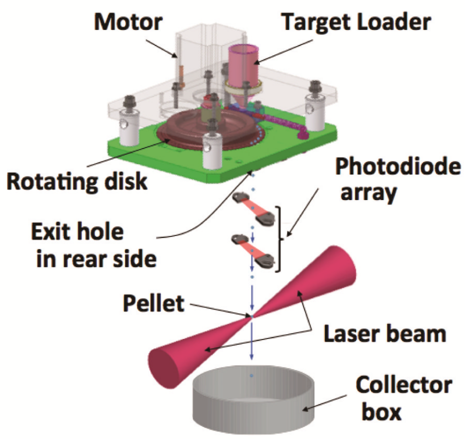

FIG. 1: **Pellet injection system.**

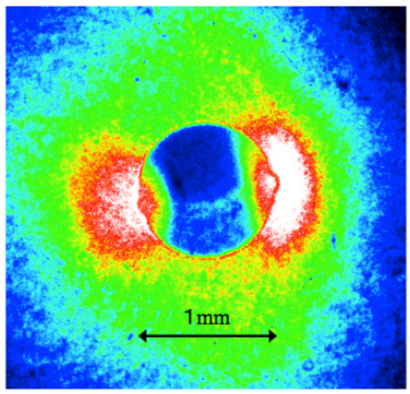

FIG. 2: **Snapshot of a flying pellet at the instance of engagement**

[1] Y. Kitagawa et al., *Plasma Fusion Res.*, 2013, **8** 2404000
[2] Y. Mori et al., *Nucl. Fusion,* 2013, **53** 073011

Low density material fabrication

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In the french simulation program, CEA Valduc is, among other missions, in charge of synthesis, shaping and assembly of low density material target elements:

- → polyHIPE foams (HIPE: High Internal Phase Emulsion) whose densities vary from 10 to 250 mg/cm^3,
- → organic aerogels (CH, CHO, CHOBr, organo-metallic or chelating doped) whose densities vary from 20 to 300 mg/cm^3,
- → silica aerogel, potentially doped with metallic particules, whose densities vary from 15 to 300 mg/cm^3,
- → tantalum oxide aerogel whose densities vary from 100 to 500 mg/cm^3.

Those different materials are transformed into target elements through different processes: machining (classic, high precision or laser) then assembling, or directly through moulding.

The target elements are then characterised in density, homogeneity, elementary composition and structure. Studies of ageing are made to warranty the material characteristics until the laser shot.

The presentation will show an overview of recent realisations using above listed materials.

Organic aerogels - manufacture and characterisation of low density carbon materials

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Aerogels are light solid materials which have the potential to hold significant mass in applied force. The complicated, cross linked internal structure gives it the highest internal surface area per gram of a known material. Because it is nano-porous and can be produced to a range of densities it is an ideal material to use as target components for the Plasma Physics experiments. Within this presentation we highlight our recent achievements in the development of low density carbon aerogels including routes to manufacture and the characterisation of the samples.

Universal Holding System for Multistep Processing of Plasma Physics Targets

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Abstract

One of the biggest challenges in the manufacture of complex three dimensional plasma physics targets is keeping a known datum/reference point for the component through the machining, assembly and metrology processes. Having this capability saves time, reduces cost, lowers risk of component damage and allows features in the component to be accurately located on different machines. This paper describes a novel approach to building an in-house capability to exchange component between precision mills, diamond turning lathes, x-ray tomography units and assembly stations. The concept relies on all reference surfaces being diamond turned, clean and free from debris/dust. The universal holding holding system comprises of an aluminum holder located around a carbide ball seated in a brass puck and allows repeated, precise re-positioning of any component in the x,y,z and c (rotation) coordinates relative to a known datum/reference point. The component manufacture, assembly and verification of this system and its advantages over commercially available solutions are discussed.

The Mossbauer spectroscopy application for iron- and tin-containing nanoparticles

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The application of Mossbauer spectroscopy gives information about charge and spin state of Mossbauer atoms and magnetic structure of the sample. The measurements in wide temperature range (from 300 K up to 1000 K) monitor the structure changes with heating. Moreover data obtained by these measurements is fitted with special mathematical algorithms[1] and as a result particle size estimation is received[2]. This non-destructive method can be used for pre-shot diagnostics of ICF and laser targets containing iron (iron oxides) and tin nanoparticles.

[1] *M.E. Matsnev, V.S. Rusakov, AIP Conf. Proc.*, 2012. **1489**, P. 178.
[2] N.I. Chistyakova, A.A. Shapkin, et al., *Hyperfine Interact.*, 2013, DOI 10.1007/s10751-013-0952-0

Tritium doping of deuterated-polystyrene targets by UV light

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Tritium-doped, deuterated-polystyrene (CD-PS) targets are being developed for laser fusion experiments. The exchange reaction between tritium and deuterium in CD-PS targets can be enhanced by ultraviolet (UV) light illumination[1]. The enhancement, however, is limited at the surface of the target because of the penetration depth of UV light. Uniform tritium doping is then necessary for CD-PS target development. In this study, action spectrum of the doping enhancement in the UV region was measured using a deuterium (D_2) lamp source. UV light emitted by the D_2 lamp was diffracted using a 1800 grooves/mm grating and was focused to a polystyrene tube. The tritium distribution in polystyrene tube was measured using an imaging plate. As shown in Figure 1, the enhancement was observed over an absorption edge of 275 nm. This result indicates the possibility of uniform tritium doping using UV wavelength. The same technique was then applied to polystyrene shells using 300 μW, 290 nm light-emitting-diodes. The doping efficiency was found to be 10 times higher than those shells without UV irradiation. Though the tritium concentrations in CD-PS targets are still low, we expect further improvements such as higher doping concentrations with the use of a Ce:LiCAF laser or the fourth harmonics of an Nd:YAG laser[2].

