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PROJECT FINAL REPORT

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4.1.1 Executive summary

Background

Scaling has driven the microelectronics industry for over 40 years and revolutionised information and communication technologies. Maintaining progress by the introduction of new technologies is an important challenge as extensions to UV-lithography may limit the feature size realizable at acceptable costs. Self-assembly techniques could provide alternative methodologies and the development of low cost, chemical based technology was the focus of the EU funded LAMAND (Large Area Molecularly Assembled Nanopatterns for Devices) project. This project aimed to develop the direct self-assembly of block copolymers into a scalable process for the manufacture of silicon devices as well as addressing other technologies where small feature size patterning might have impact. The LAMAND consortium consisted of 9 partners from 7 European countries, 6 from academia and 3 from industry, specialised in micro/nanoelectronics, polymer synthesis and nanomaterials.

Main Results

Nanopattening methodology was developed for the creation of sub 10 nm feature size patterns over large areas (up to 8”). Both line and pillar patterns were realized. These patterns were integrated into processes to allow pattern transfer to a substrate to create arrays of nanostructures of silicon, copper and germanium. In this work, a directed self-assembly techniques were integrated into manufacturing scale processes to realize functioning devices. We showed that chemically designed/tailored silsequioxane films could be coupled to a nanoiprint method to generate topographically ordered substrates to define precise pattern alignment and orientation. New, block copolymer materials of controlled structure, dimension and function were synthesized and patterns at these were defined. New metrology was developed to allow quantification of pattern defectivity. Novel plasma etching techniques were used to transfer the pattern to the substrate surface and the device performance demonstrated. Innovative characterisation techniques capable of studying both long and short range structure were developed.

Impacts

a) The work has helped the EU to develop an international profile in this area
b) Valuable intellectual property has been realized in the semiconductor, food packaging, oleophobic surfaces and metrology areas.
c) The consortium has provided European influence in the technology roadmaps.
d) Exploitation of the intellectual property is being undertaken
e) The consortium has demonstrated academic leadership in the area of block copolymer self-assembly.
f) Some of the consortium members are participating in a EU proposal to implement these methodologies into wafer manufacturing.

4.1.2 Context and project objectives

Context

At the start of the project in 2010, the potential of block copolymer self-assembly (by a process known as microphase separation) was being seriously considered as a potential method of patterning surfaces at the nanoscale [1]. These patterns could be used to generate well-ordered structures at a surface of around 10-15 nm feature size and although they could be used for development of many applications there most obvious use was for generation of surface topography for development of nanocircuitry for the microprocessor industry [2]. At this time, the feature size possible was below that realizable by conventional 193 nm lithography [3] and offered the potential to extend the lithographic limitations below 25 nm pitch size. The need for an alternative technique was clear: a) conventional UV lithography was becoming ever more challenging and expensive because of the need for multiple patterning techniques (i.e. where consecutive lithographic steps are used to trim features), b) extreme UV (EUV) lithography was being developed but progress has been slower than might have been expected or hoped and c) techniques such as e-beam lithography were not well enough developed to provide an industrial scale technique at the required processing times [see reference 3 in the appropriate Emerging Materials and Lithography Chapters].

Self-assembly techniques have long been seen as an alternative form of surface patterning [4] and techniques such as nanoparticle self-assembly, colloidal mediated self-assembly and macrophase separation of polymers were amongst the methods being suggested. The advantage of a chemistry based method of generating well-ordered surface patterns was clear. These techniques could be rapid, as defined by the kinetics of molecular diffusion etc., but (and probably more importantly) were relatively inexpensive compared to lithographic methods which now represent up to 50% of the cost of a modern processor manufacturing fabrication facility (FAB). Despite the obvious advantages, little progress has been made in integrating these methods into manufacturing because they lacked the reproducibility and reliability needed for device manufacture. Further, whilst local ordering of self-assembled patterns was well proven there was scant demonstration of ordered pattern formation over wafer dimensions.

In Europe, the development of inexpensive self-assembly based nanotechnologies was being seen as critical not only for the semiconductor industries but also for development of other technologies requiring ultra-fine patterning [5]. Consequently, FP7 provided substantial funding for self-assembly techniques and industrial scale-up. The home-based European semiconductor industry was also sensitive to changes within the large American and Asian multinationals who operated FABS in the EU but their continued presence was reliant on cost implications and the ability of the EU to advance new technologies for application in this sector. It is, therefore, necessary for European scientists to be at the forefront of emerging self-assembly techniques and their integration into manufacturing.

Of all the self-assembly techniques being explored in the late 2000s, block copolymer based methods were emerging as the most likely methodology to be integrated into semiconductor manufacture [1]. Patterns could be formed relatively easily over large substrates and techniques such as graphoepitaxy (the use of topography to direct the self-assembly (DSA)) and chemoepitaxy (the use of pre-patterned surfaces for DSA) were being developed to allow not only orientation of the pattern (to the surface plane) but also alignment (to a surface direction) [6]. Thus, provided the assembled nanopattern had dimensional regularity in terms of feature size, spacing and arrangement, the precise position of any feature could be strictly controlled and this is an absolute requirement for any semiconductor fabrication process. Despite the promise of block copolymer techniques, European researchers were not in the vanguard of this work which was being led by American, Korean and Japanese scientists. In 2005 the number of papers published by European researchers citing block copolymer self-assembly was less than 7% of the total papers (Google Scholar statistics).

LAMAND was written to address this research gap and allow Europe to develop a significant profile in this area. It was specifically centred on translating academic research into exploitable industry technologies in the semiconductor and other industries. It was focussed on addressing a number of key technical challenges:-

a) Transferring work on small substrates to large, industrial scale samples.
b) Reducing pattern defectivity through implementation of pre-patterning techniques..
c) Maintenance of ITRS defined scaling requirements (feature size). To properly address this the project has to extend its work to look at novel polymer systems and new pattern formation techniques such as solvent annealing.
d) Synthesizing novel polymers at the required purity and scale.
e) Demonstrating that polymer patterns could be transferred to the substrate by conventional methodologies.
f) Development of metrologies to assess both pattern formation, pattern defectivity and pattern transfer to the substrate.
g) Ensuring the materials and processes were consistent with modern manufacturing requirements (in terms of both their potential integration into current manufacturing lines as well as the appropriate safety requirements).

The project also had a well-defined goal to raise the European research profile in this area and to advance science to realize exploitable technologies and provide pathways for industrial uptake for those technologies.

To address these challenges, the project was centred on a number of technical workpackages to allow exploitable technologies to be developed. The specific objectives of these are described in detail below.

Project Objectives

There were a number of objectives described in the Description of Work (DOW) to achieve for the 8 workpackages (WP) described in this project. These WPs ranged from synthesising the polymers, generating substrates for DSA, generating patterns, quantifying structural regularity and defectivity, pattern transfer and device characterization and demonstrating manufacturability.

• **WP1 Formation of periodic polymer nanopatterns, pattern transfer and active pattern generation:** The aim of this workpackage was to produce block copolymer nanopatterns over large areas and at low defectivity consistent with manufacturing demonstration goals.

1) The delivery of topographically and chemically patterned substrates by Intel, ICN and LTM

2) The delivery of aligned and orientated BCP nanopatterns within topographically patterned substrates
3) The generation of active nanopatterns

• **WP2 Polymer synthesis and molecular functionalisation:** The aim of this WP is to synthetize and supply BCPs that microphase separate and SSQ materials.

1) The delivery of some BCPs
2) The delivery of PS-b-PDMS (diblock and triblock) and poly(isoprene)-poly(pentamethyl disilylstyrene) (PI-b-PPMDSS) type BCPs
3) The delivery of functionalized BCPs
4) The delivery of Novel silsesquioxane (SSQ) based polymers
5) The delivery of Novel polypeptide synthesis through NCA approach
6) The delivery of DNA diblock polymers
7) The delivery of DNA triblock copolymers

• **WP3 Substrate molecular functionalisation:** This WP was to allow the chemical engineering of the substrate polymer interface to allow pattern orientation and large area coverage to be properly defined.

1) Delivery of clean and well-defined substrate surfaces for chemical functionalisation
2) Delivery of some Molecular functionalisation of surfaces

• **WP4 Nanometrology development for self-assembled structures:** The aim of this workpackage was not only to provide a robust characterization of the surfaces used but also to allow proper quantification of the patterns in terms of defectivity.

