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# EUMINAfab

*Integrating European research infrastructures for micro-nano fabrication of functional structures and devices out of a knowledge-based multimaterials repertoire*

## Final Report – Public version

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# List of Beneficiaries

| Beneficiary Number | Beneficiary name | Beneficiary short name | Country | Date enter project | Date exit project |
|---|---|---|---|---|---|
| 1 | Karlsruhe Institute of Technology;<br>Formerly: *Forschungszentrum Karlsruhe GmbH* | KIT | Germany | M1 | M54 |
| 2 | Cardiff University | CU | United Kingdom | M1 | M54 |
| 3 | Commissariat à l'Energie Atomique | CEA | France | M1 | M54 |
| 4 | Centro Ricerche FIAT S.C.p.A. | CRF | Italy | M1 | M54 |
| 5 | Kungliga Tekniska Högskolan | KTH | Sweden | M1 | M54 |
| 6 | Fundación TEKNIKER | TEKNIKER | Spain | M1 | M54 |
| 7 | Philips Research Europe | PHILIPS | The Netherlands | M1 | M54 |
| 8 | Fraunhofer Gesellschaft | FhG | Germany | M1 | M54 |
| | IMS Nanofabrication AG | IMS-Nano | Austria | M1 | M19 |
| 10 | NPL Management Limited | NPL | United Kingdom | M1 | M54 |
| 11 | University of Birmingham | UoB | United Kingdom | M36 | M54 |
| 12 | Trinity College Dublin | TCD | Ireland | M36 | M54 |
| 13 | Vrije Universiteit Brussel | VUB | Belgium | M36 | M54 |

## Table of Contents

# Final publishable summary report

## Executive Summary

Emerging micro and nano fabrication technologies, which have the capability to structure, functionalise and replicate down to several nanometres, are expected to lead to disruptive innovation in application areas of high societal significance. Examples include medical diagnostics, point-of-care and lab-on-chip solutions; improvements in components for lighting or energy saving, storage and management; and the provision of futuristic data communication applications. These technologies are rapidly developing, often require expensive equipment and highly specialised expertise. It is simply not possible for each research organisation or SME to maintain a state of the art portfolio. This barrier to progress can be lowered by open access infrastructures which are recognised worldwide as having growing importance as “hubs for innovation”, and indeed as being crucial for developing an effective technology innovation system.

EUMINAfab, the European research infrastructure for micro-nano fabrication of functional structures and devices, is a four year I3 project which has run under FP7 Capacities specific programme (March 2009 - August 2013). Open access to unique or rare high-end technologies in nano and micro structuring, replication and characterisation has been utilised within the scope of the project by 150 transnational users from European member and associated states.

During the past four and a half years, EUMINAfab partners have successfully integrated their outstanding, diverse expertise and capabilities. From the start, we have aimed to reach out beyond the boundary of our immediate sphere of contacts, provide a user-friendly operating system, build a pan-European infrastructure which can leverage the capabilities of partners and users and create an environment where we can stimulate innovation. Experience in open access has taken us further than the original offer of a technology toolbox and opened the way for functional solution provision in key application areas.

Networking and Joint Research Activities have been designed to support the framework conditions for user access. The networking activities publicised the fully funded access to new users, controlled the running of the EUMINAfab Entry Point, allowed researchers based at partner sites exchange visits to expand their experience, and enabled the definition of a sustainable model for the mid-term operation of EUMINAfab. The Joint Research Activities promoted knowledge transfer and technological integration. This was by the establishment of a knowledge management system, metrology benchmarking and technology readiness levelling assessment. A set of twenty-five cross-infrastructure projects have led to the creation of new process chains and related technology demonstrators. These new process chains open up new possibilities for further development in future collaborative projects and, in the immediate term, have advanced the state of the art which can be offered to users.

EUMINAfab has shown such impact during the FP7 Capacities Specific Programme funding period, both between the members of the consortium and in serving an ever growing user community that the partners are concerned that the progress made in integrating the open access facilities should be continued. The aim is to acquire funding to transform the original technology toolbox to an application-oriented fabrication centre ready to serve European industry and academia through and beyond Horizon 2020.

## A summary description of project context and objectives.

The potential for enabling European researchers from academia and industry, to access new knowledge, skills and technologies at a very early stage in their development can significantly lower the barriers for the introduction of these skills by European stakeholders. In this context the project objectives were formulated, and during the course of the funding period, achieved.

### Project Objectives

1. To open transnational access in a way not only to deliver, but also to harvest from users' experiences and scientific requirements
2. To stimulate the creation of a sustainable and enduring integration in the area of multimaterial micro nano technologies (MNT)
3. To develop the vertical integration of distributed multimaterial MNT in order to achieve a higher level of interoperability, which is then demonstrated by the development of user-specific reference process chains (in collaboration with specific users and user groups)
4. To assess already classified technologies, and thus to describe their readiness and maturity level regarding a set of specific parameters in order to enhance the performance of individual multimaterial MNT
5. To evaluate and integrate the knowledge outside the consortium by means of specific interaction with external experts (e.g. interviews), using a foresight process and case studies that lead to technology-specific roadmaps
6. To compare and classify individual technologies, thus enabling potential users to specifically select the most appropriate technology
7. To develop and operate a knowledge management system (KMS) that physically integrates relevant information from the partners, as well as results from research and networking activities within EUMINAfab; it is an IT-based tool to increase EUMINAfab's performance as an ERI.

The three pillars of EUMINAfab: Networking, Transnational Access and Joint Research Activities, are supported by an efficient management.

### Networking Activities

The **EUMINAfab Entry Point** is both the "e-public face" of EUMINAfab and the central point of access to the integrated services. It creates a focal point for EUMINAfab: all material necessary to inform users of the offer of fully funded open access to EUMINAfab is available the calls published, and applications are received, reviewed and. managed. The knowledge management system, developed in the Joint Research Activities, is implemented, and serves also as a communication platform for the project participants. The resultant single entry point for user requests is compatible with the individual mechanisms of the partners' home infrastructures.

Micro and nano fabrication technologies are cross cutting technologies and serve a wide range of application areas. **Roadmapping** can give insight on possible future success stories and highlight challenges facing further progress. Roadmapping activities have focused specifically on the technologies offered by EUMINAfab with the potential of highlighting a combination of technologies which could have a major impact. To date 120 documents relevant to EUMINAfab have been analysed and two Hot Spots of activity have been recognised.

- Self-assembling technologies for direct use or mask making processes and related metrology issues.
- Non polymeric (glass, ceramic, metal) materials replication processes in the micrometre/sub micrometre range including suitable tool fabrication

Initially **dissemination activities** have focused on making known the offer of no-fee user access to EUMINAfab. This has largely taken place by being present at conferences and exhibitions using elements of the EUMINAfab Roadshow. In addition to these publicity exercises, the results of the recently completed user projects and JRA work packages are published in appropriate journal and conferences. We have been present at a wide range of events euspen, MM Live, E-MRS fall meeting, Micronora, Manufuture 2011, Fumat 2011, nanofutures 4M 2009-2013.


Fig.3 EUMINAfab partners at E-MRS Fall meeting Warsaw Sept 2010, from left to right Susan Anson (KIT), Tanja Meyer (FhG), Frank Dirne (Philips), Jorge Ramiro (TEKNIKER), Steffen Scholz (Cardiff University

Our dissemination plan extends beyond the end of the funding period. Already planned in 2013:

- Symposium at the EMRS Fall meeting in Warsaw together with the I3 projects H2FC and Quality nano (September).
- EUMINAfab session at 4M2013 Conference in San Sebastian, Spain. (October)
- Third EU-Australia Workshop in Canberra - linkage with industry plenary session jointly organised with the Australian National Fabrication Facility ANFF (November).

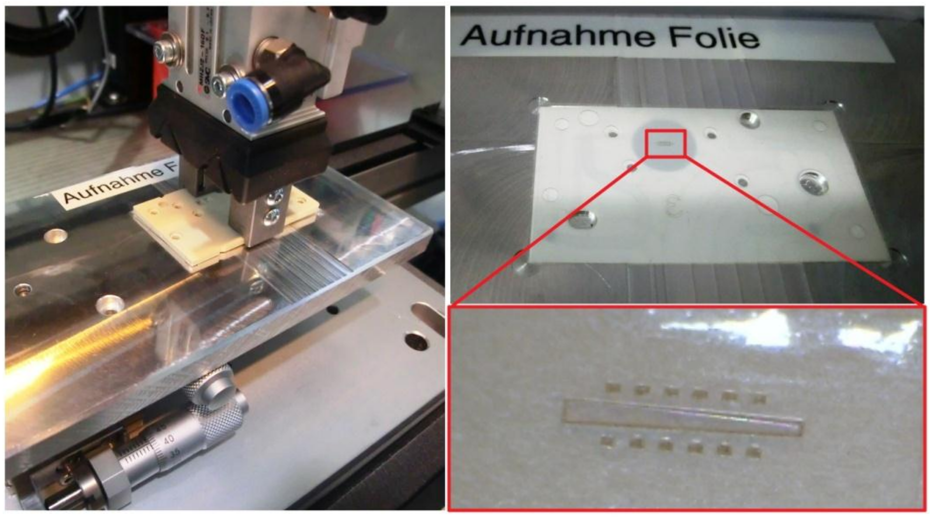
Within the **Researchers Exchange Programme (REP),** EUMINAfab researchers were able to take the opportunity of trying out ideas at partner sites. Proposals could be submitted via the project intranet and were evaluated by a panel of senior EUMINAfab scientists. The REP projects are typically of two weeks duration and often led to the design of JRA projects between two or more partners. The skills gained by the candidates could also be applied to user projects and are of particular value when a technology expert was approached by a user request requiring skills available at different partner sites.

The discussion of the **sustainability of EUMINAfab beyond 2013** has enabled us to devise a model which provides a structure for integrated transnational access to this valuable infrastructure, and is compatible with the members of our diverse partnership. Funding for transnational access is, however, very fragmented in Europe and until the difficulty can be solved, the I3 Capacities Programme is an essential underpinning element of our model. The reason for this is that each country, region and organisation has its own way of supporting open access and there is very little compatibility between the schemes. Partly as a consequence of this difficulty, and in recognition of the fact that without the input of funding the partners are not able to offer no fee access on a transnational level, but more so in response to the growth in maturity of the access offer, we have concluded that a future funding under the Capacities Specific programme in H2020 would give the optimal support for expanding the Consortium, the maturity of our services and our user base. We submitted a contribution to the EC Consultation of Infrastructures in October 2012. In this we proposed our plans to expand the current partnership to include additional upcoming technology providers and to further develop the application-focussed offer of transnational access.

## Access activities

The technologies offered in EUMINAfab each have a unique combination of technological capabilities and operational expertise. Some of the equipment is highly coveted by R&D departments unable to invest in such high-end equipment, such as e-beam facilities, x-ray lithography or helium ion microscopes. Other pieces of equipment are not necessarily expensive to run; however, they are newly emerging technologies only available at one or two locations in Europe. Examples are dip pen nano lithography and 3D laser writing. EUMINAfab is an FP7 Infrastructure project which seeks to overcome the bottleneck of the lack of widespread availability by opening the doors of several key European sites to users from across Europe. After four years of integrated user operation, the offer of no fee transnational access has enabled more than 150 users from more than 120 different academic and industrial organisations, based in twenty different EU member or associated states, to benefit from the FP7 funding allowing no fee access. EUMINAfab scientists work with the users and are available during the proposal stage to discuss the feasibility of new ideas right through to the completion of the projects.

The offer of open access by EUMINAfab partners means that users do not only have the benefit of access to unique equipment and the specific expertise at the partner sites, but also that the user projects themselves challenge the current capabilities of these technologies, demand new technology variants, new structures, devices and applications. The spin-off effect is to ensure that the new emergent MNT evolves relevant to the Europe-wide user community. Herein lays the opportunity to accelerate the uptake of emergent technologies and the transfer of the knowledge gained into application-relevant discoveries, even at this early stage.




Upper part of a bio disposable cartridge being positioned on a 12µm thin, double sided adhesive film with micro structured, laser milled through holes. (Source: ACI-ecotec, Germany, user at EUMINAfab host partner Cardiff).

EUMINAfab user projects have shown a strong application relevance to a broad range of application areas. The area of life science illustrates the versatility of the many techniques offered. Improved diagnostic sensitivity and reduced dosage in X-ray imaging is an important goal which is being reached with the aid of X-ray gratings made possible by the lithography equipment available in EUMINAfab. Another frequent type of user request is for microfluidic cartridges tailor made for specific analytical purposes to enable further research in adapted point of care diagnostics. With longer term application in mind techniques enabling the bio functionalization of surfaces are assisting advances in high through put screening, patch clamping and biodegradable cardiovascular stents. EUMINAfab services support the access to the state of the art technologies and the development of functional demonstrators and prototypes. That this is a valuable asset to SME’s can is illustrated by the user project from ACI-ecotec, Germany, visiting host partner Cardiff. (Figure)

## Joint Research Activities

The overriding objective of the joint research activities (JRAs) is to enable a strong operative interaction between European micro and nano infrastructures and R&D institutions. At the start of user operations, the basics were in place to offer users coordinated access to our facilities. During the course of this funding period, much work has been carried out to further the technology integration into new process chains, to demonstrate new capabilities and to improve the flow of information, both within the consortium and with our users. The progress made in the three JRA work packages is described below.

A workflow system for the handling of user requests was established and following this a knowledge management system (MinaBase) was developed. The MinaBase is the first step on the way to a holistic approach for an integrated organisational system. It enables a user-friendly operability and robustness of EUMINAfab's offer of user access services, which is intended to last beyond the project duration. Minabase has been publically available since November 2012, and gives users the opportunity to search more deeply for technologies, applications, and example structures and parameters possible at EUMINAfab partners' sites.

The research on "Design for manufacture knowledge" has provided an interface between a modularised "solution neutral" description of TNA requests (application/user groups oriented) and prototyping or batch manufacturing solutions offered within EUMINAfab. The results have led to the guidelines for process design - these integrate the Technology Readiness Levels of the processes and process chains, the technological capabilities, and the information gained on the reliability and robustness of processes. An essential aspect for the sound establishment of new processes is traceable metrology. With the aim of allowing the external community to benefit from a set of standards, artefacts for the calibration of areal surface topography measuring instruments have been manufactured and characterised. The full set of artefacts, known affectionately among the partners as the "Bento Box" is now commercially available along with a set of free good practice guides that describe the calibration process in simple yet detailed terms.

The activities in "Technologies and process chains" have supported the integration of EUMINAfab installations in both horizontal and vertical dimensions.

a) Horizontal integration: for the long-term sustainability of EUMINAfab, a traceable calibration system is essential. A series of reproducibility and repeatability trials have been carried out with particular consideration to the broad spread of capabilities within the technology portfolio of EUMINAfab.

b) Vertical integration: the focus is the development and characterisation/comparison of process chains in order to satisfy application-specific requirements of the EUMINAfab user community. A set of internal projects, sometimes linked with user requests with a high research factor, was carried out. The focus was, e.g., on the production of technology demonstrators using the combination of process chains, or to compare, test and improve alternative fabrication and structuring technologies.

# A description of the main S&T results/foregrounds

This section is organised in three subsections. Firstly, progress made in each of the five networking work packages is described. Secondly, a selection of highlights from transnational access projects at the host partner sites is given. This is followed by a selection of highlights from the Joint Research Activities. An analysis of the impact of the access activities is given in the Impact section.