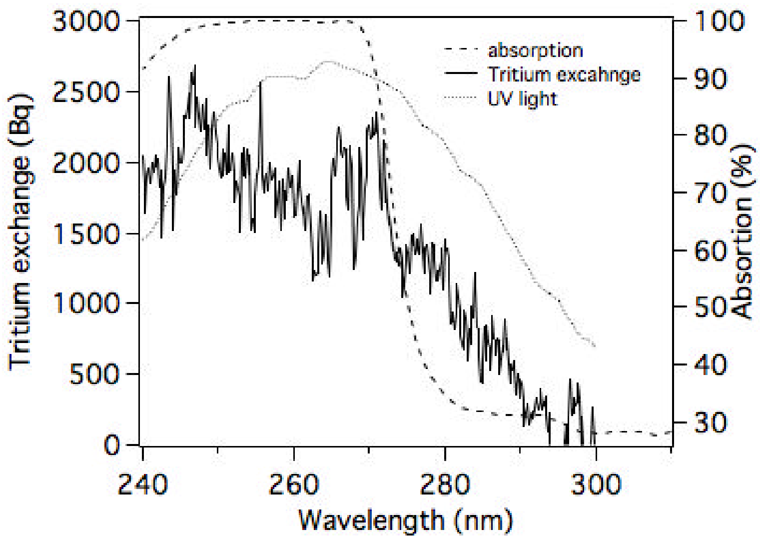

Fig. 1 Action spectrum of tritium doping and absorption spectrum of CD-PS

[1] M. Takagi, T. Norimatsu, T. Yamanaka and S. Nakai, *Journal of Vacuum Science Technology,* 1992, **10**, 239

[2] M.A. Dubinskii, V.V. Semashko, A.K. Naumov, R.Yu. Abdulsabirov and S.L. Korableva *J. Mod. Opt.,* 1993, **40**, 1

Fast Ignition Target and Laser-Beam Steering

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A PolyStyrene (PS) foam target with metal cone is designed and developed for Fast Ignition of Inertial Fusion Energy (IFE). Beam steering is required for accurate laser irradiation. We propose a phase conjugate (PC) mirror, which can steer a laser-beam with no mechanical active parts. A low intensity probe-beam is irradiated on a PS target. The scattered beam from the PS target-surface is amplified and irradiated into the PC mirror. A PC beam is generated and reversely propagates on the same pass to the PS target. The PS target moves several hundred micrometers during the laser beam propagating time form the target to it again. As shown in figure 1, a Four-Wave-Mixing (FWM) is applied to an experimental system to compensate the PC beam by adjusting an angle between two pump beams[1-4]. Figure 2 shows that the compensation angle is directly proportional to the angle between two pump beams. The Calorie Meter (CM) 2 monitors probe-beam irradiation on the PS target which is put on turntable at ~43m/s. CM4 monitors amplified PC beam irradiation on the PS target. We confirm the probe-beam irradiation and PC beam compensation in figure 3.

[1] N. Kameyama, and H. Yoshida, Plasma Fusion Res., 2013, **8**, 3404045
[2] N. Kameyama, and H. Yoshida, Fusion Sci. Technol., 2013, **63**, 120
[3] N. Kameyama, and H. Yoshida, Plasma Fusion Res. 2014, in press
[4] N. Kameyama, K. Kojima, and H. Yoshida, IOP Conference Series, 2014 in press

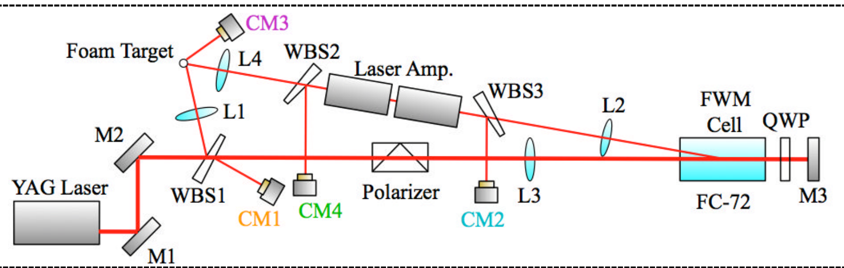

Figure 1. Experimental setup for a PC beam compensation.
WBS1−2: wedged beam splitters, QWP: quarter-wave plate, L1−4: lenses, M1-3: mirror, CM1-4: Calorie meter

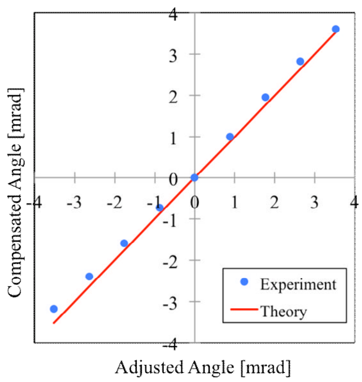

Figure 2. Compensation of a PC beam by a PC mirror.

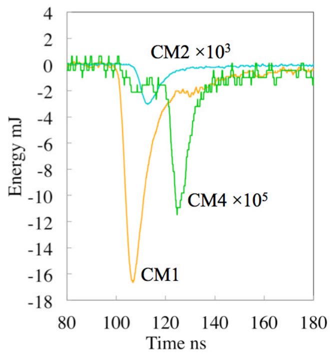

Figure 3. a PC beam is compensated and irradiated on the PS target.

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