1) Delivery of a report on the use and development of techniques for the study of self-assembled structures (all partners)
2) The delivery of a report on sub-wavelength light diffraction techniques for scalable characaterisation of self-assembled layers
3) The delivery of a report on x-ray techniques for scalable characaterisation of self-assembled layers (UCC)
4) The delivery of a report on novel image simulation analysis methods for assessment of order, alignment and orientation of BCP thin films (ICN)
5) The delivery of a report on the e-characaterisation of active nanostructures (UCC /Intel) and on quantitative aspects of non-contact characterization of conduction pathways nanostructures by AFM (UNEW, M24)

• **WP5 Large scale and 3D pattern formation :** This WP was centred on developing the methods shown above on coupon (1 cm^2) sized samples to wafer scale and to introduce additional pattern complexity without introduction of expensive multi-level processing.

1) To demonstrate graphoepitaxy with SSQ based resists (ICN, CNRS/LTM, UCC-TNI)
2) To show proof-of-principle of top down NIL (nanoimprint lithography) based graphoepitaxy and the development of multi-level interconnected structures (ICN, CNRS/LTM, UCC-TNI)

• **WP6 Technological development and scale-up :** To demonstrate technological development to industrial standards and advance science into industry ready technologies.

1) To validate materials for use in commercial processes (Intel, PRO, KAN) :
2) To report of successful large area wafer processing steps and in-line testability (PRO, CNRS/LTM, ICN, Intel, KAN)
3) To establish a roadmap for Large Area Molecularly Assembled Nanopatterns for Devices (Intel) : Task 6.3, corresponding to D6.3 (Intel, postponed from M30 to M33) D6.5 (Intel, M36)
4) To identify and exploit of near-term product opportunities (PRO, KAN, Intel, ICN, UCC-TNI, UOI)

• WP7 Project management:

1) To maintain the consortium agreements (UCC), by modifying it if necessary and informing the EU commission about proposed changes
2) To maintain the project office and project committee, and notify the EU commission of any changes in the consortium structure (UCC)
3) To management external relationship Task 7.3
4) To manage the financial aspect of the project (UCC)
5) To create and maintain the consortium website (UCC)
6) To manage the financial aspect of the project (UCC)
7) To ensure that interim reports are delivered in time (UCC)

• WP8 Intellectual Property Management : This WP was wholly necessary to manage advances be properly so that any intellectual property might be properly exploited within the consortium.

1) To ensure the capture and reporting of all forms of scientific output and to manage the use of the dissemination activities

2) To ensure that all valuable IPR and know-how is properly captured

3) To set up and maintain the project IP and commercialisation database

4) To manage a meeting/workshop for the wider scientific community in particularly regard to developing technological outputs by appropriate publicity and invitations so that routes to commercial exploitation might be developed

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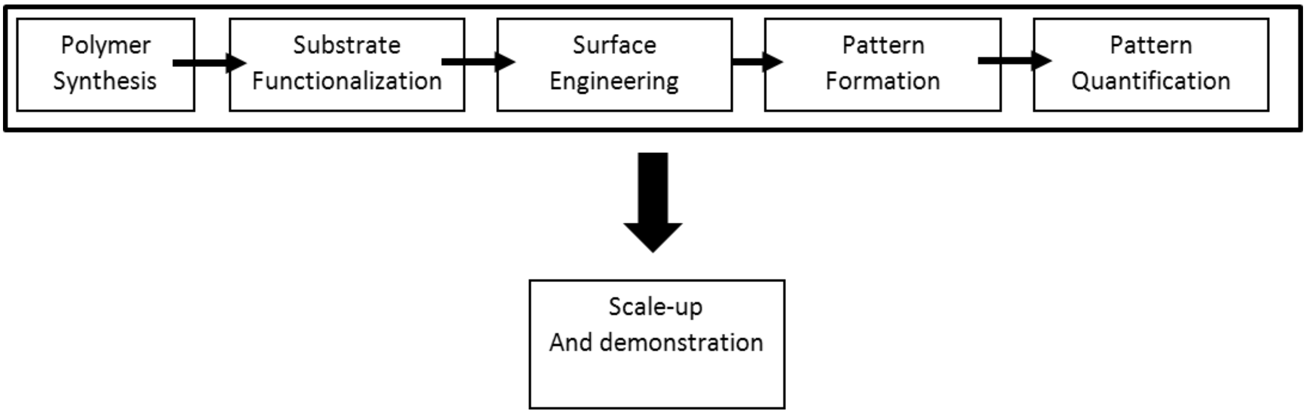
4.1.3 Main S&T results/foregrounds

LAMAND represented a highly ambitious project geared to fulfil some key scientific and technical goals. At the start of the project, centres such as IMEC were beginning to explore how block copolymer (BCP) lithography could be scaled into a manufacturable methodology. During the course of the LAMAND project there was demonstration at both academic and industrial laboratories that the PS-b-PMMA system could be coupled with the chemoepitaxy techniques pioneered by Paul Nealey at Wisconsin/Chicago (see e.g. P Nealey et al, "Density Multiplication and Improved Lithography by Directed Block Copolymer Assembly", Science 321(2008)936) to produce ***almost*** lithographic quality patterns. The PS-b-PMMA system is a good prototype for demonstration/integration since both PS and PMMA can be used within modern FABS, the polymers were relatively amenable to the Nealey based chemical pre-patterning techniques, well-ordered patterns can be formed relatively simply by thermal annealing and pattern transfer from these polymers to the substrate was established on the microscale. However, the pitch size realizable via PS-b-PMMA is relatively large in comparison to current and future scaling demands and the insertion of BCP lithography into manufacturing will require chemical modification of the system or the development of new polymer systems and processing methods. The scientific focus within LAMAND was to explore the limitations in BCP lithography and extend the PS-b-PMMA work towards the delivery of new polymers into a large area processing method. An idealized schematic of the scientific work programme is described below.



Here, polymer synthesis was as described in WP2 as the synthesis of BCPs (for pattern formation) and resist materials (for developing NIL masks to topographically pattern the substrate for DSA). Substrate functionalization relates to generating the correct chemistry at the surface to define high surface coverage and pattern orientation and was described in WP3. Surface engineering is the topographical patterning of the substrate to align patterns to a pre-defined topography and so confer feature registry. Both NIL of designed UV-sensitive polymer and more conventional silicon fabrication techniques were used (WP1 and WP5). Pattern formation is the realization of well-defined BCP patterns encompassing film deposition, film processing and pattern transfer to the substrate and was described in WP1. Pattern quantification centered on how these ultra-small feature size arrangements might be imaged and explored to provide a quantifiable measure of pattern control and defectivity (WP4). Finally, these techniques were combined in WP6 to show how these scientific developments could be combined into a process flow for development of manufacturing methodologies. Two distinct areas of work were explored. Firstly, integration into a conventional silicon fabrication process flow for delivery of ultra-small device structures. Secondly, we also explored how the methods might be scaled in a cost-effective chemical process for coating very large areas of substrates for non-electronic applications such as anti-microbial packaging. All these individual elements were successful and progress within each individually described objective (4.1.2) was clearly demonstrated. Key results in each of these areas is summarized below.

Polymer Synthesis

Several BCP systems were fabricated successfully. The aim of this work was to produce a series of polymers that provided the required phase separated nanostructure at the correct pattern dimensions. In several cases, commercial materials were available but in many instances (such as low molecular weight lamellar systems for ultra-small line patterns, polystyrene-b-polyethylene oxide was a suitable example) these were not available. These polymers were produced at high purity and low polydispersity allowing reproducible process methods to be developed. Typical examples are given in Figure 1. The ability to synthesize > 100g of polymers was a key advantage as many experiments to optimize processing were possible and this can be limited by the high cost of commercial materials.

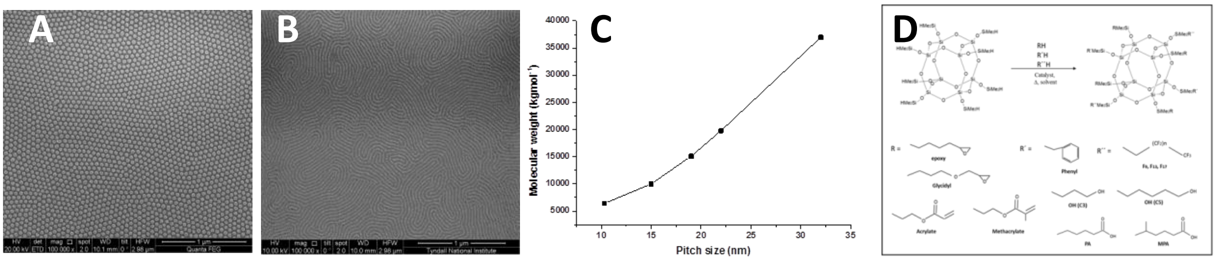


Figure 1 : A, B, Orientation controlled PS-b-PDMS nanopatterns from a BCP manufactured in this work. C, variation of feature size with molecular weight for typical BCP. D, typical POSS materials produced here.