## Networking work packages

### WP N1 EUMINAfab Entry Point

The main achievement has been the establishment of a centralised access system for user requests. Before the start of EUMINAfab, each partner had their own protocol for the handling their user requests. In order to establish an integrated access system, there needed to be a mutually acceptable proposal submission system for the consortium, which also considered the needs of our target groups of users. We attempted to lower the barriers as much as possible for industrial users and agreed upon a continuous evaluation of proposals. Only proposals submitted via the entry point using a EUMINAfab application form are considered valid EUMINAfab user projects and eligible for EC support. Since EUMINAfab projects can only account for a maximum of 20 % of the user time available at the partner sites, the individual home mechanisms for users would of course continue to function in parallel during the EUMINAfab funding period.

The proposal handling protocol was governed by a set of business processes, each having several stages, and was structured via check lists and control questions. This enabled the user office to be operated by newcomers and to function continuously.

The five main business processes in EUMINAfab which were operated by the knowledge management work flow system were:

- Intake (four sub processes).
- Evaluation (five sub processes).
- Work Break Down four sub processes).
- Realisation (six sub processes).
- Escalation procedure.

A major breakthrough was that each partner accepted the judgement of the EUMINAfab peer review board when it came to the recommendation to proceed for the proposals. Several partners already had a peer review panel for their home infrastructure – so agreement was reached, not only with the partners, but also with their independent review panels, to respect the judgement of the EUMINAfab peer review board.

### WP N2 Roadmapping

This work package was dedicated to selecting future Key MNT for multimaterial devices. The methodology adopted approached the issue from three main aspects. Firstly from what is reported in the literature. Secondly to gather the external opinion of experts from the MNT community, and thirdly the assessment of the potential for impact of EUMINAfab user projects.

An initial search for relevant documents resulted in the identification of 125 documents relevant to EUMINAfab access activities. The content of these documents was analysed and two main hot spots were identified.

- Self-assembling technologies for direct use or mask making processes and related metrology issues.
- Non polymeric (glass, ceramic, metal) materials replication processes in the micrometre/sub-micrometre range including suitable tool fabrication

In order to give a broader range of results gained additional to carrying out the above mentioned expert interviews it was decided to collaborate with the MINAM CSA project which was about to carry out a closely related online survey. By combining the information provided by MINAM (benchmark of emerging technologies in micro and nano manufacturing) and the analysis of user requests received by EUMINAfab, it was possible to deduce that:

- the portfolio of EUMINAfab is in line with the expectation of the users
- the portfolio incorporates technologies that present a real future potential

The results of the analysis of user requests confirmed the cross cutting nature of the emergent MNT in EUMINAfab.

### WP N3 Dissemination

Dissemination activities began with the preparation of the EUMINAfab roadshow. This was a portfolio of publicity information: a standard poster, flyers, presentation slides and exhibition stand and exhibits. These were regularly updated and very well used. EUMINAfab was represented at a total of more than 100 events, conferences and exhibitions. The main aim was to promote the potential and results of transnational access to potential EUMINAfab users. The need for this became clear at one of our very first events at Euronanoforum in Prague in June 2009. Although the concept of peer reviewed open access has been well established in Europe for many years, to e.g. synchrotron facilities, the concept of a similar model to open access facilities for multimaterial micro and nano fabrication and characterisation was found to appear quite unusual among our potential user community. It was an important paradigm in EUMINAfab to reach out beyond our immediate sphere of contacts to users not known to us personally.

Contact with multiplicator (?) organisations assisted the announcement of the calls for proposals. The European Technology platforms of Nanofutures and EPoSS, euspen the 4M Association, and the MINAM sub-technology platform to Manufuture, were helpful in distributing news on open calls. National networks, such as the UK KTN networks, also regularly published news of the calls.

Both our technology experts and users were encouraged to acknowledge the support of EUMINAfab at scientific conferences. Special sessions have been organised at the 4M Conference, EMRS fall meeting and Industrial Technologies in Aarhus.

Summer and winter schools have been organised to attract specific groups of users. The first of these was in March 2009 hosted by CEA in Grenoble.

It is important also to disseminate the achievements and lessons learned in integrating technology providers in the area of multimaterial MNT. In this light presentations have been given in dedicated sessions, e.g. at COMS 2012 and the Quality nano conference in 2013.

### WP N4 Researchers Exchange Programme (REP)

Within the REP programme the main impact lies in the variety of skills and further experience gained by the candidates who benefitted from this exchange programme (see following table) Participants have gained new skills in processing and fabrication technologies complementary to those available at their home organisation. The further development of skills from the laboratory into application was also encouraged.

As described in the JRA activities significant progress has been made in raising the awareness and level of experience within the consortium on the importance of traceable metrology for MNT. This naturally attracted REP proposals to further develop skills in this area, and to carry out test measurements on home produced structures.

| Title | Visitor Institution | Host partenr |
|---|---|---|
| Round robin test for measurement of x-ray LIGA structures | KIT | NPL |
| Tool making capabilities for hot embossing | KIT | CU |
| Comparison study and compressive injection moulding | CU | KIT |
| Microinjection moulding for medical applications | CU, | TEKNIKER |
| NIL process for mechanically active SMA composite structures | KIT | TEKNIKER |
| follow-up visit of VUB researcher to KIT for final exposure, development and metrology ; visit of KIT researcher to VUB for mask testing | VUB/KIT | KIT/VUB |
| Induced stress due to lattice parameter mismatch in metallised MEMS devices | UoB | TCD |

Gaining these new skills does not only benefit the exchanged researcher as an individual, but they also improve the knowledge they can offer to users at their home infrastructure and help with solving the challenges of the rather more complex user requests which require skills located at more than one partner site.

### WPN5 Sustaining EUMINAfab

The longer term sustainability of EUMINAfab has been a goal since writing the project proposal. Initially, efforts were focussed on defining the structure of a model compatible to sustaining the integration attained during the course of the funding period. A survey was carried out among partners, and some peer infrastructures to find out the most common types of user access. It rapidly became clear that the offer of no fee access without external funding would not be possible.

A series of workshop style meetings were carried out, in conjunction with meetings of the EUMINAfab Scientific and Technical Council, to ensure the participation of the high level participants from each partner. These workshops defined

- The scientific and technical scope of EUMINAfab access services
- The content of a cooperation agreement which could be extended to new participants
- Mid to long term goals for further funding
- The proposed structure of EUMINAfab submitted to the infrastructure consultation

As a result, a partner agreement has been defined. This agreement describes how EUMINAfab partners will continue to cooperate in the short-term, with the aim of maintaining the achieved level of integration and securing funding to be able to further develop the access services.

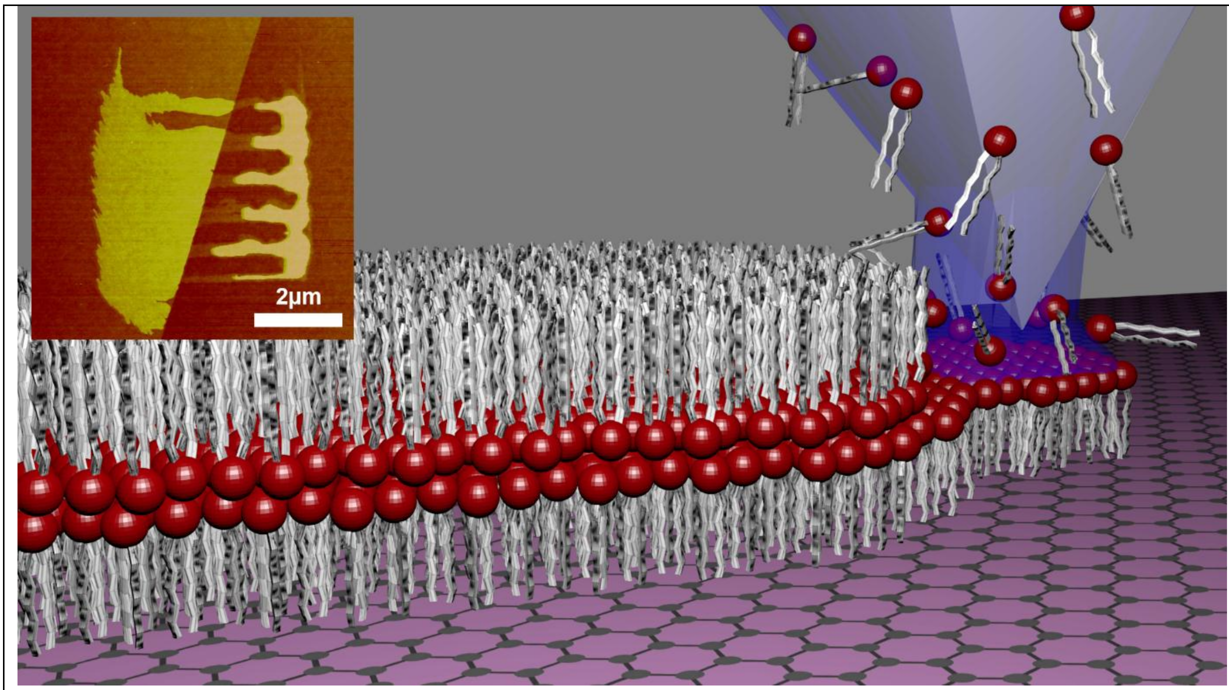
## Transnational Access Highlights

During the course of EUMINAfab 150 users from across Europe have benefitted from fully funded access to a comprehensive portfolio of technologies and expertise in multimaterial fabrication and characterisation. The following are selected user projects carried out at EUMINAfab partner sites.

### Graphene as substrate for biomimetic lipid membranes

*User organisation:* University of Manchester, UK *Host Partner:* KIT

The main aim of this project was to elucidate the feasibility and characterise the application of dip-pen nanolithography (DPN) with phospholipids, to fabricate tailored biomimetic lipid membranes on graphene. The proposed functionalisation of graphene was successfully implemented and effects of electrical coupling of charged lipids with the graphene were observed: the fluorescence of labelled lipids was quenched by the graphene substrate. Raman microscopy measurements established that the charged lipids had a doping effect on the graphene. Selective protein binding to functionalised lipids with matching moieties was also demonstrated. Taken together, these results point to the feasibility of using graphene-based devices, functionalised with artificial lipid membranes, as novel sensors for protein binding (with applications in medical diagnostics) and to observe the behaviour of membrane ion channels (e.g. for drug research). This future road is the subject of ongoing follow-up projects at the Karlsruhe Nano Micro Facility (KNMF) at KIT. EUMINAfab was a key factor in establishing the collaboration and giving Dr Vijayaraghavan the opportunity to visit KIT for the basic experiments and prolonged access to our DPN facility.




Scheme of the DPN writing process with lipids on graphene. The inset shows an AFM image of a membrane written on the edge of a graphene flake (left) on silicon oxide (right). The membrane part positioned on the graphene is merged, while the part on the silicon oxide is still separated.

Publication:

Hirtz M, Oikonomou A, Georgiou T, Fuchs H, Vijayaraghavan A 2013Multiplexed biomimetic lipid membranes on graphene by dip-pen nanolithography *Nature Communications* **4** 2591.

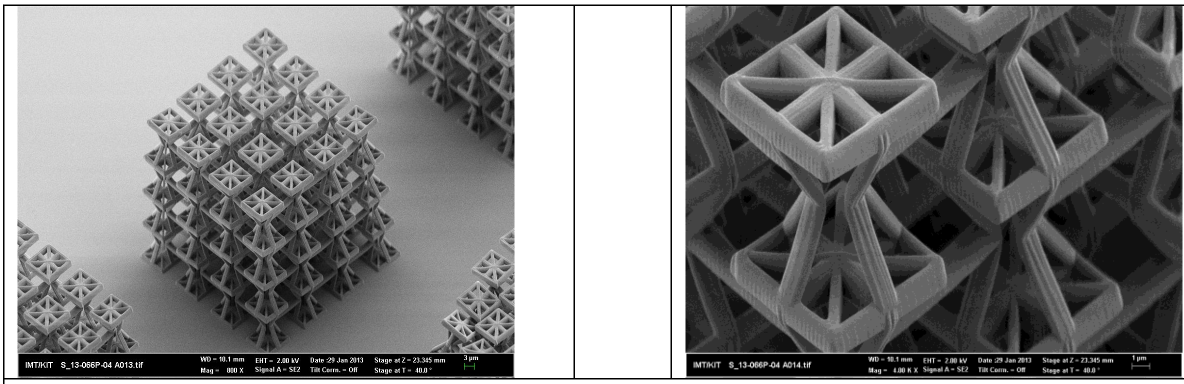
### Additive nanomanufacture of 3D auxetic metamaterials

*User organisation* Universidad Politecnica Madrid, *Host Partner:* KIT

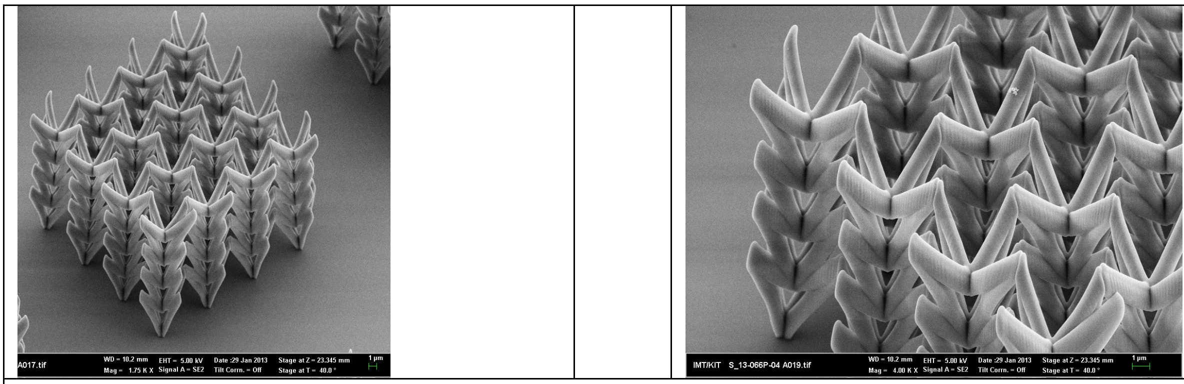
Auxetic materials, which when stretched become thicker, have been known for many years; however, the ability to create such structures on the sub-micro or nanometre scale has only recently become possible with the advancement of technologies such as the Nanoscribe 3D laser lithography tool, which became available to EUMINAfab users in 2012.

The EUMINAfab user wanted to explore the viability of manufacturing 3D auxetic structures on a nanometric scale and validate their 3D auxetic behaviour for potential applications in smart actuators.

Within this project, two different types of auxetic structures have been fabricated by 3D laser lithography using the negative resist IP-Dip. Their structural quality has been analysed by scanning electron microscopy. The quality of the structures depends on several parameters, such as e.g., the resist system, the laser intensity, the strategy of writing the structures, the ratio between voxel and structure size, and the shrinking behaviour of the resist during the polymerisation process. By optimising these parameters, initial lack of stability of the structures could be avoided. High quality structures are shown in figures 1 and 2. The widths of the structural bars are in the range of 1 µm or less. The height of the overall structure is approximately 50 µm.