Another advantage of being able to synthesize BCPs was to be able to explore the minimum feature size that can be attained. This is determined by the molecular weight and chemical incompatibility of the blocks and has a lower value beyond which phase separation can not be attained. This is not possible with commercial systems because of the prohibitive costs. A typical example is seen in Figure 1C which allowed us to demonstrate scaling to sub 12 nm pitch (6 nm feature size).

The other notably successful polymer synthesis work was in the production of POSS (polysilsesquioxane) resists. Some of these are illustrated in Figure 1D These materials had an important function in LAMAND. We exclusively used graphoepitaxy to afford DSA of the patterns. Whilst a number of wafers were manufactured by silicon fabrication methods, their continued use would have been prohibitively expensive for pattern optimization. We this used nanoimprint lithography (NIL) to pattern substrates. This needed a UV curable resist so that a robust topography could be developed and the POSS materials were developed for this function. However, the work we carried out was elevated by the synthesis of POSS with different terminal organic groups. This allowed the surface chemistry (i.e. hydrophilic v hydrophobic) to be tuned to maximize pattern coverage and structural order. The work was so successful that we believe that both the POSS materials represent exploitable technology and further that the POSS-NIL based methods for topography generation could be used for delivery of block copolymer lithography to polymer substrates with the promise of generating printable logic circuitry.

Substrate Functionalization

The wetting of a polymer at a surface is partially controlled by the interfacial energies. For block copolymer systems there is also an interfacial energy determined preference for one block. This will frequently ordain pattern orientation. In lamellar PS-b of this -PMMA films, vertical alignment of the individual lamellae is only possible for 'neutral surfaces' where both blocks interact equally with the surface. This can be achieved by the attachment of a random copolymer brush to the surface. This requires synthesis of the polymers, their terminal functionalization and careful attachment procedures. The highlight of this work was the definition of simple small molecule procedures via gas or solution exposure to define the surface chemistry. These methods represent a facile, rapid and low cost method that could be used in industry. Typical results are shown in Fig. 2. Where an ethylene glycol brush at various coverages could be used to control pattern defectivity.

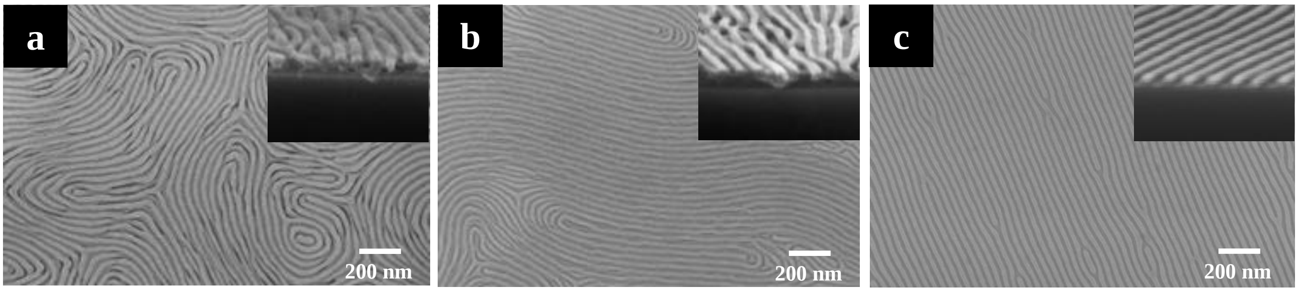


Figure 2: PS-b-PDMS patterns on silicon substrates following exposure to 1, 3 and 5% (L to R) ethylene glycol solutions. The pattern has been partially etched to show the structure.

Surface Engineering

In the graphoepitaxial technique the physical topography of a substrate surface is used to direct the block copolymer pattern to align with the topography. It is not a physical technique though. If, for example, we are using 2D channels as the aligning topography, it is the preferred interaction of the sidewalls with one of blocks that ordains alignment. However, the size and depth of the channels must be consistent with the BCP pattern dimensions. Further, the shape of the channels must be strictly controlled and uniform. Ideally, the size walls should be perpendicular to the surface plane. Substrate topographical patterning was critical to our success since his allows patterns to have the positional and directional accuracy needed for device fabrication.

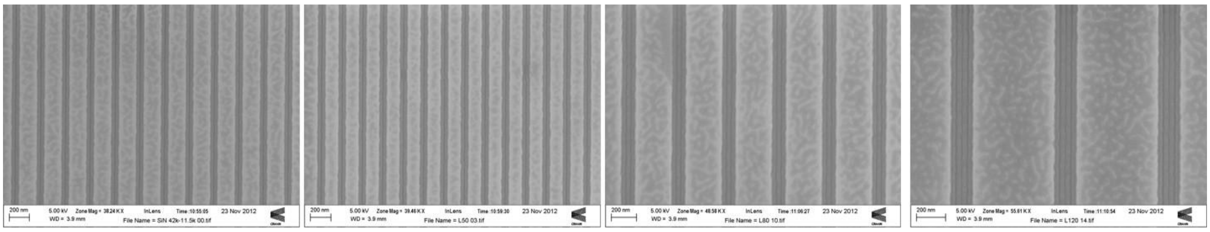


Figure 3: SiN substrates ov varying topographical dimensions to form 1, 2, 3, 4 BCP line structures.

Two types of substrates were available to us. Firstly, we had silicon, silicon nitride and carbon coated which were manufactured by Intel using conventional UV-lithography. These proved extremely valuable as they consisted of pre-patterns that had spacings of various values that were highly accurate and were also varied on the nm scale allowing us to determine the optimum dimensions for a particular BCP. An example of these substrates is shown in Figure 3 where SiN topography dimensions were varied to control the number of BCP features in each channel.

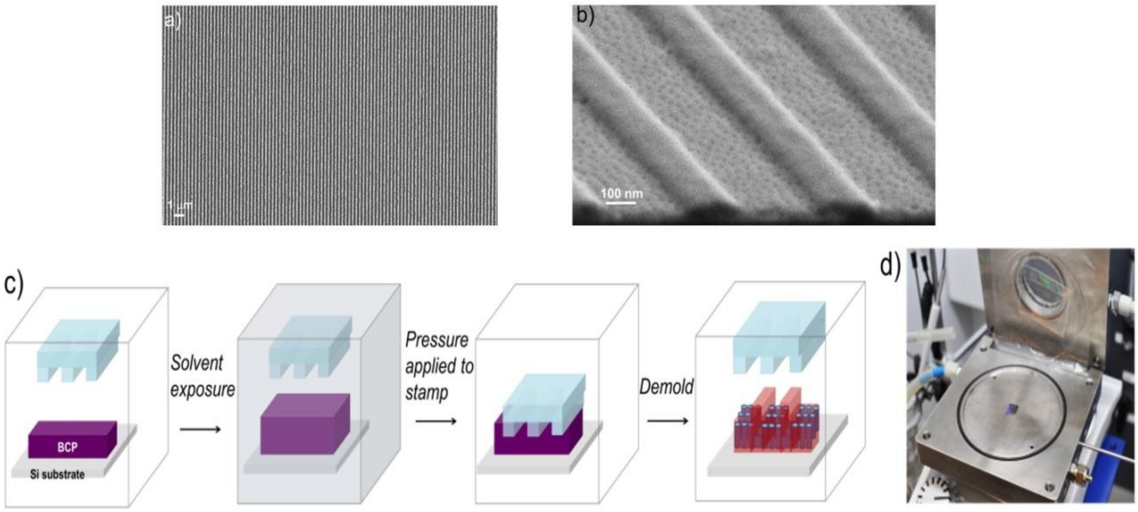


Figure 4: The insitu graphoepitaxial method where a NIL stamp acts as aligning topography, a) and b) are typical patterns at different magnifications, c) a simple schematic and d) a photograph of the apparatus designed and built in the LAMAND project.

The second type of substrates used were manufactured in the project. Nanoimprint lithography (NIL) was used to make these substrates. NIL was viewed as an ideal laboratory method since it is significantly less expensive than alternative methods such as e-beam. The availability of these substrates allowed a large number of samples to be used for pattern formation and transfer process optimization. The major advance of the work, however, was that it provided a unique method to control the chemistry of the sidewall and channel base to allow ideal graphoepitaxial alignment and low defectivity. This work advantaged the range of functionalized POSS resists prepared here. The methodology was scaled and is described in more detail below. The NIL advances reached a level of maturity that allowed *insitu* generation of topography and pattern generation using techniques pioneered by us. The advantage of these techniques was that it could be used to minimize the number of process steps used in pattern formation. This is illustrated in Figure 4. In this method, the NIL stamp is imprinted into the BCP to pattern and align the BCP simultaneously. The apparatus built allowed polymers to be solvent annealed within the cell and in this way a number of individual process steps are carried out at the same time. Whilst this method might not be consistent with large scale silicon fabrication, it may have potential in other areas such as low cost printable electronics and substrates for applications such as biological media.

Pattern Formation

Pattern formation is, of course, at the heart, of the LAMAND project. Progress was dependent on the other work areas since we had to use synthetic polymers, engineered and functionalized surfaces. Many examples have already been provided above and more below. There were a number of objectives:-

a) To provide robust process conditions for a number of polymer systems
b) To provide polymer systems reaching very small feature size
c) To provide patterns of low defectivity

We worked on thermal annealing but because of need to move towards systems capable of ultra-small feature size, we had to develop solvent annealing methods. In solvent annealing, the polymer film is exposed to solvent vapours at relatively low temperature. Solvent molecules enter one or more blocks (depending on chemical affinity), increasing free volume and sponsoring polymer movement and allowing the systems to reach the minimum free energy as a microphase separated pattern. For the small dimension forming patterns, the blocks are very chemically different and the blocks have quite different glass transition temperatures and melting points and hence quite different mobilities at various temperatures. Thus, achieving high order can be problematical. Using solvent annealing, and e.g. selective solvent mixtures, block mobilities can be matched. An example of our progress in this area is represented by our use of microwave assisted solvent annealing. This has the advantage of decreasing process times from hours to the order of 1-5 minutes. A typical example is shown in Figure 5 where well-ordered patterns of PS-b-PDMS were formed under microwave irradiation in periods of around 2 minute.

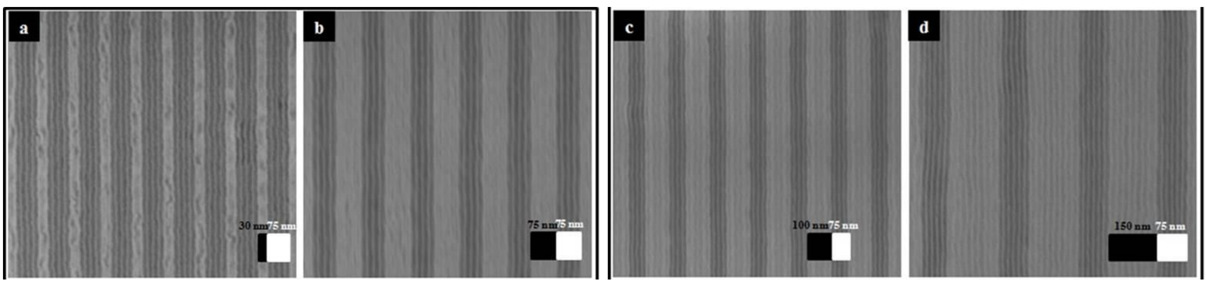


Figure 5: microwave assisted solvent annealing as described in text. Patterns on various topographical substrates, dimensions as shown in figures.

The other aspect of the work worth noting particularly is the feature size reduction. Working with the polystyrene-poly vinylypyridyl (PS-b-P4VP) we were able to get to sub 16 nm pitch size. Typical data are shown in Figure 6. Using tehse systems we were able to reach a feature size of around 5 nm and demonstrate it can be pattern transferred to the substrate.

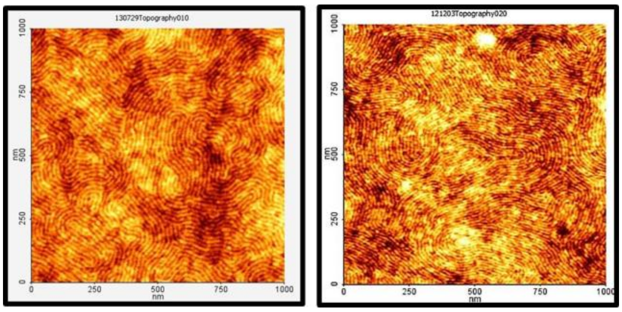


Figure 6: Phase separated BCP patterns from molecular weights of 10,000 (L) and 6,000 ® g mol-1 showing pitch sizes of around 15 and 11.3 nm.

Pattern Quantification

Characterizing these systems is critical and further proper quantification is pivotal in assessing their ability to intersect the demands of the semiconductor industry where low defect concentrations are a pre-requisite. Metrology for assessment of these patterns in terms of defining defect density, line-edge roughness, positional accuracy will need to be developed to assess the integration of new technologies into FABS as well as the 'on-line' characterization of manufactured wafers.

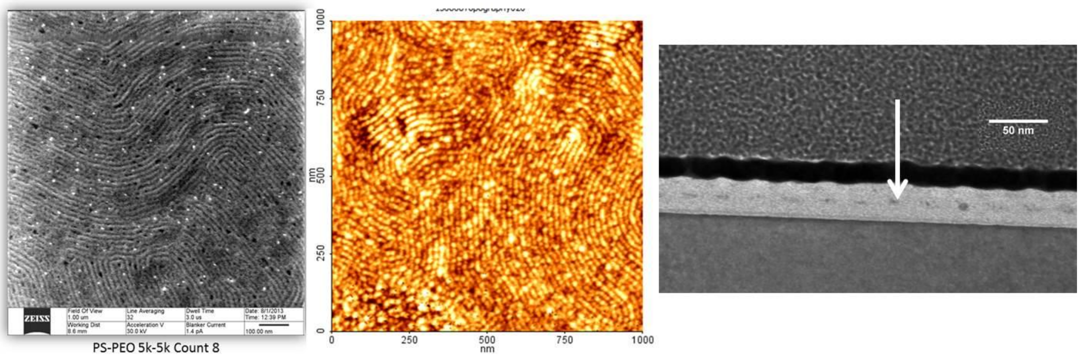


Figure 7: PS-b-PEO images. L, He ion microscopy images, M AFM images and R X-section TEM data

Two significant problems for metrology exist. The first is the image analysis used for examining very small feature sizes and, further, how 3D (i.e. through film) morphology rather than simple top-down information can be ascertained. On approach we have used is the possible use of helium ion microscopy (HIM), and within this project we have reported data using this form of analysis for the first time. HIM has a resolution between SEM and TEM. The advantage of using this technique can be seen in Figure 7 where HIM can be compared to AFM of a lamellar PS-b-PEO system of pitch around 14 nm. SEM and AFM are challenging and whilst AFM reveals phase separation, the lines are indistinct and broken. However, in HIM, well-resolved lines are clearly seen. The image is of sufficient quality to measure line roughness and interface effects. Also visible are some holes in the pattern which are due to partial removal of the hydrophilic PEO block and also some white defects which arise from carbon contamination during analysis. We have also pioneered TEM x-section imaging as also seen in Figure 7. This has required careful optimization of the FIB sample preparation. Seen above the film is a dark region which is dense Pt to protect the sample during the cut and above this particulate/crystallites of Pt. Clearly visible are PEO cylinders. This is the first image of its kind and shows that cylinders are 'flattened' due to in-plane film stresses.

The other area where the project has made a significant contribution to the science of BCP systems as well as providing significant intellectual property for exploitation is in developing software for image analysis allowing proper quantification of defects. Code was developed which allows a complete analysis of a pattern in terms of dimension, dimension regularity, pattern anisotropy and positional accuracy. It also allows an extensive analysis of specific defects such as dislocations, disclinations, missing elements and curvature. Additionally, the code is also capable of quantifying order and periodicity of the assembled structures, estimating line widths and line-edge roughness. These represent critical parameters for assessing pattern regularity for use in circuit manufacture. The advantages of this new software relate to its exclusive development for BCPs although it has relevance to the analysis of any surface pattern and might have industrial use for any lithographic process. It further reduces analysis times to a few minutes and can be used for large area analysis. Typical examples are shown in Figure 8 for both dot and line type patterns.