SEM picture of auxetic structure. Design: Re-entrant cuboid



SEM picture of auxetic structure. Design: Pyramid US Patent

Publication:

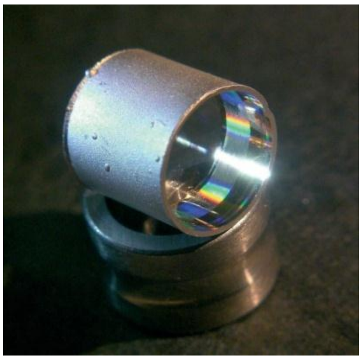
Álvarez Elipe J C, Díaz Lantada A 2012 Comparative study of auxetic geometries by means of computer-aided design and engineering *Smart Materials and Structures* **21** 105004.

## Cylindrical gratings

*User organisation* Laboratoire Hubert Curien UMR CNRS 5516, University of Lyon at Saint-Etienne, France, *Host Partner:* Cardiff

The requirement was for a cylindrical submicrometre grating of millimetre-long lines and nanometre grooves in the wall of a cylinder.

The cylindrical gratings, of sub-micrometre period, in the walls of cylinders or disks, are required for use in rotation encoders and spectrometers. The two main difficulties to overcome in the manufacture of such gratings are: the definition, particularly for the manufacture of rotation encoders, of an integer number of sub-micrometre periods in one 360 degree turn. The second difficulty is to make the lines of such cylindrical gratings of sufficient length

| | |
|---|---|
|  | Image of the cylindrical grating shim (inner diameter of the rod: 6mm) showing sub micrometre structured inner surface of nickel cylinder |

The user had already designed a proprietary origination method allowing them to overcome the above-mentioned difficulties. The original (the master) is made of a PMMA cylinder with a corrugated wall, allowing the dissolution of the master after the Ni-shim has been grown. A typical cylinder size is from 8 mm to 25 mm in diameter and from 1 mm to 10 mm in length. They wished to develop the related downstream shim and replication technologies in cooperation with the replication partner. As a first trial, it was proposed to try to manufacture the disk of a rotation encoder with 2 mm groove length, about 600 nm period and 400 nm groove depth, in a binary corrugated shape. Firstly, the user supplied Cardiff with a test rod — a glass rod with a simple unstructured coating of standard positive Shipley photoresist. This allowed Cardiff to optimise the sputter coating process, ensuring a uniform conductive coating of gold to facilitate the electroforming process. With this process optimised, the user then supplied Cardiff with a glass rod coated with a micro-structured resist. This was then coated in gold to enable the electroforming of a nickel shell onto this micro-structured resist coated cylinder wall comprising 32768 = 215 periods exactly. The period of the resist grating at the flank of the 8 mm diameter cylinder is 776 nm and the corrugation depth in the resist layer is about 360 nm. First observations by Cardiff show that the resist grating 'survived' the nickel growth conditions (thermally and chemically). It was decided that the separation between glass-resist master and nickel shim would be made by Lyon University. It was the first time that processes, which are usually applied to planar surfaces, have been utilised to replicate a nanostructured cylindrical test part. Process settings for uniformly electroforming a shim around a cylindrical glass rod covered with gratings in a PMMA resist have been established by Cardiff. It can be concluded that this challenging project has successfully met its objectives.

Publication:

Hirshy H, Scholz S G, Jourlin Y, Tonchev S, Reynaud S, Boukenter A, Parriaux O 2013 2N period submicron grating at the inner wall of a metal cylinder *Microsystem Technologies* 1-5

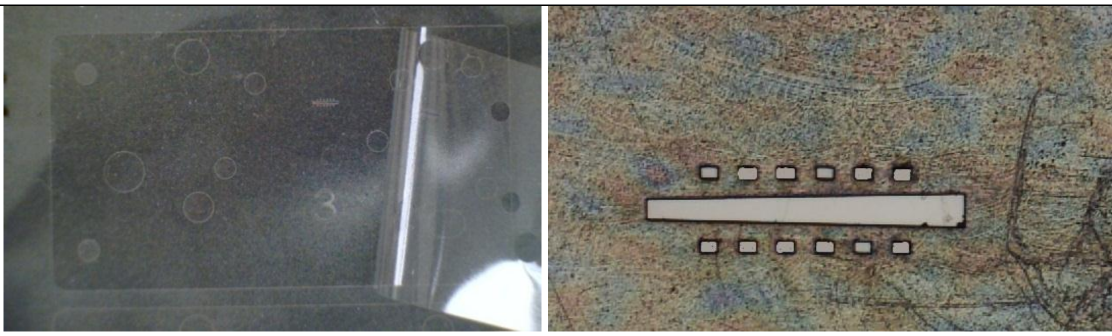
### Laserstructuring of thin polymer films with extremely small geometries

*User organisation* ACI-Ecotec GmbH, Germany, *Host Partner:* Cardiff

The goal of this project was to structure very thin polymer films with small dimensions. This would expand the possibilities of biotechnological applications in new microfluidic disposable systems. The use of thin polymer films, either as a form of cover plate or a sandwich layer between a polymer upper or lower side, has often been cited in the literature. The latter is of interest for this SME user project. The polymer film itself shall be used as a fluidic system, while the fluidic contact and the sensing devices are stored in the respective upper and lower parts of the disposable. Due to the design the layer thickness and micro structures partially very close to each other are critical features. Most of the scientific publications report examinations being carried out by comparatively thick film layers, with 100 or more micrometres thickness. However the structuring of thin polymer film layers (e.g. the TESA film with 12 µm) and especially of composite films (e.g. a PET TESA film as shown below), consisting of carrier film adhesive layer(s) and release liners, is rarely cited. As the solution, the critical component was manufactured using laser technology within the EUMINAfab consortium


A component playing critical role in the point of care device was to be manufactured from these layers. The geometry of the components has feature tolerances below 20 µm and tolerances for distances between geometric features below 5 µm.

As the whole component was to be cut out, it presented a challenge of achieving extremely high accuracy over large area, as well as combining very small features (100µm) with relatively large features (50mm). Finding the correct parameters to cut through all five layers of different materials with different properties without any thermal damage was crucial for the success. Laser wavelength of 355nm was found to be most suitable for the laser processing. During the processing substrate was held flat in order to maintain focus position of the beam and the handling was as per medical grade.



Left: micro-structured foil and release liner. Right: close up of the microstructures (squares 100 µm x 150 µm)

This approach was successfully tested to seal the lid onto an electrophoresis chip which has potential as a microfluidic diagnostic device.

### Observation of nanostructures of granulates by high resolution x-ray tomography

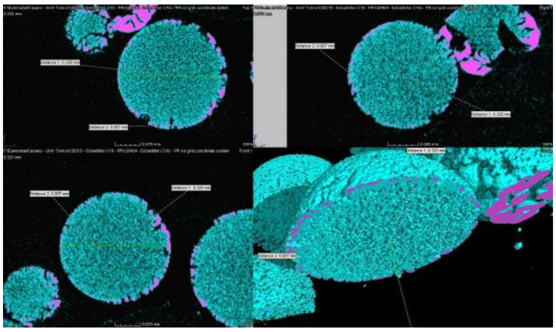
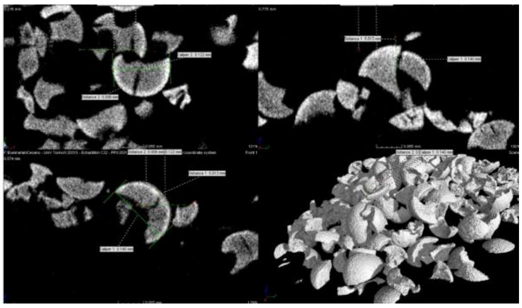
*User organisation* Cesano, Politechnico Torino, Italy, *Host partner* CEA

Politecnico Torino has developed an easy synthesis technique for preparing metal-free conductive tracks starting from the incorporation of selected quantities of carbon nanotubes (CNTs) into melting polyolefin polymers (e.g. high density polyethylene, polypropylene).

At their level of study, the main goals now were i) to individuate at the micro-scale level the conductive tracks along the length, ii) determine the size of the electrically active region (cross-sections), iii) to define from ii) the resistivity/conductivity dimensions of the tracks by applying Ohm's Law; and iv) to study the integrity of the tracks.

At this stage of the development of this technology, the user wanted to observe by x-ray tomography the structure of granulates (internal porosity in particular).

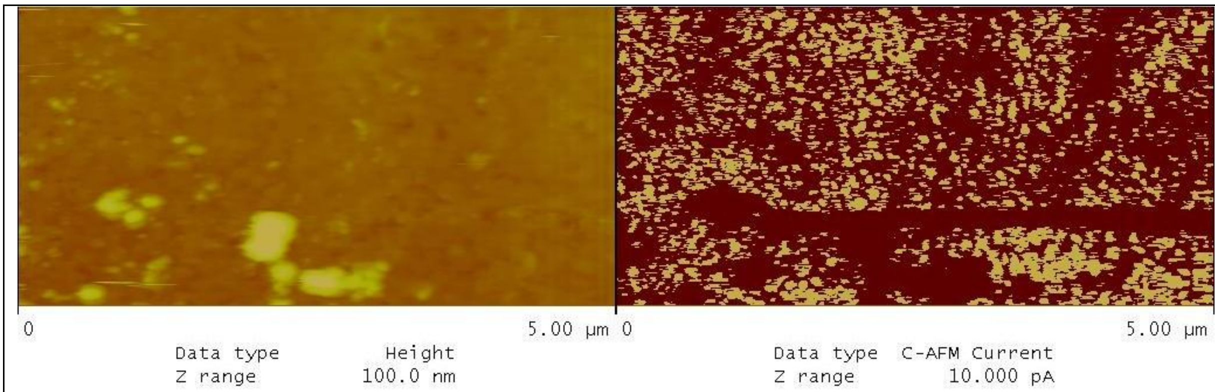
The project was very successful as the observation allowed precisely to set-up an accurate observation of the internal structure of granulates. This will be very useful to set-up the process for the production of such granulates.

|  |  |
| --- | --- |
| Internal structure of granulates | General observation of many broken granulates. |

### Studies on nanoarchitectonics of the self-assemblies of nanoparticles of metals or metal oxides – layered double hydroxides (LDH) matrices and their electro-optical properties

*User organisation* Technical University Ghe Asachi of Iasi, Romania, *Host Partner*: CRF, CEA

The user has long experience in synthesis of nanoparticles deposited on the layered matrices of MgAlLDH and ZnAlLDH anionic clays. The user needed to carry out a characterisation of the electrical properties of her materials but she had not experience in that field. Moreover, the materials were in the form of powder so it was not easily managed for contact bonding. CRF suggested the user use the screen printing machine to prepare suitable substrates for the powders, with silver electrodes on alumina. The user synthesized nine different kinds of nano-clays that were deposited by dipping on the special substrates made by the CRF screen printing facility. The samples were characterised using the electro-optical characterisation installation. It was possible to measure the I-V curves of the powders and to collect some conductive-AFM pictures that show the current distribution over the nano-clays. It was necessary to get information about the nanoparticles size and distribution but the AFM was not suitable for this kind of analysis, so in parallel the powders were observed using Titan TEM at CEA. The results obtained by the analyses of the current-voltage curves reveal that the semiconducting properties of the samples are influenced by the clay composition. The images obtained by using Titan microscope show the presence of nano-grains.

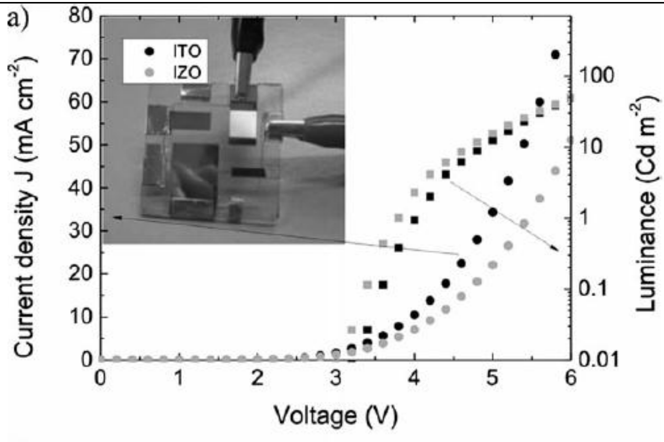



Height picture (left) and current distribution (right) of a LDH nano-clays, obtained by conductive-AFM with 2V applied voltage

### Flexible OLEDs

*User organisation* CENIMAT - Universidade Nova de Lisboa, Portugal, *Host Partner*: CRF

The aim of this project was to test the feasibility of flexible OLEDs with indium zinc oxide (IZO) anodes. In the medium and long term, the user intended to improve the technological process for flexible substrates in order to get multicolour and flexible devices. The user needed to manufacture OLED prototypes using his flexible substrates of IZO. This manufacturing process includes using several machines (UV exposure, sputtering, thermal evaporation spin coating) and the process should be carried out in a very clean environment. Moreover, the characterisation is time-critical and needs to be done shortly after the manufacturing process in order to get the initial performances and the lifetime. CRF provided both the facilities for device manufacturing and for characterisation through two installations: PVD cluster for organic device fabrication and electro-optical characterisation. The first installation is placed in a clean room so high quality devices were assembled. Finally, it was possible to get OLED devices with IZO anodes with better efficiency than ITO, both on rigid and flexible substrates. These results led to a joint publication. In Figure 1, an example of sample characterisation is reported a working device is shown along with the relative I-V-luminance curve.




Current–voltage–luminance (I–V–L) of OLED devices made on ITO and IZO

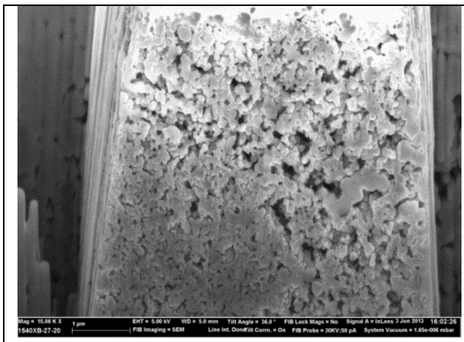
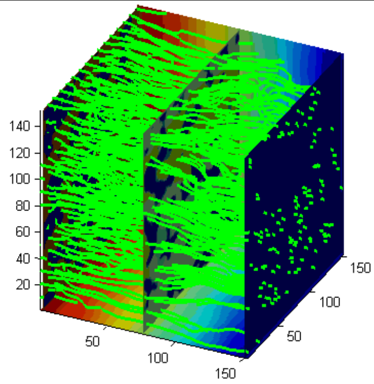
Publication:

Gonçalves G, Grasso V, Barquinha P, Pereira L, Elamurugu E, Brignone M, Martins R, Lambertini V, Fortunato E 2011 Role of room temperature sputtered high conductive and high transparent indium zinc oxide film contacts on the performance of orange, green, and blue organic light emitting diodes *Plasma Process. Polym.* **8** 340-345.