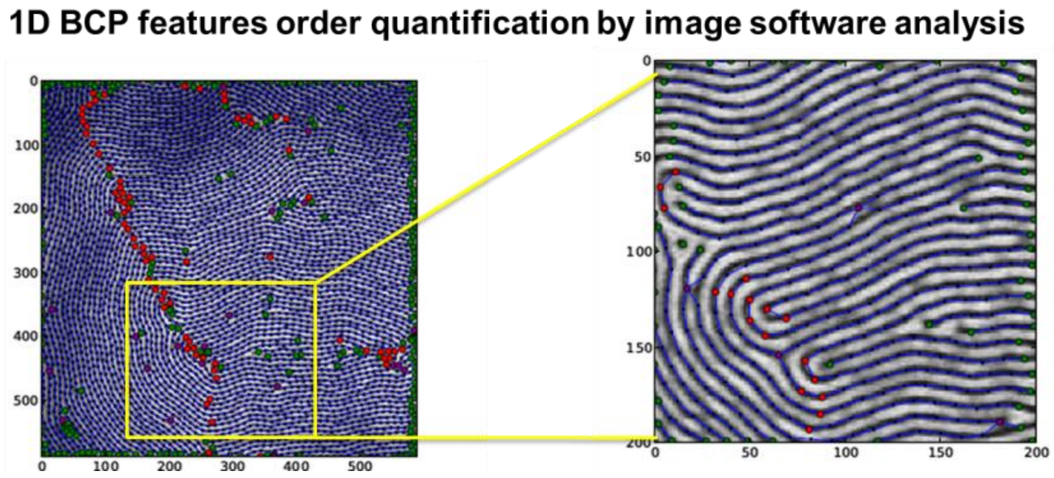


Figure 8: SEM images of linear patterns formed from self-assembled block copolymers: linear elements and defects identification and analysis. Red and green spots represent defects of various types.

Scale-up and demonstration

The ultimate success laid with integrating each of the individual work programmes into a process flow which could be used industrially and demonstrating the process flow across a wafer sample. These process steps can be identified:

1. sample cleaning: generation of a reproducible surface for subsequent treatments
2. topography formation: ultimately this was a lithographically carbon hard mask engineered substrate consistent with state-of-the-art nanodevice fabrication used industrially
3. surface functionalization: to affect high surface coverage and uniform polymer film deposition
4. polymer film deposition (PS-b-PDMS): by spin-coating using solvents consistent with industrial use
5. pattern formation: a solvent annealing process for which a prototype chamber allowing full process control was fabricated
6. pattern transfer: a state-of-the-art plasma etch process was developed for selective block removal and silicon pattern transfer

Images representing the advances are described in Figure 9. (A) represents the in-house manufactured carbon hard mask samples. SiARC is the carbonized silicon layer. (B) represents the first stage of pattern transfer where the PDMS cylinders are transferred into the SOC layer. The uniformity of the samples should be noted. Note that the original PS-b-PDMS pattern is converted into silica like lines by oxidation and hydrocarbon removal in other plasma etch processes. (C) is the second stage of pattern transfer where the pattern formed in (B) is transferred into the silicon substrate. (D) is a photographic image of the constructed solvent annealing chamber. Solvent annealing is an area which requires detailed attention for use in industry and the work here is a major step in the eventual uptake of this technique for BCP integration.

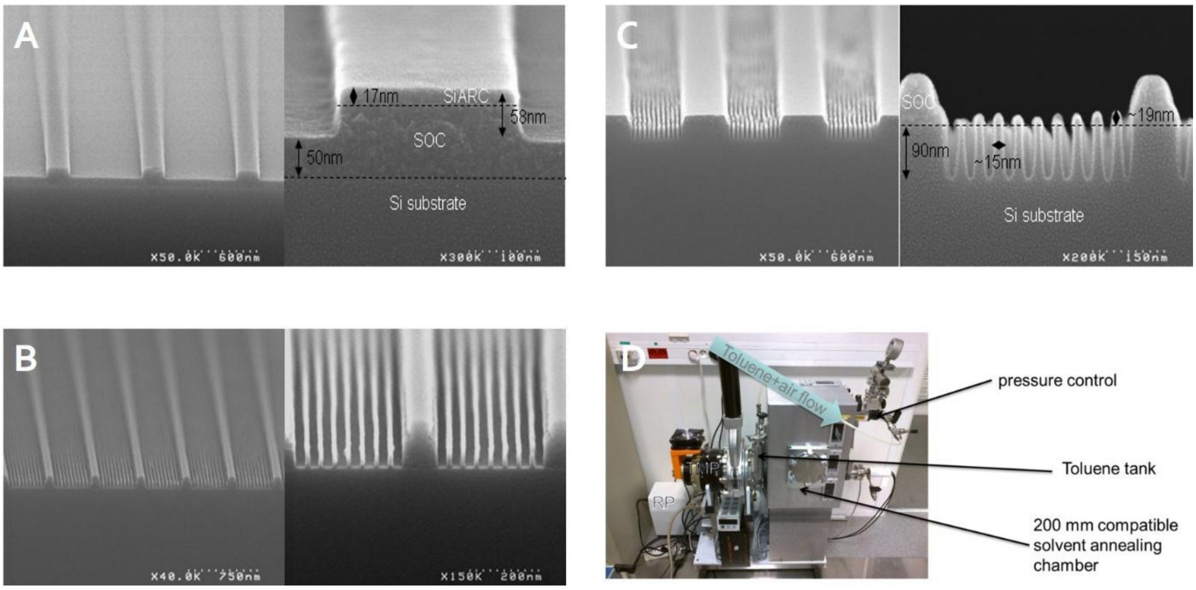


Figure 9: Scale up for PS-b-PDMS system

4.1.4 Potential impact

The **scientific impacts** of the project can be very briefly summarized:-

1) Around 50 papers from the project will have been published
2) Over 75 scientific presentations will have been presented at various national and international conferences and meetings
3) The academic groups involved in the project have significantly increased their scientific reputations:-
   - The group have organized 2 international DSA meetings in 2012 and 2013. The latter one was held in the Euronanoforum meeting in Dublin and attracted 75 international participants
   - The meeting in 2012 was attended by senior ITRS and SRC representatives and were testimony to the international reputation of the group
   - M A Morris has contributed to the last two iterations of the ITRS Roadmap for Emerging materials; MAM will give an international WEBINAR on BCP lithography in October 2013

- Further international funding for work on etchless techniques has been provided by the SRC
- Cork have been invited to host a session at the Internationally recognized SPIE conference which is the most important lithography conference in the World. We have had acceptances from 6 of the most respected leaders in the field.

The **industrial application and uptake** of the methods in the semiconductor industry has been advanced through our DSA workshops and the ITRS engagement as well as direct interactions with Intel. As well as this, the LTM and Cork groups together with Intel are partners in a ENIAC pilot line proposal for delivery of BCPs for integration of technology into manufacturing lines. This proposal is led by Arkema and has reached the final phase of the applications.

Intellectual property has been developed and a number of patents have or about to be submitted. These are fully detailed elsewhere and are summarized here.

NANODOTS –A method for providing a nanopattern of metal oxide nanostructures on a substrate (Application No. 11189329-2222). This patent relates to using BCPs to generate a hard-mask which can then be used to produce high aspect ratio, hi-fidelity substrate patterns.

An antimicrobial food package (Application No. P10939EP00). This relates to the use of BCP nanopatterns to generate oxide and metallic nanodots which impart antimicrobial activity on a substrate.

Software image analysis. This is described above and relates to the new code for pattern quantification. It is believed to be highly valuable and a number of companies have expressed interest.

Sub-wavelength light diffraction techniques. These methods allow pattern quantification using light and is a complimentary technique to high resolution electron microscopy. Its value lies in being consistent with in-line analysis for manufacturing assessment.

Desk top multipurpose nano-imprint lithography module. This is an invention that allow insitu processing of polymer films and will have short term academic impacts and may be scaled for large area film processing.

Commercial impacts have been developed with some success. The work with Kanichi has allowed a simple cost effective technique for developing BCP patterns over very large areas consistent with the preparation of large rolls of materials rather than hard substrates. With this we have been able to progress further commercialization of the technologies developed here. The on-going commercialization work is briefly summarized.