### Visualisation of porous structures of a fuel cell catalyst layer

*User organisation* University of Thessaly, Greece. *Host partner* UoB,

The catalyst layer of a fuel cell is regarded as the heart of the system, as the performance of the catalyst layer contributes significantly to the overall performance of the fuel cell. The porosity of catalyst determines how liquid and gas go through it and create ions. This project is set out to visualise the nanostructure of a catalyst layer from inside to outside using the focused ion beam (FIB) based nano tomography techniques provided by EUMINAfab. The work was carried out at the University of Birmingham Nanotechnology Centre in response to the research needs of Dr Andreas Podias from University of Thessaly, Greece. During the 3D reconstruction of the catalyst layer, over one hundred layers were removed using FIB and images were aligned to form the digital structure of the catalyst layer. Figure 1 shows an SEM image taken during the reconstruction process. Figure 2 is a reconstructed model of a catalyst layer. Porosity, average pore size, permeability and tortuosity of the catalyst can be analysed from the digital model of the catalyst layer. The model can be used in computer simulations to understand how gas and liquid go through the layer. Figure 3 shows the tracks of the pressurised gas penetrating the catalyst layer. The analysis helps researchers to choose a suitable catalyst layer to achieve the best electricity generation performance.

|  |  |   |
|---|---|---|
| Figure 1. An SEM image of the catalyst layer sectioned using FIB | Figure 2. A reconstructed catalyst layer. | Figure 3. A reconstructed catalyst layer structure - to illustrate how pressurised gas goes through nanosized pores in a flow simulation of a fuel cell |

Publication:

Podia, A. "Probing and visualising the 3D structure of fuel cell electrodes via Focused Ion Beam Nanotomography" at EMRS2013 Warsaw.

### Characterization and functionalization of patterned and UV activated $TiO_2$ substrates

*User organisation*: Nanoate SL, Madrid, Spain, *Host Partner:* TCD

The user project proposed the characterisation of micro-patterned surfaces on $TiO_2$ single crystal substrates fabricated by MeV ion beam lithography. Furthermore, the indentation was to test their suitability for further bio functionalisation.

Helium ion microscopy (HIM) was employed to obtain a high resolution characterisation of the modified $TiO_2$ surfaces. The results allow a better understanding of the reason why the surface of ion-beam modified $TiO_2$ presents a different nanostructure from other amorphous $TiO_2$ i.e. sputtered or oxidised surfaces. As $TiO_2$ is an insulating material, standard SEM on this type of sample gives very a low resolution. HIM allows better characterisation of insulating samples, and has improved surface sensitivity and resolution, compared to SEM.

The surface nanotopography of the micro-patterned samples, with and without fixed cells, were examined by HIM employing an ORION PLUS microscope from Carl Zeiss SMT. The examination of the surface nanotopography on the patterned samples by HIM showed noticeable differences between the smooth single crystalline surfaces, on the top of the walls, and surfaces in the micro-wells. The vertical wall edges of micro-wells are not perfectly defined due to imperfections on the employed mask edges. A detailed view of the surfaces at the bottom of the micro-wells is shown below. The surface in the micro-wells has a characteristic rough or nanostructured appearance, which was difficult to image with SEM. Previous characterisation using SEM and AFM gave resulted in a smoother due to limitations in resolution (charging effects in SEM) and tip limitations (convolution effects)

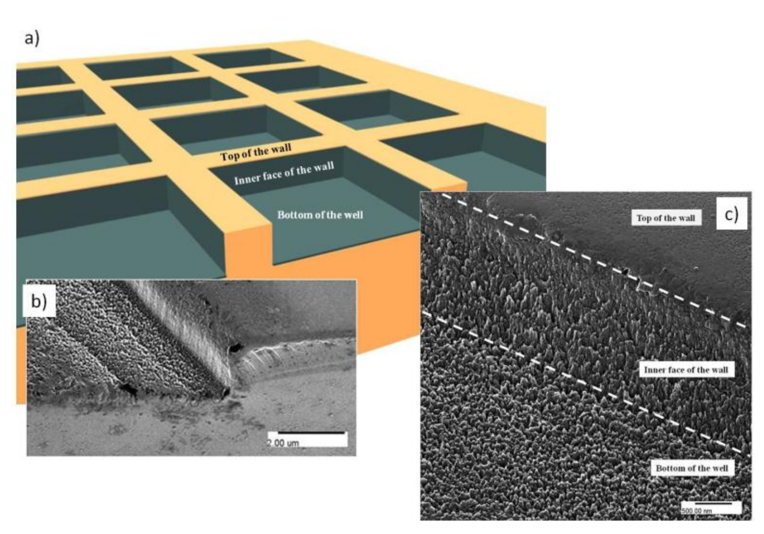



Figure 1. HIM images of the cross-section of a micro-well.

a) Sketch of microwells

b) Cross-section view

c) Detailed view of the top of a wall, inner face of a wall and bottom of a micro-well.

Publication:

Hirtz M, Perez-Giron J V, Bell A P, Sanz R, Jensen J 2-13 Patterned biofunctional $TiO_2$ surfaces created by ion-beam based lithography *EMRS Spring meeting* WHERE, PAGES – also submitted *to Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms*.

## Thin film and nano-structured sensors for transformer oil analysis

*User organisation:* Camlin Technologies, Lisburn, Northern Ireland *Host Partner:* TCD

The aim of this project was to develop optical thin film based sensors to monitor the condition of oil used to insulate and protect transformers used in electrical power generation, transmission and distribution. The sensors need to be tailored to sense the various fault gases and dielectric changes in transformer oil. The company, aimed to characterise the response of various thin film materials and thicknesses to both hydrogen gas and dielectric changes in oil. This characterisation would enable them to determine the optimum parameters for a prototype device that would operate in-situ inside a transformer.

The fabrication of multiple depositions of thin films (gold and palladium) onto 90 degree prisms and glass slides was performed using the Temescal evaporator. Nano structured surfaces of gold and silver were also produced using a pulsed laser deposition technique (nano and femto-second lasers) in the photonics laboratory at CRANN. These nanostructures were imaged using SEM (Figure 1).

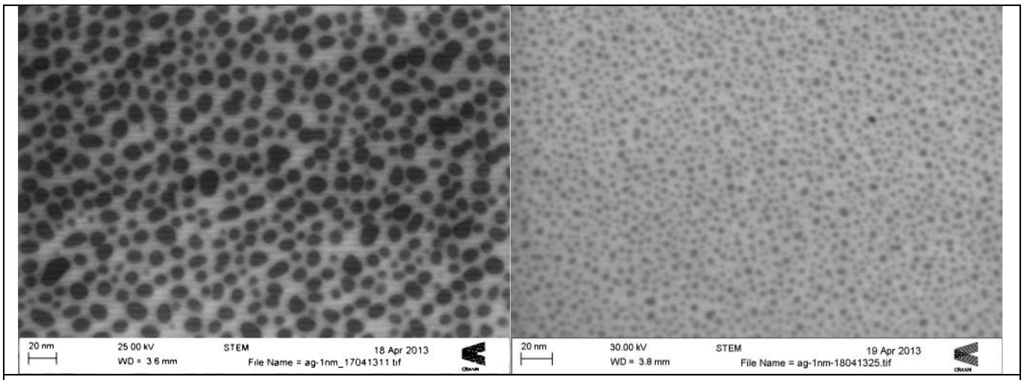



Figure 1. Nanostructured surfaces of gold and silver with the following particle size distribution; (Left) 7 nm thick sample is 10 nm, (Right) 1 nm thick sample is 3 nm

The thin films and nanostructures were provided to specification. Figure 1 shows two examples of gold nanoparticles deposited via PLD. On the left there are 10 nm diameter Au particles and on the right, 3 nm sized Au particles (Figure 2). The sensitivity of the nano-films was not adequate and redesign is required to make this a viable solution.

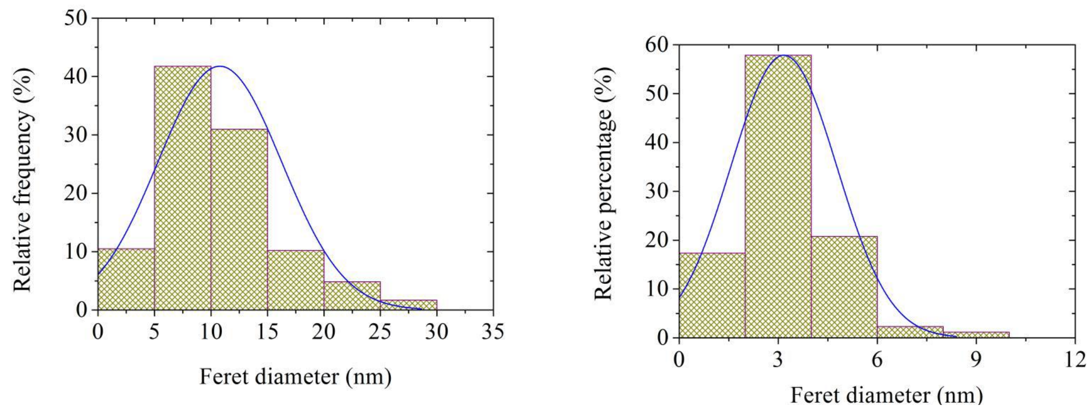



Figure 2. Size distribution measurements (Left) 10nm sized particles; (Right) 3nm sized particles

### Silicon structuring by etching with liquid chlorine, fluorine and hydrogen based precursors using femtosecond laser pulses

*User organisation*: National Institute for Laser, Plasma and Radiation Physics, Romania,
*Host Partner:* TEKNIKER

The user wanted, in the longer term, to nanostructure, in a reliable and reproducible way, square millimetre areas of silicon surfaces using femtosecond laser pulses in liquid chlorine, fluorine and methanol environments. The aim of the work was to establish the appropriate parameters to obtain those nanostructures. The process variables such as laser power, laser repetition frequency, overlapping of the scanned laser lines, appropriate focal point for each liquid had to be optimised and understood in order to make this kind of ultra-fast processing reproducible.

The work, involved a ten day stay, divided into two phases, of Dr. Magdalena Ulmeanu at Tekniker,

1) Identifying the appropriate pulse duration for this type of processing
2) Establishing the right scanning parameters to create large size areas

To achieve the first objective, both an IR (1064 nm) and UV (355 nm) 15 ps laser and UV (400 nm) 90 fs laser were employed. Experiments were carried out in a liquid environment, i.e. chlorine, fluorine and hydrogen-rich (methanol). The best pulse duration regime for this kind of nanostructure was found to be in the femtosecond range.

A number of trials were carried out to determine the best laser scanning pattern to be employed in structuring these surfaces. It was established that the best results were produced by scanning line after line.

1x1 square millimetre areas with a relatively uniform topography were achieved. 4x4 square millimetre areas were also created. These areas will be used as biological scaffolds and to study the topographical response of the cells. The areas created by the laser processing will be transferred, by replication processes, to biocompatible polymers for use in medical applications.

SEM and contact angle measurements were carried out and the results are shown in Figures 1 and 2. The images illustrate the achieved large processed areas of silicon. The 2D fast Fourier analysis indicate an ordered area, with periodicity in the order of 400 nm (on X scale) and 230 nm (on Y scale). The contact angle measurements indicate a change of the contact angle from 65º (unprocessed silicon) to 38º processed silicon. Raman spectroscopy measurements indicated that the silicon had become porous, but with no significant difference in porosities being observed when the different liquid precursors were used.

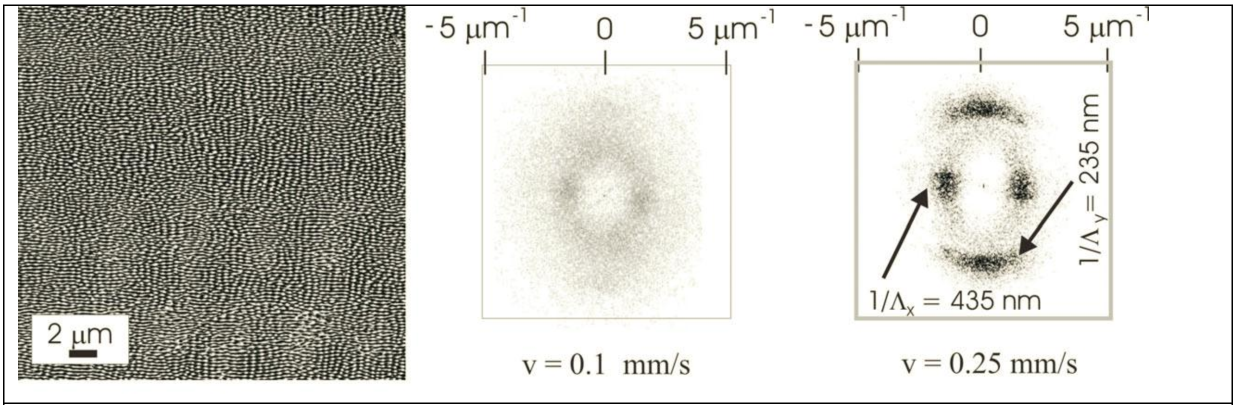



Figure 1. SEM photograph of silicon processed in methanol (left), and 2D fast Fourier analysis of silicon processed at a rate of 0.1 mm/s (centre) and 0.25 mm/s (right)

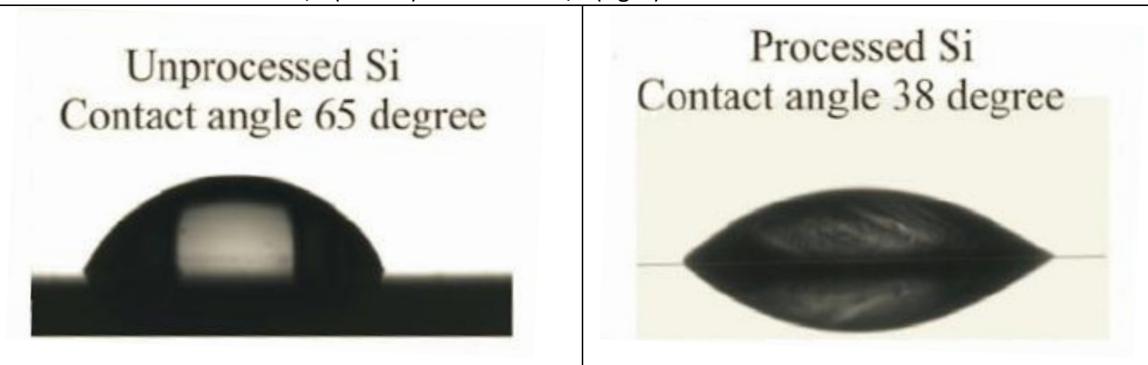



Figure 2. Contact angles of unprocessed silicon and of silicon processed by laser

Publication:

EUMINAfab Case Study in the Commercial Micro Manufacturing International magazine (Vol. 6 No.3 2013 pp 24-25). Paper for the *Current Topics in Medicinal Chemistry* is in preparation.

## Microstructure for orientation and immobilisation of diatoms

*User organisation*: Swerea IVF *Host Partner:* TEKNIKER

A diatom is microscopic plankton found almost anywhere where there is water. They can occur in large amounts and forms and the number of species is estimated to be over 100 000. Their photosynthesis accounts for approximately 25 % to 30 % of the organic carbon sequestration and thus a significant part of the world's oxygen production. The shell is basically composed of $SiO_2$ and can create fanciful forms. Diatoms are a good role model for building micro and nano systems. They are small factories that build nanostructures with very high accuracy. Diatoms can grow 3D nano- and microstructures of 200 µm to 50 µm with features down to 10 nm in the same unit.

The user’s objective was to employ diatoms to produce micro- and nano-structured systems, and to investigate the principles of how to use the genome and proteins to guide and control the manufacture of 3D micro- and nano-structures. Different methods to orient and immobilise the diatoms (unsymmetrical, such as Suriella) were being investigated. Their project focused on two areas: the controlled production of structurally modified diatoms and new principles for orientation and immobilisation of diatoms.

For the orientation and immobilisation of the diatoms, the user needed PDMS stamps for printing of organic and inorganic materials on glass substrates and a patterned glass plate for light illumination. There were two versions of the pattern for the illumination, one with a single hole structure and the same dimension as the stamp, and other with two smaller holes in the same pattern as the stamp. The glass plate had to be covered with a titanium layer with enough thickness so that the light only came through the holes.