Development of novel food packaging materials. Funding has been obtained for assessing the technology, the optimum route to market and a full consultancy report from an international expert.

The work has been favourably received and further funding is now being applied for to develop prototype materials.

Development of oleophobic polymer films. Using techniques described here, super-hydrophobic materials can be produced at low cost. These substrates can be used for screens and displays that are resistant to dirt and grease.

We are also in discussion with one company on using these methods in light emitting diode applications but this is under a confidentiality agreement at the moment.

We are working with a chromatography company to pattern silicon for on-chip column applications and are currently testing the first prototype device.

In summary, we believe that the LAMAND project has made a very strong contribution to European science in this area and enhanced the EU reputation and allowed significant international impact. We have allowed the EU to be at the forefront of international work to integrate BCP techniques into large scale silicon device manufacture with pilot-line manufacture expected within 3 years. We assert we have developed valuable intellectual property which will be exploited by EU companies. The impacts have warranted the investment made in the LAMAND team and the advances and impacts have exceeded what might be expected from the level of funding.

4.1.5 Address of the project public website

Project public website : http://www.tyndall.ie/projects/lamand

Lamand Logo :

List of beneficiaries :

Beneficiaries name	Contact details
1. UNIVERSITY COLLEGE CORK, NATIONAL UNIVERSITY OF IRELAND, CORK (UCC-TNI)	Prof. M. Morris Tel. +353 21 4902180 Fax +353 21 4274097 E-mail: m.morris@ucc.ie Department of Chemistry, University College Cork, Cork, Ireland
2. UNIVERSITY OF NEWCASTLE UPON TYNE (UNEW)	Prof. Andrew Houlton School of Chemistry University of Newcastle upon Tyne Bedson Building Newcastle upon Tyne NE1 7RU United Kingdom Tel: +44 191 222 6262 Fax: +44 191 222 6929 E-mail: andrew.houlton@nci.ac.uk
3. UNIVERSITY OF IOANNINA (UOI)	Apostolos Avgeropoulos, PhD Professor of Polymer Science

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4. CATALAN INSTITUTE OF NANOTECHNOLOGY (ICN)	Prof. Clivia Sotomayor Torres Tel. + +34 93 586 8304 Fax +34 935868313 E-mail: clivia.sotomayor@cin2.es Phononic and Photonic Nanostructures Group
5. SELCUK UNIVERSITESI (SU)	Prof. Dr. Mustafa Ersoz Department of Chemistry Selcuk University 42075 Konya Turkey Tel. (90) 3322412484 Fax:(90) 3322412499 E-mail: ersozm@gmail.com
6. CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE (LTM)	Dr Marc ZELSMANN Laboratoire des technologies de la microélectronique (L T M) 17 rue des Martyrs 38054 Grenoble Cedex 9 France Tel. +33-4-38789292 Fax +33-4-38785892 E-mail: marc.zelsmann@cea.fr
7. INTEL PERFORMANCE LEARNING SOLUTIONS LIMITED (Intel)	Jennifer McKenna, EU Research Project Manager c/o Intel Ireland Ltd Mailstop IR6-1-1 Collinstown Industrial Park Leixlip, Co. Kildare, Ireland E-mail : jennifer.mckenna@intel.com
8. PROFACTOR GMBH (PRO)	Dr. Bernd DITTERT Tel: +43(0)7252 885-406 Fax: +43(0)7252 885-101 E-mail: bernd.dittert@profactor.at Functional Surfaces and Nanostructures, PROFACTOR GmbH, Steyr-Gleink, Austria
9. KANICHI RESEARCH SERVICES	David Killworth, Company CEO

LIMITED (KAN)	tel +44 7802 788436 Email : david@beacon-management.co.uk Beacon Management 33 Hough Lane, Wilmslow Cheshire SK9 2LH

4.2 Use and dissemination of foreground

- Publications and conferences

The publication management is effected by all consortium members on a regular basis. Abstracts are submitted to the project office and the coordinator, and reviewed within a week by the members of the IPCDC (Intellectual Property Commercialisation and Dissemination Committee) and all consortium members. If the abstract is approved, the full publication is sent to the project manager who upload it onto the Lamand website, the author can then submit the abstract to the selected peered reviewed journal or conference. Every 3 or 4 months the IPCDC teleconference meetings are held, where publications are recorded. During the whole project, 47 participations to conferences/workshops/seminars and 29 publications were recorded. A list of conference participations as well as a list of publications have been established and are as follows (tables A1 (publications) and A2 (dissemination activities)):

TEMPLATE A1: LIST OF SCIENTIFIC (PEER REVIEWED) PUBLICATIONS, STARTING WITH THE MOST IMPORTANT ONES										
NO.	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers[2] (if available)	Is/Will open access[3] provided to this publication?
1	*Direct top-down ordering of diblock copolymers through nanoimprint lithography*	*M. Salaün*	*J. Vac. Sci. Technol. B*	*29(6)*	*American Vacuum Society*	*United States of America*	*2011*	*06F208 (5 pages)*	http://dx.doi.org/10.1116/1.3662399 Proceedings of the The 55th International Conference on Electron, Ion, Photon Beam Technology and Nanofabrication (EIPBN 2011) Published 18/11/11	*No*
2	*Low temperature direct imprint of polyhedral oligomeric silsesquioxane (POSS) resist*	*N. Kehagias*	*Microelectronic Engineering*	*88(8)*	*Elsevier*	*The Netherlands*	*2011*	*1997-1999*	http://dx.doi.org/doi:10.1016/j.mee.2011.02.047 Proceedings of the 37th International Conference on Micro- and Nano-Engineering Published 16/02/11	*No*
3	*DNA-based Nanowires. Towards bottom-up nanoscale electronic*	*A. Houlton*	*Ann. Rep. Prog. Chem. Sect. A : Inorg. Chem.*	*107*	*RSC Publications*	*United kingdom*	*2011*	*21-42*	*DOI: http://dx.doi.org/10.1039/C1IC90017J* Published 25/05/11	*No*
4	*Soft graphoepitaxy of hexagonal PS-b-PDMS on*	*C. Simao*	*J. Photopolym. Sci. Technol.*	*25 (2)*	*Japan Science and Technology*	*Japan*	*2012*	*239-244*	https://www.jstage.jst.go.jp/article/photopolymer/	*yes*

[2] A permanent identifier should be a persistent link to the published version full text if open access or abstract if article is pay per view) or to the final manuscript accepted for publication (link to article in repository).
[3] Open Access is defined as free of charge access for anyone via Internet. Please answer "yes" if the open access to the publication is already established and also if the embargo period for open access is not yet over but you intend to establish open access afterwards.

	nanopatterned POSS surfaces fabricated by nanoimprint lithography				*Information Aggregator, Electronic (J-Stage)*				25/2/25_239/_pdf Proceedings Published 10/08/12	
5	*Synthesis, characterization and electrical properties of supramolecular DNA-templated polymer nanowires of 2,5-(bis-2-thienyl)-pyrrole*	*Scott M. D. Watson*	*Chemistry – A European Journal*	*18(38)*	*Wiley*	*United States of america*	*2012*	*12008-12019*	http://dx.doi.org/10.1002/chem.201201495 publication date : 09/08/12	*No*
6	*Quantified Comparison of Ordering in Self-Assembled Block Copolymer Films of Different Molecular Weights by Image Analysis Method*	*T. Kehoe*	*MRS Proceedings*	*1412*	*Cambridge University Press*	*United Kingdom*	*2012*		DOI : http://dx.doi.org/10.1557/opl.2012.733	*No*
7	*Block copolymer lithography: feature size control and extension by an over-etch*	*S. Rasappa*	*Thin Solid Films*	*522*	*Elsevier*	*The Netherlands*	*2012*	*318-323*	DOI : http://dx.doi.org/10.1016/j.tsf.2012.09.017 published 11/09/12	*No*
8	*Block Copolymer Self-assembly on Ethylene Glycol (EG) Self-assembled Monolayer (SAM) for Nanofabrication*	*D. Borah*	*MRS Proceedings*	*1450*	*Cambridge University Press*	*United Kingdom*	*2012*	*mrss12-1450-cc06-24*	DOI : http://dx.doi.org/10.1557/opl.2012.1224	*No*
9	*Magnetic and Conductive Magnetite Nanowires by DNA-Templating*	*H. D. A. Mohamed*	RSC Nanoscale	4(19)	*RSC Publications*	*United kingdom*	*2012*	5936-5945	DOI : http://dx.doi.org/10.1039/c2nr31559a Published 02/08/12	*No*
10	*Orientation and Alignment Control of Microphase Separated PS-b-*	*D. Borah*	*ACS Applied Materials & Interfaces*	*5*	*ACS Publications*	*United States*	*2013*	*88-97*	DOI : http://dx.doi.org/10.1021/am302150z Published 10/12/12	No