Nuthalapati Greeshma from Swerea IVF was able to visit TEKNIKER for the fabrication steps and gained knowledge of the process for the fabrication of the silicone masters and titanium-on-glass masks, and was also trained to make PDMS stamps and handle the masters.

For the fabrication of silicon masters, photolithography and deep reactive ion etching (Bosch process) processes were performed, to obtain 30 µm deep holes with diameters of 20 µm (Figure 1). Silanisation was carried out on some masters, and a number PDMS stamps (using a commercial mixture, Sylgard 184) were fabricated (Figure 2).

For the fabrication of titanium-on-glass plates, glass wafers were coated with a positive resin, soft baked, exposed to UV using a photomask and developed. Then, a layer of titanium (190 nm) was deposited using PVD sputtering. Lift-off was carried out in hot acetone. This process was valid to obtain 20 µm diameter holes (Figure 3). Some modifications (such as the use of a thicker layer of photoresist and the deposition of titanium using e-beam evaporation) were applied for the fabrication of 3 µm holes (Figure 4).

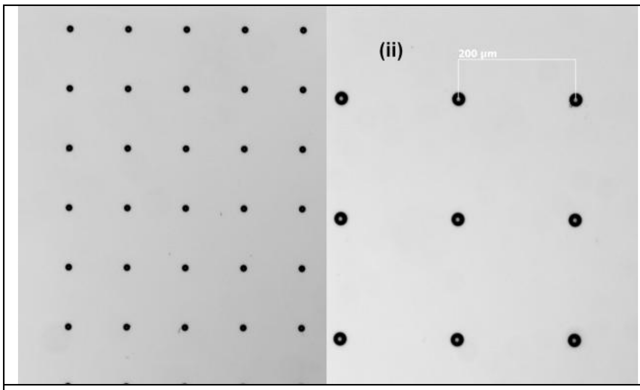



Figure 1. Photographs of fabricated silicon masters (20 µm diameter, 30 µm holes)

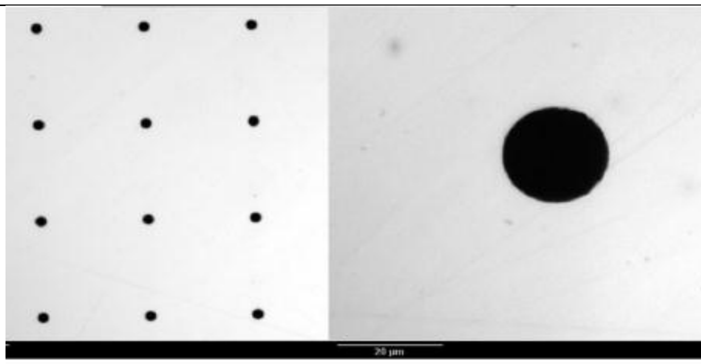



Figure 3. Photographs of fabricated titanium-on-glass plates. 20 µm diameter holes.

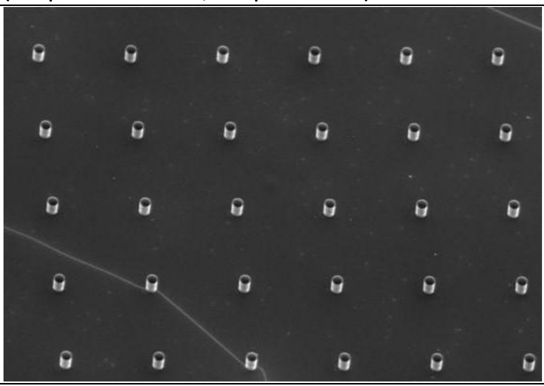


Figure 2. Details of PDMS stamps

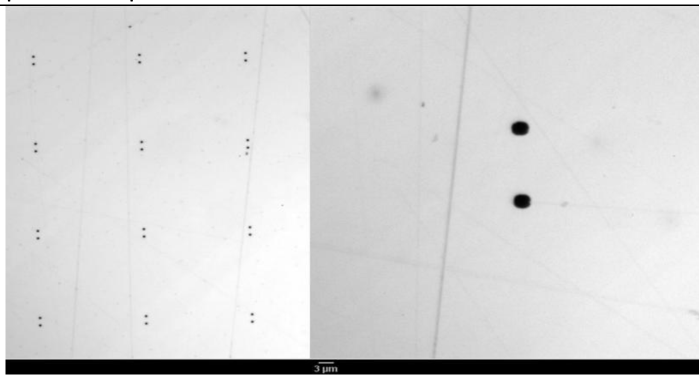



Figure 4. Photographs of fabricated titanium-on-glass plates. 3 µm diameter holes

Publication

The work was part of the Master Thesis of Nuthalapati Greeshma, “Diatoms for Nanomanufacturing: New Principles for Orientation and Immobilization” Diploma work No. 50/2011, Department of Materials and Manufacturing Technology, Chalmers University of Technology, Gothenburg, Sweden

Greeshma N, Godhe A, Blomberg A. Per Johander P 2011 Orientation and immobilisation of diatoms *4M 2011 8th International Conference on Multi-Material Micro Manufacture Stuttgart, November*

## JRA Highlights

Highlights from the JRA activities covered the breadth of an operational Knowledge Management System, cross infrastructure projects between partner sites to promote technology integration, through to the development of metrology artefacts which are now part of a set of commercially produced certified standards.

### Management System and Minabase

Partners involved – Lead partner KIT, Contributions - all partners

The activities in JRA 1 were dedicated to the development of an infrastructure for an effective collaboration. Standard operation procedures (SOPs) had been elaborated within the consortium to support the researcher during all phases of a user request, from intake to finalisation and review. The business processes, identified and agreed between the partners, ensure a proper handling and decision finding in all project stages. A management tool had been developed supporting the user office by the provision of advanced workflow services allowing for the flexible monitoring of decision making processes for each user project. The user office had been provided with a "management dashboard" allowing for a high level overview on the status of ongoing projects. The tool also allows a more detailed view when necessary and includes an automatic email reminder function. The system was evaluated and proved during the course of the project, where more than 160 proposals had been submitted. The method allows all participants in the proposal evaluation and execution stages to complete the necessary paper work by interactive PDF sent by automatic email, which avoids the need to log-in to an (online) information system. This was welcomed by partners, PRB members and users alike, and has since been adapted for use in other Infrastructure projects.

At a very early stage in EUMINAfab, the consortium voiced the difficulty of identifying technological capabilities available to users, especially in the case of complex user requests. A simple process data sheet cannot address the requirements, since the technical capabilities strongly depend on aspects of influence such as machines available, material used, or even the documentation of the application-specific context. Studies of the technical maturity of the processes, benchmarking and round robin tests were conducted to learn more about these service-relevant aspects.

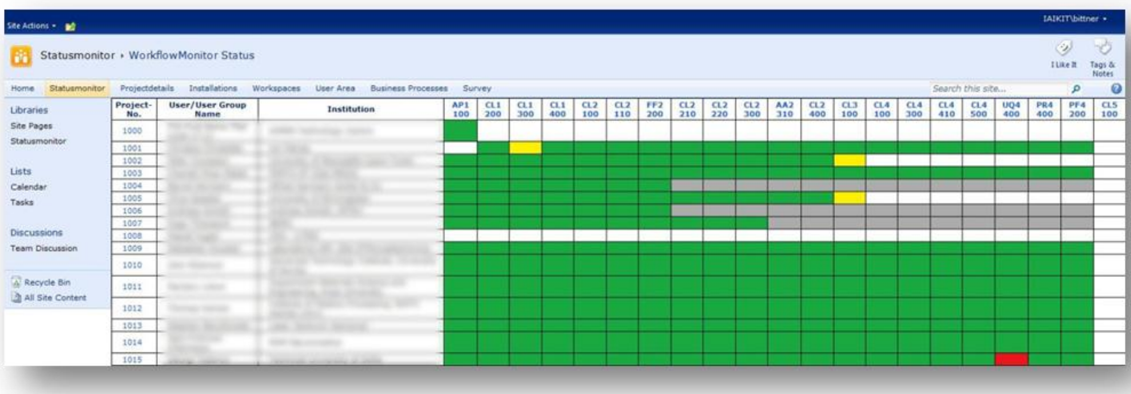



Figure 1 EUMINAfab management support system

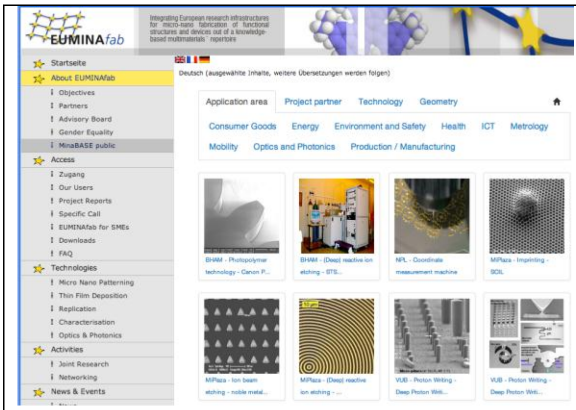


Figure 2 Easy to use browsing of technological capabilities stored in MINAbase for external users of the project website

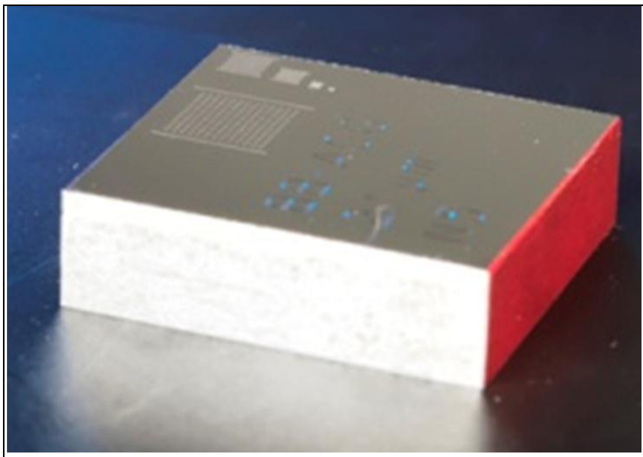
During several workshop the partners agreed on a common format for modelling and description of their technical competences in the planned knowledge management system given the name of MinaBase. The extensive technology descriptions and results of other work packages were stored in a database building on the comprehensive ontology. This web based database tool today allows for an in depth search within a set of competences and parameter data sets, helping the researchers to maintain and exchange their collective knowledge about the expertise available at the partner sites.

### Calibration artefacts a single set of material measures for the calibration of areal surface topography measuring instruments: the NPL Areal Bento Box

*Lead partner* NPL, *Contributions* - Philips, KIT, CU,

**Aim** – to develop a number of material measures to address the need for methods to calibrate areal surface topography measuring instruments

The use of areal surface topography measuring instruments has increased significantly over the past ten years as industry starts to embrace the use of surface structuring to affect the function of a component. This has led to a range of areal surface topography measuring instruments being developed and becoming available commercially. For such instruments to be used as part of a quality control system during production, it is essential for them to be calibrated according to international standards. As part of a joint research activity case study, NPL and KIT have recently developed a series of artefacts that can be used to determine the ISO 25178 metrological characteristics for calibrating areal surface topography measuring instruments. These artefacts include step heights, lateral grids, star-shapes and an optical flat for calibration; and irregular artefacts that can be used to performance verify the instrument. Whilst complex machining methods have been used to manufacture the artefacts, replication techniques have then been used to allow cost-effective artefacts for sale.



ACG artefact – 2 µm Ni final artefact ©NPL

calibrated “Bento Box” for sale

The full set of artefacts, known affectionately as the Bento Box, is now commercially available along with a set of free good practice guides that describe the calibration process in simple yet detailed terms. Figure 1 shows the full set of artefacts. The Bento Box artefacts are calibrated at NPL using traceable instrumentation and analysis software is freely available.

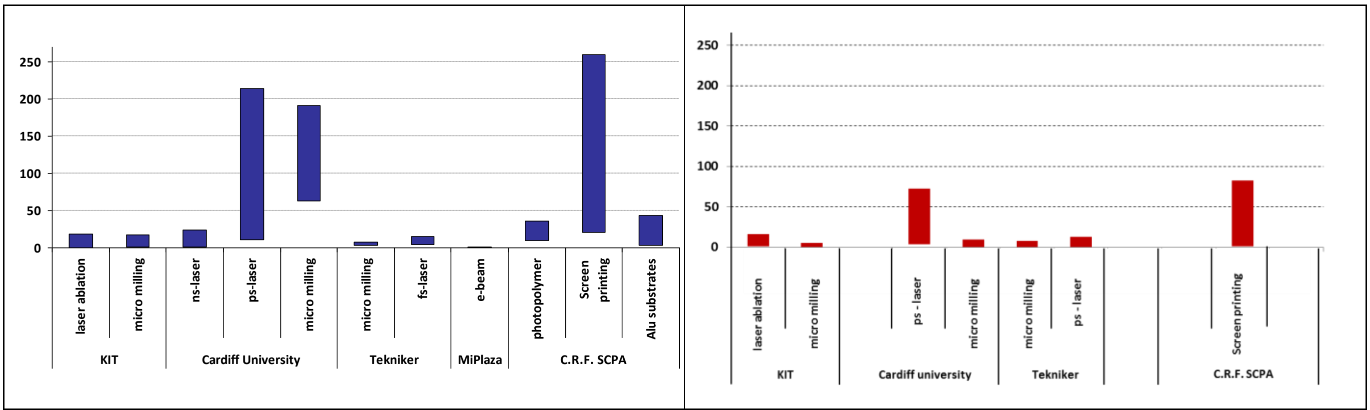
Publication

Leach R K, Giusca C L, Rubert P 2013 A single set of material measures for the calibration of areal surface topography measuring instruments: the NPL Areal Bento Box *Proc. Met. & Props, Teipei, Taiwan, Jun.* Also, article published in Commercial Manufacturing Magazine (Dec 13) “Thinking outside the Bento Box” and papers under review in *Surf. Topog.: Metro. Prop.*

### Benchmarking activities of the X,Y positioning accuracy

*Lead Partner* KTH, *Contributing partners* - all

A considerable effort has been made in JRA 3.1 to verify the performance of the X,Y positioning accuracy of micro-milling, laser machining and screen printing facilities used by the transnational access partners. Such investigations have not been done before as the belief has been that the specifications of the machine manufacturers are valid. The benchmarking made by KTH, as an independent evaluator not participating in the transnational access, using precision metrology equipment and dedicated image analysis algorithms, revealed large errors at several installations. The impact was, therefore, obvious – better calibration and fixturing was needed. A second carefully planned design of experiments was then carried out to reveal, not only X,Y position errors, but also repeatability, reproducibility and straightness of the installations. In total, more than 4000 images were analysed with uncertainty levels < 1 µm for the well-defined machined crosses, and a few micrometres when they were poorly defined due to burrs. The full data is presented in the report and a summary of the improvement of the installations´ accuracies are shown below.




Deviations (µm) from the expected positions of the equipment in the first evaluation (blue) and second evaluation (red)

A summary of the results was presented as two publications on the 10th International 4M Conference in October 2013. The appreciation of this work was confirmed by the conference jury selecting PhD student Bita Daemi at KTH Industrial Metrology group as the best paper/presentation.