	PDMS Substrate Patterns via Polymer Brush Chemistry									
11	*In-situ visualization and order quantification of symmetric diblock copolymer directed self-assembly*	*M. Salaün*	*Thin Solid films*	In press available on line	*Elsevier*	*The Netherlands*	*2013*		*DOI : http://dx.doi.org/10.1016/j.tsf.2013.01.003 Published 10/01/13*	No
12	*The sensitivity of random polymer brush – lamellar PS-b-PMMA block copolymer systems to process conditions*	*D. Borah*	*Journal of Colloid and Interface Science*	*393*	*Elsevier*	*The Netherlands*	*2013*	192-202	*DOI : http://dx.doi.org/10.1016/j.jcis.2012.10.070* *Published on 15/11/12*	No
13	*Fabrication of highly ordered sub-20 nm silicon nanopillars by block copolymer lithography combined with resist design*	*Mathieu Salaun*	*Journal of Materials Chemistry C*	*1*	*RSC Publications*	*United kingdom*	*2013*	*3544-3550*	*http://dx.doi.org/10.1039/c3tc30300d* *Published on 03/04/13*	No
14	*Swift Nanopattern Formation of PS-b-PMMA and PS-b-PDMS Block Copolymer Films Using a Microwave Assisted Technique*	*D. Borah*	*ACS Nano*	*Just Accepted Manuscript Publication Date (Web): July 16, 2013*	*ACS Publications*	*United States of America*	*2013*		*DOI: http://dx.doi.org/10.1021/nn4035519*	No
15	*Sub-10 nm Feature Size PS -b -PDMS Block Copolymer Structures Fabricated by a Microwave-Assisted Solvothermal*	*D. Borah*	*ACS Appl. Mater. Interfaces*	*5*	*ACS Publications*	*United States of America*	*2013*	*2004-2012*	*DOI : http://dx.doi.org/10.1021/am302830w Published 19/02/13*	No

	Process									
16	Fabrication of Germanium Nanowire Arrays by Block Copolymer Lithography	S. Rasappa	Sci. Adv. Mater	5(7)	American Scientific Publishers	United States of America	2013	782-787	DOI: http://dx.doi.org/10.1166/sam.2013.1518 Published 01/07/13	No
17	Tuning PDMS Brush Chemistry by UV-O_3 Exposure for PS-b-PDMS Microphase Separation and Directed Self-assembly	D. Borah	Langmuir	29	ACS Publications	United States of America	2013	8959-8968	http://dx.doi.org/10.1021/la401561k Published 10/06/13	No
18	Fabrication of a sub-10 nm silicon nanowire based ethanol sensor using block copolymer lithography	S. Rasappa	Nanotechnology, available on line	24	IOP Publishing	United Kingdom	2013	065503	http://dx.doi.org/10.1088/0957-4484/24/6/065503 Published 22/01/13	No
19	Electrically conductive magnetic nanowires using an electrochemical DNA-templating route	S.M.D. Watson	Nanoscale	5	RSC Publications	United kingdom	2013	5349-5359	DOI : http://dx.doi.org/10.1039/c3nr00716b Published 24/04/2013	No
20	Achieving Structural Control with Thin Polystyrene-b Polydimethylsiloxane Block Copolymer Films: The Complex Relationship of Interface Chemistry, Annealing Methodology and	B.M.D. O'Driscoll	European Polymer Journal		Elsevier	The Netherlands	2013		DOI : http://dx.doi.org/10.1016/j.eurpolymj.2013.07.022 Just accepted 15/07/13	No

	Process Conditions									
21	*Soft-Graphoepitaxy Using Nanoimprinted POSS Substrates for the Directed Self-Assembly of PS-<i>b</i>-PDMS*	*D. Borah*	*European Polymer Journal*		*Elsevier*	*The Netherlands*	*2013*		*[DOI : http://dx.doi.org/10.1016/j.eurpolymj.2013.08.011](http://dx.doi.org/10.1016/j.eurpolymj.2013.08.011)* *Just accepted 04/08/13*	*No*
22	*White light photosensor based N, N'-di (2-ethylhexyl)-3,4,9,10-perylene diimide thin film phototransistor*	*C. Tozlu*	*Sensors Actuators. A: Physical*	*Submitted*	*Elsevier*	*The Netherlands*	*2013*			*No*
23	*Directed self-assembly of a block copolymer thin film by in situ solvent-assisted nanoimprint lithography: geometrical confinement effects and order quantification*	*C. Simao*	*Adv Funct Mater*	*Submitted 17/04/13*	*Wiley*	*United States of america*	*2013*			*No*
24	*Fabrication of 3-D Nanodimensioned Electric Double Layer Capacitor Structures Using Block Copolymer Templates*	*S. Rasappa*	*Journal of Nanoscience and Nanotechnology*	*Submitted*	*American Scientific Publishers*	*United States of America*	*2013*			*No*
25	*A Comparative Study on phase separation of PS-PMMA bloc copolymers based on*	*B. Ertekin*	*Journal of Pol. Sci. Part A: Pol. Chem.*	*In preparation*	*Wiley*	*United States of america*				

	different techniques									
26	*Nanopatterning of Colloidal Nanocrystals for CdSe-Polymer hybrid solar cells*	*M. Kus*	*Sol. En. Mat. Solar Cells*	*In preparation*	*Elsevier*	*The Netherlands*				
27	*Synthesis, characterisation and surface depostion of PS-DNA oligomer diblock and triblock copolymers*	*S.M.D. Watson*	*Nanoscale*	*In preparation*	*RSC Publications*	*United kingdom*				
28	*Nanoscale silicon substrate patterns from self-assembly of cylinder-forming polystyrene-block-polydimethylsiloxane block copolymer on silane functionalized surfaces*	*D. Borah*	*Adv. Mater.*	*In preparation*	*Wiley*	*United States of america*				
29	*The effect of nanowire resistance on electric force microscopy phase images*	*S. Pruneanu*	*Nanotechnology*	*In preparation*	*IOP Publishing*	*United Kingdom*				

In total 21 papers were already published, 16 were published in peered reviewed journals with high impact factor such as ACS Nano, Langmuir or RSC Nanoscale, and 5 are proceedings. Another 3 papers were submitted to peered reviewed journals, and are currently under revision. Finally an extra 5 papers are in preparation.

TEMPLATE A2: LIST OF DISSEMINATION ACTIVITIES								
NO.	Type of activities[4]	Main leader	Title	Date/Period	Place	Type of audience[5]	Size of audience	Countries addressed
1	*Symposium*	B. R. Horrocks (UNEW)	Biomineralization Symposium	*Jan 2011*	Newcastle University, UK	*Scientific community*		*All*
2	*Seminar*	D. A. Fulton (UNEW)	Polymer Chemistry at Newcastle	1st Feburary 2011	Universiti Teknologi MARA, Selangor Darul Ehsan, Malaysia	*Scientific community*	*50*	*Malaysia*
3	*Conference*	M. Shaw (Intel)	*SPIE Conference/ DSA workshop*	*March 4th-5th 2011*	*San Jose, USA.*	*Scientific Community, Industry, ITRS*	*2350*	*All*
4	*Seminar*	D. A. Fulton (UNEW)	Templating conductive materials on DNA	June 2011	Durham University, UK	*Scientific community*	*50*	*UK*
5	*Conference*	*B. R. Horrocks (UNEW)*	*Electrochemical Horizons 2011, University of Bath, UK*	*5-6 Sept 2011*	*University of Bath, UK*	*Scientific community*	*200*	*All*
6	*Conference*	*A. Houlton (UNEW)*	*5th EuCheMS Conference on Nitrogen Ligands in Coordination*	*4-8 Sept 2011*	*Grenada, Spain*	*Scientific community*	*230*	*All*

[4] A drop down list allows choosing the dissemination activity: publications, conferences, workshops, web, press releases, flyers, articles published in the popular press, videos, media briefings, presentations, exhibitions, thesis, interviews, films, TV clips, posters, Other.