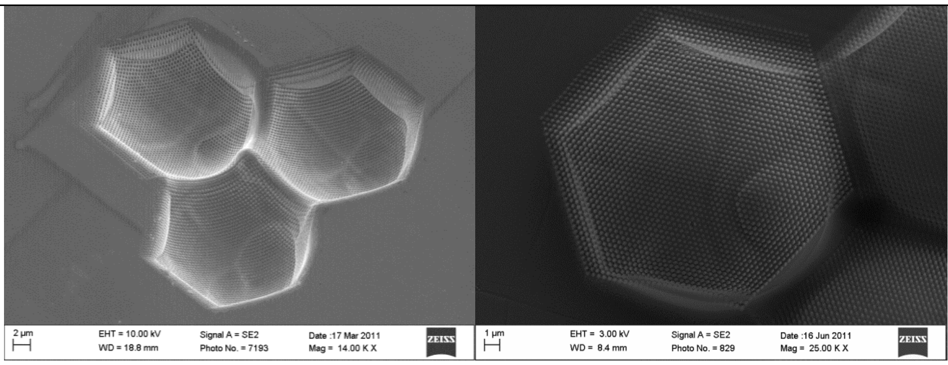
Bita Daemi receives the "The Elena Ulieru - Innovation Award" with the motivation: *"We appreciate your excellent paper, top level presentation and direct connection of your topics with the industrial applications as the call request. The selection jury fully agreed with your nomination as the best winner of the award."*

Dr. Dumitru Ulieru of SITEX awarded EUMINAfab/KTH precision metrologist Bita Daemi the Elena Ulieru - Innovation Award for the best paper/presentation at the 4M Conference 2013

## Micro replication using compression injection moulding

*Contributing partners:* CU, KIT

The goal of this project was to show advantages and limitations of the new replication technology compression injection moulding in comparison to the conventional injection moulding process. Recent advances in manufacturing and structuring show limitations of the current state of the art mass replication process injection moulding. Developments shown in high precision hot embossing and nano imprint technologies are now to be converged with the mass production capability of the compression injection moulding process. The advantages of the new process was investigated and the different flow direction, pressure distribution and material exposition to heat, of the processes was taken into account. The results did not show the expected improvements for all micro features; however tool restrictions have been found and important experience in the advantages and disadvantages of the process for different dimensions and types of structures has been gained which can now be applied in future research and infrastructure projects.

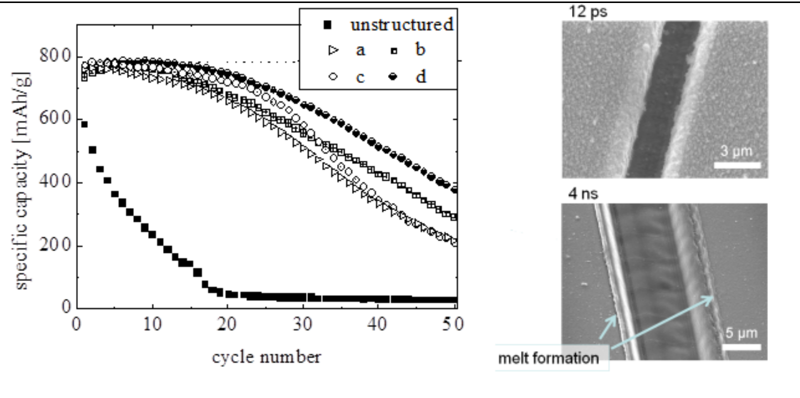



SEM views of FIB-made ommatidia cavities (left) and corresponding compression injection moulding replication in PMMA (right).

## Laser structuring and modification of electrode materials

Contributing partners: KIT,CU

To improve the electrical capacity ps and ns lasers have been used for structuring of thin film SnOx electrodes, which can compensate mechanical film cracking and film delamination effects. It was demonstrated, that even for larger patterns of about 20 µm, a significant improvement of capacity retention can be achieved. Smaller structure sizes led to further improvement of the cycling performance. The outcome was a description of process chains for laser structuring and laser annealing of thin film electrode materials. It has been proven that a significant improvement of capacity retention can be achieved by laser processing of the electrodes.

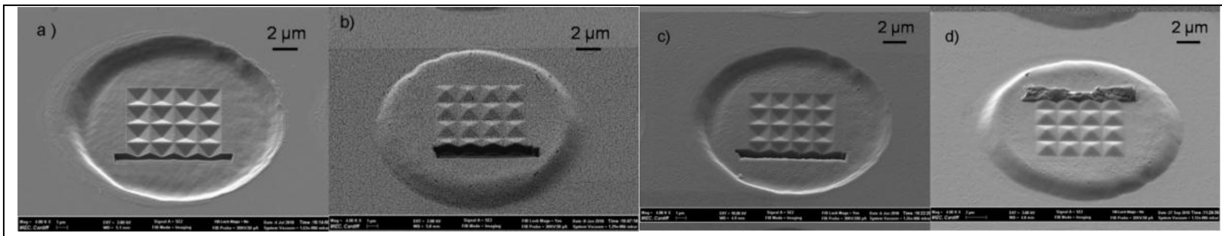



Specific discharge capacity of nanosecond pulsed (a, c, d) and picosecond pulsed (b) laser structured SnO2 thin film electrodes

## Repeatability and reproducibility of layer-based micro / nano structuring technologies

Contributing partners: CU, NPL

A cost effective route for the fabrication of 3D structures and for achieving FLSI in products was proposed and validated in this study. It integrates innovatively compatible, and at the same time complementary structuring and replication technologies, operating at their considered optimum processing windows, to fabricate Ni shims incorporating different 2.5D and 3D length-scale features. A complex 3D functional pattern was designed and generated as an executable data file by means of specially developed software. Through FIB milling a UV template was structured and then replicated on a larger area employing the S-FIL process. The resulting NIL imprints were utilised to produce a Ni shim for serial replication. As a final step in the proposed fabrication route the Ni shim was utilised as a master for hot embossing of an array of micro pyramids. This complex 3D functional structure was successfully and cost-effectively replicated. Thus the proposed process chain can be considered a viable manufacturing route for achieving FLSI in existing and new emerging products, especially for producing components incorporating 2.5D and 3D features at the micro and nano scale.

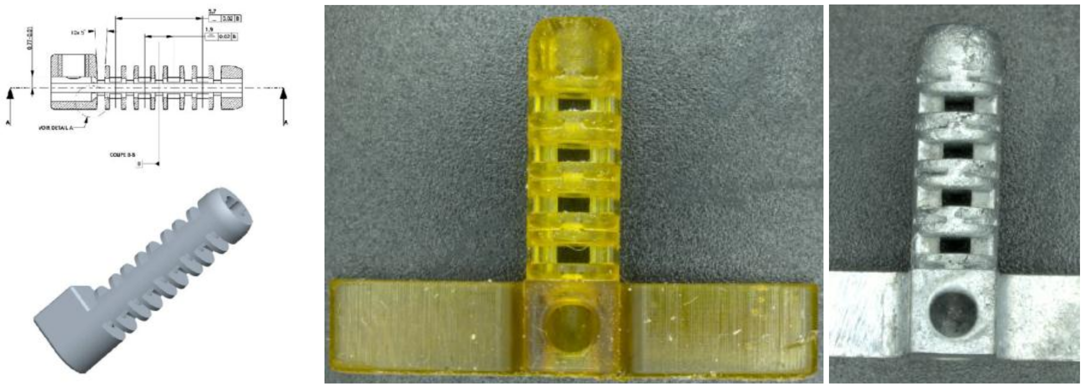



Cross-sectional profiles of the 3D structures on: (a) the fused silica template, (b) the NIL imprinted replica of the template, (c) the shim fabricated from the NIL imprint and (d) the HE replica of the shim.

## Investigation on process chains for a neuromedical electrode device

Contributing partners: CU, KIT

Different processing technologies have been used to produce a neuromedical electrode device. The first parts produced by rapid prototyping technology to plastic parts, as well as cast metal parts have been used for design tests.. The final parts were produced by the combination of different processing technologies including micro milling, micro EDM and injection moulding. The results showed the suitability of prototyped parts for functionality tests and revealed limitations of direct writing process technologies for mass production.

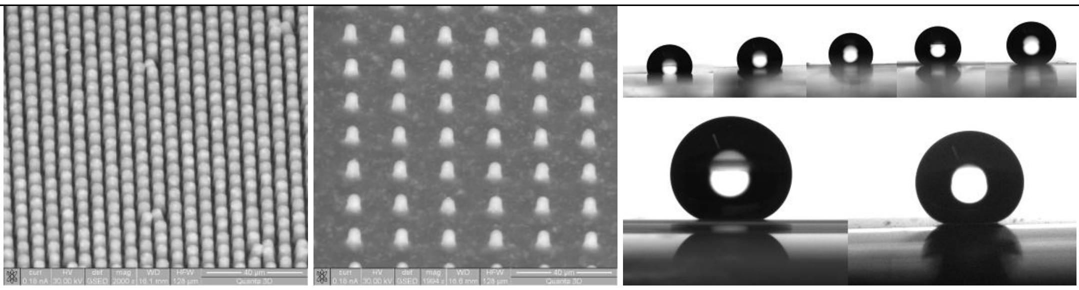


Scema of the neuromedical connectors and top views of the produced parts in plastic (middle) and metal (right).

## Ultrahydrophobic plastic film for self-cleaning surfaces

Contributing partners: CRF, TEKNIKER

This project has been run to demonstrate the integration of master making, replication and characterisation into one process chain. A demonstrator illustrates the capabilities in meeting user's request: starting from the design of a microstructure a process chain has been developed to realise the structure on selected materials. The master has been manufactured by photolithography and DRIE with the Bosch process. The replication of the master was first done by acrylic-photopolymers:, a contact angle higher than 150° has been achieved, still revealing the critical demoulding step due to the scalloping of the master walls and the stiffness of the polymer. As an offered alternative PDMS elastomer was used, with very good results, both in terms of contact angle and optical transparency.

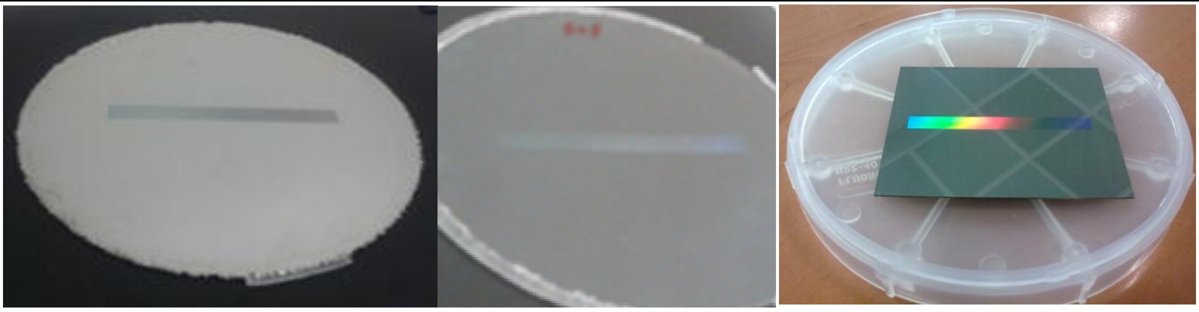


SEM images of two exemplary designs and (left) and contact angle visualisation of the flat and structured surfaces (right) .

## Characterisation of second generation nickel stamps obtained by NIL

Contributing partners: TEKNIKER, NPL

To be able to offer master copies, this project was done to characterise the dimensions of a second-generation nickel stamp, and to compare them to the dimensions of the original nickel stamp. For this purpose, a nickel stamp was replicated using nanoimprint lithography. First a silicon substrate was coated by nanoimprint resist and nanoimprint processes was carried out. After residual layer etching, silicon etching was carried out using combined DRIE. After resist cleaning, the dimensions of the nanowells were measured using similar techniques to that of the stamp, but compensating for the numerical aperture limitations. Nickel was grown by electroplating to have a nickel replica of the original stamp. Using the same techniques developed for the stamp characterisation, the Ni replica was measured. In addition, hot embossing processes were carried out with both the original stamp and the replica on polymer sheets, and the characterisation of the dimensions of the embossed features showed only a minor quality loss, which gave evidence of this approach to produce numerous metal masters from a single original master.

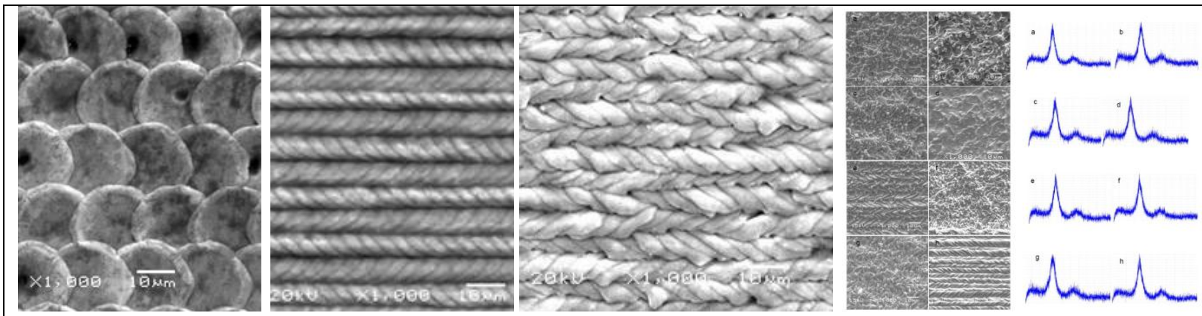


Images of the first generation nickel stamp (left), polymer replication (middle) and second generation nickel stamp (right).

### Development of BMG-based master making process chains

Contributing partners: UoB, CU

The goal of this project was to design and validate a process chain for producing bulk metallic glass (BMG) masters that utilise hot embossing to form a BMG layer on a metal substrate with a thermal expansion coefficient similar to that of BMG, nanosecond and pico-second laser processing to produce replication cavities and annealing for surface smoothing. The targeted surface roughness of the produced masters of an *Ra* better than 0.1 µm was not achieved with high temperature zirconia based BMG but improved the state of the art tool making capabilities. A low process roughness of *Ra* = 0.26 µm was achieved, maintaining the amorphous material structure of the BMG and a mirror finish of *Ra* = 0.16 µm was achieved, tolerating a low crystallisation of the surface layer.

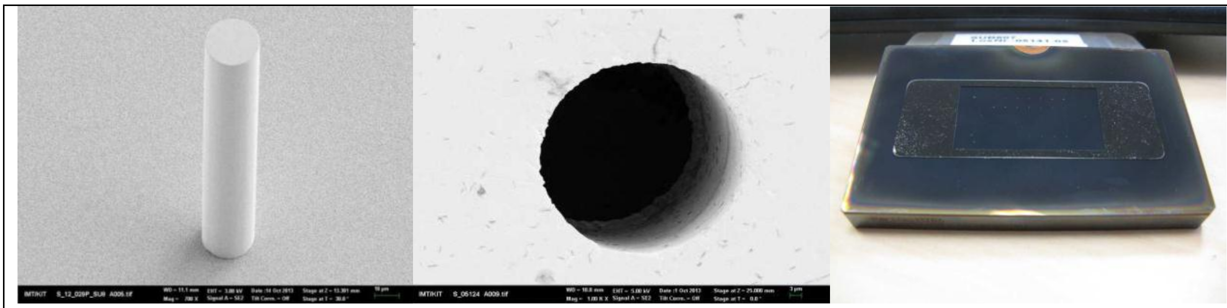


Images of different laser processed surfaces in bulk metallic glass (BMG) and corresponding XRD pattern to check crystallinity (right).

### Metal mask fabrication for Deep Proton Writing

Contributing partners: KIT, VUB

Deep proton writing technology (DPW) is a fast alternative technology to structure masters, e.g. for rapid prototyping, more deeply than with conventional electron beam writing. This project aimed to build a new focusing system to improve the precision of the high-energy proton beam (8.3 MeV, 16 MeV and higher), which is focused by a high aspect ratio 50 µm diameter hole, to illuminate a photoresist. Successful results would offer better precision of DPW for future user projects. A thick (minimum 750 µm) metal mask plate with the defined micro hole for focusing the beam was needed to focus the proton beam. To achieve the required thickness several plates of 250 µm thickness were produced with a number of circular and square apertures with sizes down to 10 um. Six nickel plates of 250 µm thickness each have been produced using the synchrotron radiation LIGA process. The ten micrometer hole was not stable enough within the 250 µm thick plate but three plates consist of 20 µm holes, 4 of 25 µm and all of 30 µm holes. By tacking the individual plates to the required aperture plate thickness the quality might be improved to a new standard of DPW technology.

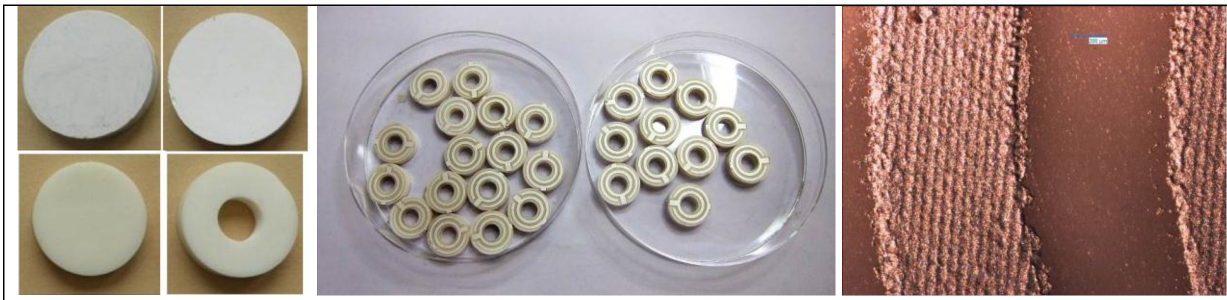


SEM images of the resist structures (left) resulting holes in the nickel plate (middle) and photograph of one finished plate (right)

## Ceramic contact sensor

Contributing partners: CRF, CEA

The goal of this project was to produce a demonstrator which can be used for future user enquiries involving technologies of several project partners. A multi-material ceramic washer with a screen printed contact sensor on one side was manufactured which has to withstand very high peak temperatures up to 400 °C. For this reason, a specific conductive ink for the ceramic material was selected. The raw parts were produced by injection moulding using alumina powder as the base material and were checked for internal cracks by x-ray detection. The reproducibility was measured giving size deviations below 3.2%. The next step was the deposition of two metallic electrodes by screen printing. Then the ceramic washers were tested to evaluate the adhesion of the silver electrodes, the capability of detecting the end point position and the geometrical features. Depending on the user's requirements, more specific tests such as wear and tear resistance, thermal cycling, and resilience can be carried out in order to address the outcome to a more specific application.

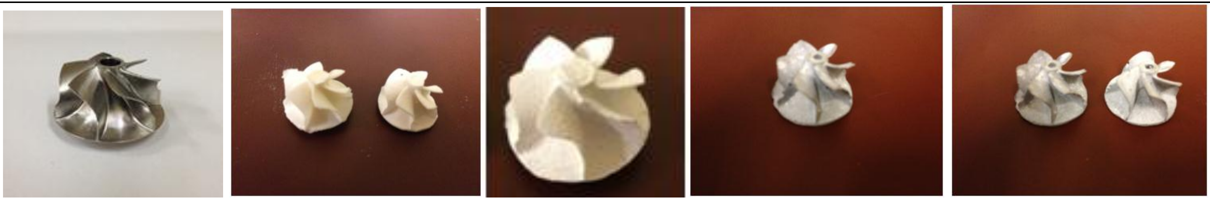


Ceramic parts after each process step (left), final ceramic washers (middle), optical surface characterisation (right)

## Micro 3D Components using x-ray tomography

Contributing partners: UoB, CEA

This project showed the variety of materials which can be processed to form 3D complex shape micro components. A modified soft lithography process was used due to its low cost, simplicity and applicability to soft materials. By applying x-ray tomography method the key technical factors for successful replication could be defined. These include the demoulding ability, geometry uniformity and internal defects. Although not all samples have been characterised by x-ray tomography, the results obtained from the PDMS moulds and alumina samples show the current evaluation, and inform the future development of the manufacturing process. It was shown that a modified soft lithography process is not only restricted to the extruded 2D structures but can also be adopted to fabricate 3D complex shaped micro components. The cutting procedure is one of the main critical steps, as it may result in poor assembly of the mould sections, and blade edges of the sintered samples. Final characterisation of the internal structures showed that porosity is uniform across the body of the samples and the average diameters of the pores are less than 0.05 mm³.

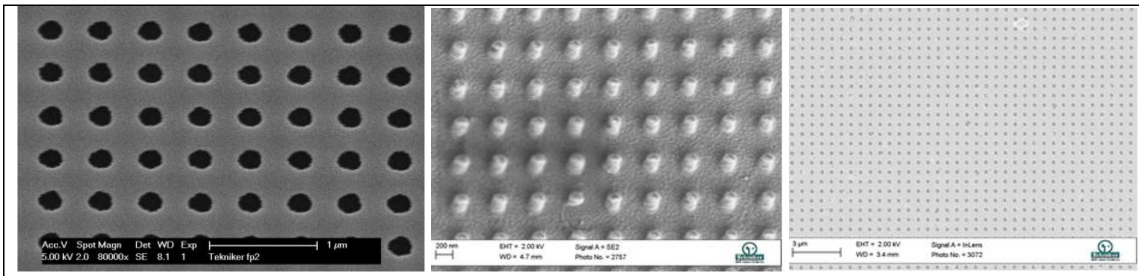


Micro turbines fabricated by micro machining and by thermal slurry consisting of alumina, zirconia, stainless steel and silicon nitride

## Fabrication of gold-array nano holes

Contributing partners: TEKNIKER, PHILIPS, CRANN, CU, IPA, NPL

The aim of this study was to benchmark nanofabrication of gold array nanoholes by focussed ion beam and different recipes under nanoimprint lithography. The project was intended to validate the surfaces by metrological characterisation and optical transmission through nanoholes, selecting the optimised protocol ensuring repeatability and lack of loss of critical dimensions. Different gold films perforated by nanoholes have been produced, which constitute a powerful platform for surface plasmon resonance biosensing. The demonstrator parts consist of a 100 nm gold layer on glass with eight different arrays of holes on the gold (each array with an area of 100 µm x 100 µm, with a diameter of the holes ranging from 100 nm to 150 nm, to 250 nm, and pitches ranging from 400 nm to 500 nm). The characterisation of each nanohole array of each processing technology helped to understand technology-specific limitations and parameters, which will ease future projects.

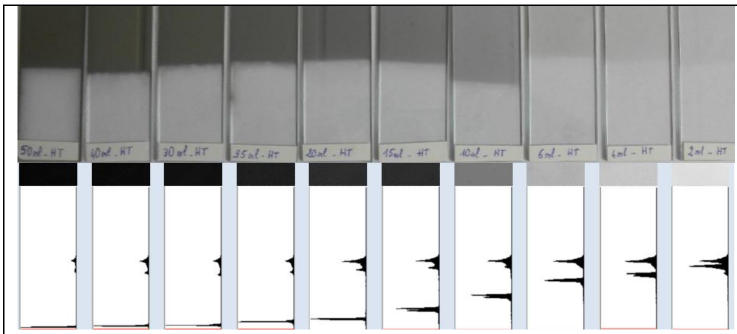


Fabrication steps of one nanohole array: Silicon master (left), etched and coated with gold (middle) and after NIL process (right).

## High-contrast 2D structures and surface characterisation

Contributing partners: IPA, CEA, CRANN, CRF, UoB

The aim of the project was to use different micro/nanofabrication technologies to produce a standard to check the size calibration of microscopic systems fulfilling the state of the art requirements. The need of particle calibration standards covering a certain range of brightness and material contrast is urgent to check, not only the calibration of the system, but also to determine the influence of the operator on the analysis. Therefore, the objective of this activity was to assess the possibility to assemble representative calibration standards using EUMINAfab installations. By use of the broad range of specialised facilities within the EUMINAfab consortium, various surface particles and contaminations have been created. The obtained surfaces have been checked and evaluated to find the best standards using five different approaches. As a result, platinum deposition followed by laser processing was spotted to be the most promising approach, as grey values can be produced precisely and in various geometries. This new development of a particle standard offers unique capabilities which will be available to the European micro/nano fabrication community.



Grey value distribution of Pt deposited samples.

## Gender awareness

The gender awareness activities in EUMINAfab focussed on an evaluation of the situation of female scientists within the consortium. Multimaterial MNT is an area which traditionally has few women. In fact taking a look at the list of technology experts in EUMINAfab highlights the situation.

A gender equality survey was carried out by both female and male participants. The aims of the survey was to identify how male and female scientists deal with the compatibility of work and family life, how the work environment for both genders is organised and how they see the battle of the sexes within the work environment. An almost equal number of male and female interviewees filled the questionnaire. The 50 interviewees come from ten different countries and all kinds of organisations. Furthermore a broad age range covered.

The compatibility of work and family life can be considered to be the most important concern of the interviewees. Many organisations try to make the compatibility of work and family life easier for the employees by offering different support activities and the survey showed that conventional programmes for working parents (teleworking, part-time working, day care facilities …) are indeed popular. Nevertheless a lot of problems still occur during a business trip. More than 50% of the interviewees had at least one business trip with an overnight stay in the last year and had problems to organise child care and in general to arrange the daily life of the family.

In general the survey results provided new and interesting information and can serve a basis for further improvement of the compatibility of work and family life at company level.

# The potential impact (including the socio-economic impact and the wider societal implications of the project so far) and the main dissemination activities and exploitation of results.

The main impact of EUMINAfab is in the establishment of a successful pan-European infrastructure with a recognised brand and an efficient, user-friendly interface for multimaterial micro and nano fabrication and characterisation.

On the first level, the establishment of a single entry point for user requests has integrated the access services of the current access providers. The possibilities offered by incorporating technologies based at different partner sites have given users significant added-value over and above applying to the individual providers, as well as the possibilities of combining technologies at different partner sites. In the mid-term, the impact of the results of the internal RTD projects, focussing on the development of new process chains and demonstrators, are available for development in future collaborative projects.

The *raison d'être* of EUMINAfab is the provision of integrated transnational access, especially for users who do not normally have the opportunity of benefitting from the use of such equipment and expertise. User access in EUMINAfab began with a strong technology focus and the technologies marketed as a "technology toolbox". We soon observed that the demand was more complex. Indeed, at our mid-term review meeting the user projects were commended as "mini-collaborative" projects. An evaluation of the nature of the user requests showed strong application relevance and the necessity of a solution provision approach. In response to this, we issued a specific call for user proposals which targeted the areas of health, energy, ICT, optics and photonics, and characterisation and metrology. Following the steady response experienced with the previous calls, this call resulted in a 100 % increase in the number of proposals submitted. The nature of user projects ranges from feasibility testing of new structures, functions and materials, one-off products frequently required for specific research purposes, through to prototype structures and devices.

Our access resources are now oversubscribed.

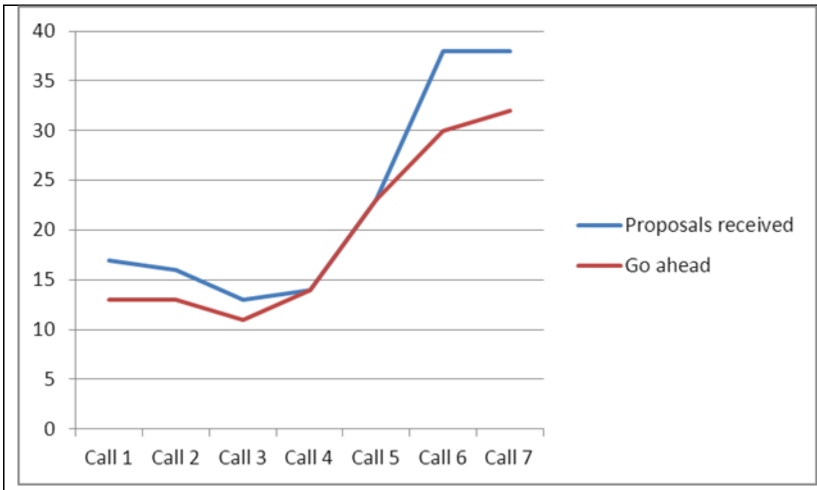



Fig. 1 Growth in proposals received per call.

The increase at call 6 corresponds to the launch of application specific calls.

The progress made during the funding period has laid a sound foundation for future evolution and expansion of the infrastructure.

## Provision of a centralised user access system

The first success was to achieve a centralised access procedure acceptable and compatible with all access partners and EC reporting requirements, whilst keeping the needs of, users, and in particular those of SME's paramount. In doing so, we also established an independent peer review panel (PRB). Partners already operating a home infrastructure via peer review of proposals gained the agreement of the home PRB to accept the decision of the EUMINAfab PRB for EUMINAfab user projects. The policy of recommending users to contact the EUMINAfab experts to discuss their initial ideas, and the continuous handling of proposals, enabled the rapid evaluation of proposals (in some cases less than two days) and the high rate of success of proposals.

## EUMINAfab serving the European Community

Transnational access to EUMINAfab enabled 150 users from twenty EU member and associated states to benefit from the technologies and expertise at the partner sites. EUMINAfab is open to both young and mature researchers. Approximately 50% of users were experienced researchers, with Postdocs and postgraduate students each accounting for about 20 %. The proposals were often directly related to other EU projects and infrastructures e.g. Polaric and Soleil, and contributed directly to several PhD and master theses.

Our efforts to attract industrial and in particular SME users were rewarded with a total of 19% industrial users, of these 75% were SME's. Considering the often reserved nature of SME's when it comes to travelling across borders, as well as concerns over IPR and assesment by peer review, the uptake of our services by SME's shows a perhaps surprisingly high readiness to access the facilites.

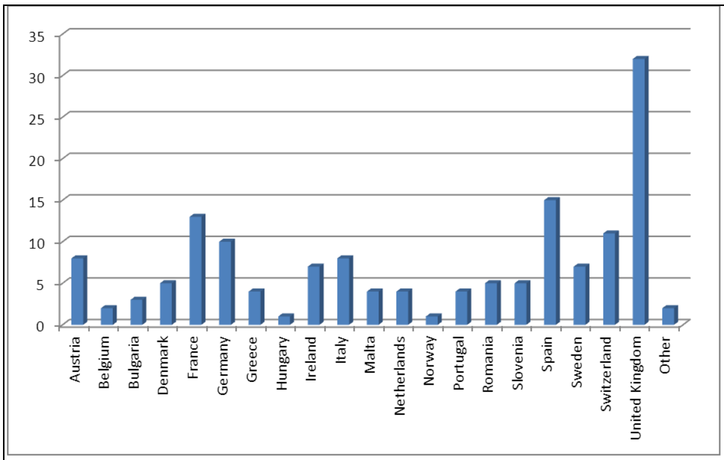



Fig. 2 Country of origin of user proposals.

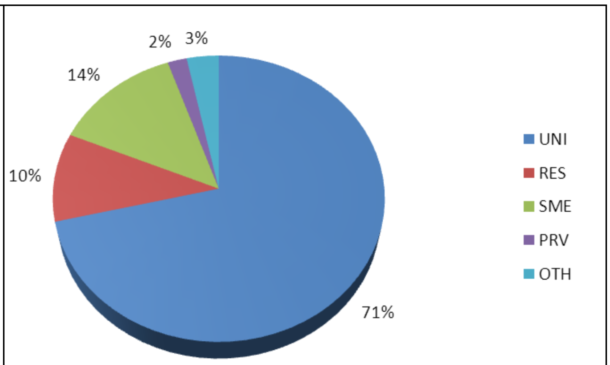



Fig. 3 type of home organisation of user

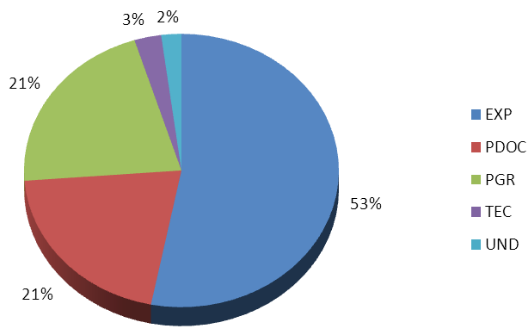



Fig. 4a) level of experience of users

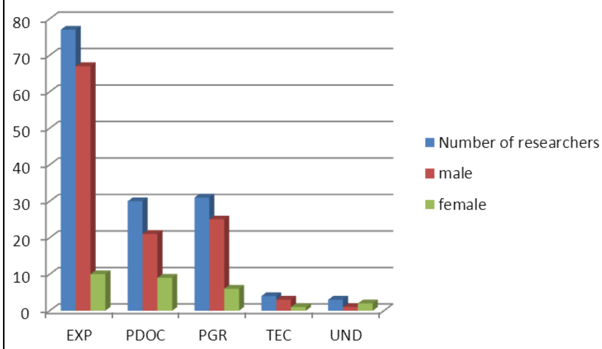



Fig 4b) relative proportions of male and female users.

## Impact of transnational access to EUMINAfab

In order to assess the potential impact of EUMINAfab a methodology was defined to envisage the links in the value chains from material, through to the results of the user access and beyond to the intended application of the new knowledge, structures or devices. This was based on an empirical bottom up method. For each user project, the type of task carried out, the intended use of the result and the most relevant application areas were deduced. Additionally the level of maturity of the tasks was determined by the output of the work.

### Level of maturity and types of user request

The most application ready types of task requested were the fabrication of micro-nano components and devices. They are often individual objects intended for a specific use by the user or prototype devices for further development. These are components or devices with nano or micro structures playing the key dimensions. Examples of such are

- sensors
- OLED's
- micro cantilevers
- AFM tips
- phase gratings
- moulds and stamps, fabricated and intended for use in replication processes

Acting as a test bed for new ideas, materials and processes is an important role played by EUMINAfab in supporting a longer term sustainable base for future innovation. Particular tasks with upcoming potential are:

- The fabrication of 3D or 2D nanostructures using e-beam, lasers and laser lithography.
- Microstructuring of structures such as micro rods, pillars and arrays of these, also holes and high aspect ratio bores.
- Surface functionalisation to change e.g. tribological properties
- deposition and patterning of thin films for a broad range of applications, ranging from intended utilisation in 3D batteries to *in vitro* high throughput screening e.g. to biofunctionalise surfaces by the targeted positioning of bio-molecules

### Application areas served by EUMINAfab user projects

The cross cutting nature of multimaterial MNT was confirmed by the analysis of the relevant application areas to EUMINAfab user projects.

Important areas of application for EUMINAfab user projects are in fields which are themselves cross cutting technologies. Therefore for the purposes of this study, engineering and technology, new production processes, materials and nanoscience and nanotechnology were taken as application areas.

Figure 5 shows the breadth of application areas served and the relative type of maturity of the tasks requested. The size of the circles is proportional to the number of projects falling into the category.

<u>The life science</u>

Life sciences appears to be the most promising area for application and a strong demand was observed for the types of user requests for the production of prototypes, right across the broad spectrum of sub-application areas. As such relevance to diagnostics, point of care, high throughput screening, drug development and drug delivery, as well as implants was observed. User projects focussed on a range of topics, such as the development of polyimide wave guides for low cost photonic biosensors, functionalised surfaces for patch clamping, cell differentiation experiments, cardiovascular stents are among a few of the mentioned applications.

Energy-

The characterisation of fuel cell electrodes, feasibility testing relating to the development of sensors for use in transformers, and the deposition and structuring of thin films for application in 3D micro batteries are examples of user projects in the area of energy.

Optics

User projects in the area of optics tend to focus on specific requirements, examples are prototype optical elements such as 2D gratings and cylindrical gratings and prototype phase components for use in cameras. A single high end application produced was a 2D grating for use in x-ray synchrotron beam lines

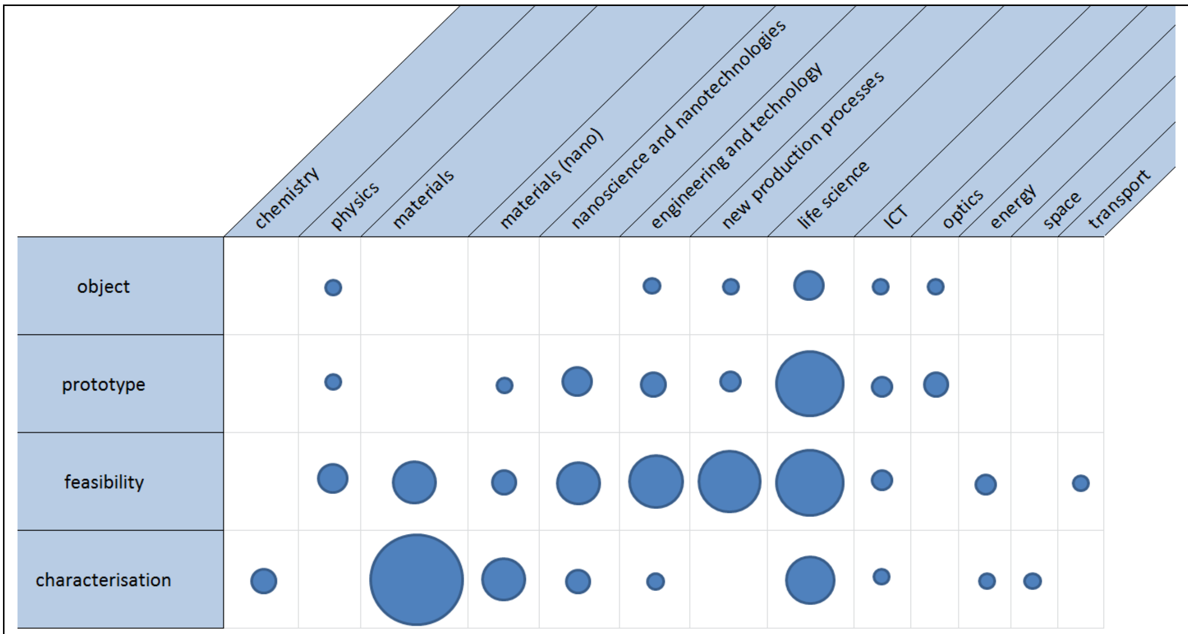



Figure 5 Relative distribution of application relevant user projects, and an indication of the relative maturity of the type of task

ICT

The projects relating to ICT tend to be quite a long way from application. They include for example the creation of nanopatterned templates by e-beam, with the intended use for memory storage devices, and the creation of nano array structures (object) for spin-torque memory devices applications.

Engineering and technology

For the most part this group of projects refers to the improvement of micro-engineering techniques. Ultimately, application areas such as health, consumer goods, and energy saving devices will benefit from these advances.

The investigation of process steps and chains with the potential to create new production processes was found to be a major focus of user projects. For the most part these were feasibility studies towards the development of new, or improvement of existing production processes. Some of these were, e.g. for the development of nano scale processes, some for micro scale process development

New production processes

The investigation of process steps and chains with the potential to create new production processes was found to be a major focus of user projects. For the most part these were feasibility studies towards the development of new, or improvement of existing production processes. Some of these were e.g. for the development of nano scale processes, some for micro scale process development. Installations commonly used were laser and mastermaking including machining methods. Projects involved the investigation of machining processes to improve performance of micro-injection moulding and the investigation of moulding and demoulding processes and the development of the capability to create nano scale structures in master dyes for the fabrication of components

Nanoscience and nano technologies:

Many of the user projects first focus was on progressing the state of the art in nanoscience and nanotechnologies. The work carried out was relatively early stage and explored new concepts or designs indicative of knowledge gain and longer term innovative potential. Improvements to the state of the art of nanoimprint lithography by adding nanoscale features to master dyes for use in NIL applications, and the ability to create novel stamps and tools were high on the agenda. Technologies such as DPN are providing novel ways to nano functionalise surfaces on materials such as grapheme by the deposition of biomolecules. A snap shot of other projects includes the fabrication of nanostructures for the design of new graphene based metamaterials for sensor applications, the use of self-assembly, e-o-characterisation for the creation of highly regular nanostructures for electrochromic applications and the fabrication and testing of AFM tips for advancing state of the art in AFM machining.

Materials/nanomaterials

A significant proportion of the user projects was related to the characterisation of materials, including nanomaterials. The knowledge gained by characterising e.g. the microstructure of alloys, high performance materials, and superconducting thin films brings an essential understanding of the behaviour of new materials in intended future applications, such as non-volatile memory devices,, optical devices and even aircraft engines. The determination of particle adhesion forces was also popular and relevant to avoid contamination in the medical field as well as in the clean room environment.

The feasibility of using new materials in developing processes for the production of smart actuators, and the patterning of bulk metallic glasses are just two examples of investigations into the future utilisation of new materials.

## Summary of main achievements of EUMINAfab

The recognition of the application contexts of user projects gained in the four years of operation of EUMINAfab highlights the cross cutting nature of multimaterial micro and nano technologies in areas of societal and economic relevance such as the life sciences, energy, and information and communication. The maintenance and growth of a sustainable high tech industry in Europe also benefits from the exploration of alternative of new process chains and new technological advances.

A summary of the achievements of EUMINAfab is given below:

- Created a common identity
    - “One for all and all for one approach” among partners
- Created a single access point for multimaterial micro and nano fabrication and characterisation
- Brand of EUMINAfab
- Common platform for marketing and the exchange of knowledge
    - Enables in-roads into new user communities
    - Broader base of contacts for reaching users
- Opened transnational access so as to enable a “real world” test bed for emerging technologies
- Established niche of functional solution provider specialising in the design and creation of nano and micro structured components

  - Cross fertilisation of ideas
  - Avoids divergent evolution of technologies at local sites
- Increased mobility of researchers across Europe (150 transnational user projects)
- Developed an application approach for functional solutions, a step further than the technology tool box originally planned in the GA
- Defined - EUMINAfab longer term goals

| **Success factor** | |
|---|---|
| Percentage of access oversubscription<br>(in terms of total access costs of units used compared to DoW) | 20,6% |
| Number of users | 150 |
| Number of user organisations | 119 |
| Number of countries | 20 |
| Type of home organisation of user | 71% Universities, 10% research organisations, 19% Industry, |
| Number of access units used | 6646 |
| Number of oversubscribed installations<br>criterion - number of units used is more than that offered in DoW) | 24 installations |
| Number of conferences and exhibitions attended by EUMINAfab representatives | 120 |
| Number of publications | 70 |
| Number of capability maps; | 82 |
| Number of competences in Minabase | 480 |
| Number of application specific process chains tested | 25 |
| Number of technology demonstrators developed. | 14 |

### Some comments from our users

*"The benefits of the EUMINAfab scheme cannot be overstated as access to otherwise out of reach techniques has been invaluable to this users work".* Project 1050

*"We had good and direct contact to the partners we needed"* Project 1136

*"Excellent service - allowed us to demonstrate feasibility of a key technology very quickly. Would recommend it to anyone."* Project 1085

*"I truly hope that the EUMINAfab project will be continued, as the initiative is one of the most generous joint research proposals I have ever seen. Not only do the EUMINAfab partners provide support with the manufacture of micro and nano systems, but they also give inspiring advice."* Project 1097

*"The assistance of the Auger nanoprobe operator was perfect".* Project 1109

*"The idea of this project is great. It especially helps the researchers from less equipped institutions to gain the access to the state of the art equipment and realize the research goals which would be otherwise impossible to achieve. All the best to all working on EUMINAfab."* Project 1124

## Main dissemination activities and exploitation of results

In these early days following the closure of the funding period for EUMINAfab, dissemination events are still being attended.

A highlight was the symposium at the EMRS Fall meeting in Warsaw 2013, co-organised by Quality Nano and H2FC infrastructure projects. The symposium attracted a total of thirty-seven presentations, fourteen of these in the EUMINAfab session. We also shared a stand with KNMF the Karlsruhe Nano Micro Facility and publicised the possibility of fully-funded access.

EUMINAfab has always had a close relationship with the 4M Association and at the 4M 2013 conference we had a session with presentations from the JRA activities.

The experience gained in EUMINAfab as a first infrastructure for micro and nano fabrication and characterisation has raised interest from across the Globe, therefore, we were asked to contribute to the Linkage with Industry Plenary session of the Third EU-Australian workshop on Research Infrastructures in Canberra, November 2013.

### Future Plans

During the course of the funding period, the application relevance of the technologies and expertise offered in EUMINAfab has become much more apparent, as indeed have the benefits of marketing these technologies in terms of application fields. Potential has been identified in further developing this to form application hubs, where upcoming technologies from more scientifically-based partners can be encouraged towards application by integrating with the knowledge and dedicated capabilities of more application-focused – industry-near – partners. Additionally, during the course of the past four years there have been new open access facilities coming on stream which have aims consistent with the longer term goals of EUMINAfab.

The consortium jointly submitted a contribution to the Consultation on Infrastructures in October 2012. This contribution proposes the further evolution of EUMINAfab by integrating new and upcoming infrastructures and technology providers with the aim of extending the possibility of integrating upcoming nanoscale phenomena into applications. This contribution was well received and is listed in the selected topics of the report on the consultation. .

## Project public website and relevant contact details

The project website www.euminafab.eu was established and will be maintained after project end in order to publicise the ongoing activities.

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Figure 6 Logo of EUMINAfab

## EUMINAfab consortium partners:

| | |
|---|---|
| KIT | Karlsruhe Institute of Technology |
| CU | Cardiff University |
| CEA-Liten | Commissariat à l'Energie Atomique |
| CRF-Fiat | Centro Ricerche FIAT S.C.p.A. |
| CRANN | CRANN, Trinity College Dublin |
| FhG | Fraunhofer Gesellschaft |
| TEKNIKER | Fundación TEKNIKER |
| KTH | Kungliga Tekniska Högskolan |
| Philips | MiPlaza, Philips Innovation Services |
| NPL | National Physical Laboratory |
| UoB | University of Birmingham |
| VUB | Vrije Universiteit Brussel |