[5] A drop down list allows choosing the type of public: Scientific Community (higher education, Research), Industry, Civil Society, Policy makers, Medias, Other ('multiple choices' is possible).

			Chemistry, Metal-Organic Chemistry, Bioinorganic Chemistry, Materials and Catalysis					
7	*Conference*	C. M. Sotomayor torres (ICN)	2011 MRS Fall Meeting and Exhibit	28 Nov-2 Dec 2011	Hynes Convention Center, Boston, MA, USA	*Scientific Community*		*All*
8	Conference	O. Lorret (PRO) T. Kehoe (ICN)	37th International Conference on Micro and Nano Engineering	19-23 September 2011	Berlin, Germany	*Scientific Community*		*All*
9	Conference	M. Salaun (LTM) N. Kehagias (ICN)	The 55th International Conference on Electron, Ion, Photon Beam Technology and Nanofabrication (EIPBN 2011)	31 May- 3 June 2011	Las Vegas, Nevada, USA	*Scientific Community*		*All*
10	Conference	C. Sotomayor Torres (ICN)	International Conference on Materials for Advanced Technologies (ICMAT 2011**)**	26 June- 1 July 2011	Suntec, Singapore	*Scientific Community*		*All*
11	Conference	N. Kehagias (ICN)	Nanospain Conference	11-14 April 2011	Bilbao, Spain	*Scientific Community*		*Spain*
12	Conference	C. M. Sotomayor Torres (ICN)	EuroNanoForum 2011	30 May- 1 June 2011	Budapest, Hungary	*Scientific Community, Industry, Policy makers*		*All*
13	Symposium	A. Avgeropoulos	5th Panhellenic	30 June - 1 July 2011	Heraklion, Crete, Greece	*Scientific*		*Greece*

		(UOI)	Symposium of Porous Materials			*Community*		
14	*Conference*	*A. Houlton (UNEW)*	*10th International Conference on Materials Chemistry MC10*	*4-7 July 2011*	*Manchester, UK*	*Scientific Community*	*550*	*All*
15	Conference	A. Avgeropoulos (UOI)	8th International Conference of Nanoscience and Nanotechnologies (NN11)	12 – 15 July 2011	Thessaloniki, Greece	*Scientific Community*		*All*
16	Conference	D. Borah (UCC-TNI)	MRS Directed Self-Assembly of Materials Workshop	28 Sept- 1 Oct 2011	Nashville, Tennessee, USA	*Scientific Community*		*All*
17	Conference	M. Karakassides (UOI)	3rd International Conference-NANOCON 2011	21-23 September 2011	Brno, Czech Republic	*Scientific Community*		*All*
18	Conference	A. Avgeropoulos (UOI)	Intel European Research & Innovation Conference	12 – 14 October 2011	Leixlip, Dublin, Ireland	*Scientific Community, Industry*		*All*
19	Symposium	A. Houlton (UNEW)	*RSC Postgraduate Symposium on Nanotechnology, Birmingham, UK*	*December 2011*	*Birmingham, UK*	*Scientific Community*	60	*All*
20	Symposium	A. Houlton (UNEW)	University of Bristol Materials Symposium	April 2012	Bristol, United Kingdom	*Scientific Community*		*All*

21	Conference	D. Borah (UCC-TNI)	2012 MRS Spring Meeting and exhibit	9-13 April 2012	san Francisco, California	*Scientific Community*		*All*
22	Conference	B. Kosmala (UCC-TNI)	7th International ECNP (European Centre for Nanostructured Polymers)	24-27 April 2012	Prague, Czech Republic	*Scientific Community*		*All*
23	Conference	M.Ersoz (SU)	Apostille Workshop	27-28 April 2012	Novi Sad, Serbia,	*Scientific Community*		*All*
24	*Seminar*	*B. R. Horrocks (UNEW)*	*Conductive nanowires and quantum dots*	*May 2012*	*Leica Microsytems, UK*	*Scientific Community, Industry*	*50*	*UK*
25	Conference	C. Simao (ICN) M. Salaun (LTM)	56th International Conference on Electron, Ion, and Photon Bean Technology and Nanofabrication (EIPBN 2012)	29-31 May 2012	Waikoloa, Hawaii	*Scientific Community*		*All*
26	Conference	S. Buyukcelebi (SU)	Large Area Organic Printed Electronics (LOPE-C) Conference	19-21 June 2012	Munich, Germany	*Scientific Community*		*All*
27	Conference	M. Ersoz (SU)	Workshop Nano-bicolloidal materials and non equilibrium self-assembly, joint Meeting of WG3 and WG4 COST Action CM1101	18-19 June 2012	Barcelona, Spain	*Scientific Community*		*All*
28	Conference/Lamand stand	B. Kosmala	Industrial Technologies	19-21 June 2012	concert Hall, Aarhus,	*Scientific Community,*		*All*

		(UCC-TNI)	2012		Denmark	*Industry, Policy makers*		
29	Conference	C. Simao (ICN)	29^{th} Int. Conf. Photopolymer Sci & Technol (CPST)	26-29 June 2012	Chiba University, Japan	*Scientific Community*		*All*
30	*Conference*	*B. R. Horrocks (UNEW)*	*Electrochemical Horizons 2012, Dublin, Ireland,*	*2-4 Sept 2012*	*Dublin, Ireland*	*Scientific Community*	*180*	*All*
31	Conference	A. Houlton (UNEW)	40 International Coordination Chemistry Conference (ICCC40)	9-13 September 2012	Valencia, Spain	*Scientific Community*		*All*
32	Conference	C. Simao (ICN) O. Lorret (PRO) M. Salaün (LTM)	38^{th} International Conference on Micro and Nano Engineering	16-20 September 2012	Toulouse, France	*Scientific Community*		*All*
33	Workshop	M. Morris(UCC-TNI), A. Avgeropoulos (UOI), C. Simao (ICN), M. Zelsmann (LTM), M. Shaw G. D'Arcy (Intel)	Intel workshop on Patterning by Self Assembly and Advanced Self Assembled materials for CMOS applications	1-2 October 2012	Leixlip, Kildare, Ireland	*Scientific Community, industry*		*All*
34	Conference	M. Ersoz (SU)	XXVI. Ulusal Kimya Kongresi,1-6 Ekim 2012 Fethiye-Muğla	5^{th} October 2012	Fethiye-Muğla , Turkey	*Scientific Community*		*Turkey*

35	Conference	C. Simao (ICN)	11th International Conference on Nanoimprint & Nanoprint Technology	24-26 October 2012	Napa, California, USA	*Scientific Community*		*All*
36	School	A. Houlton (UNEW)	5th European School of Molecular Nanoscience (ESMOL-NA)	28 October- 2 November 2012	Ceunca, Spain	*Scientific Community*	100	*All*
37	*Symposium*	*M. Kus (SU)*	*One Day symposium on Materials for Bio-Organic Electronics,* *Johannes Kepler University of Linz TNF Tower HS 12*	*29 January 2013*	*University of Linz, Austria*	*Scientific Community*		*All*
38	Conference	D. Borah (UCC-TNI)	SPIE Conference on Advanced Lithography	24-28 February 2013	San Jose, California, USA	*Scientific Community*		*All*
39	*Symposium*	*B. R. Horrocks (UNEW)*	*RSC Chemical Nanoscience Symposium*	*March 2013*	*Newcastle University, UK*	*Scientific Community*		*All*
40	Conference	O. Lorret (PRO)	Third International Conference on Multifunctional, Hybrid and Nanomaterials (Hybrid Materials 2013)	3-7 March 2013	Sorrento, Italy	*Scientific Community*		*All*
41	*Seminar*	*A. Houlton (UNEW)*	*DNA-based nanoscale materials*	*April 2013*	*Cardiff University UK*	*Scientific Community*	*50*	*UK*
42	Conference	B. Kosmala	Annual Tyndall internal Conference	25th April 2013	Cork, Ireland	*Scientific*		*Ireland*

		(UCC-TNI)				*Community*		
43	*Conference*	*S. Watson* *(UNEW)*	*Scanning Probe Microscopy Conference and User Meeting*	*8th May 2013*	*University of Sheffield, UK*	*Scientific Community*		*All*
44	*Conference*	*M. Kus (SU)*	*Apostille workshop on Printed, Flexible and Nanoelectronics*	*9th May, 2013*	*Novi Sad, Serbia*	*Scientific Community*		*All*
45	*Symposium*	*A. Houlton (UNEW)*	*RSC Supramolecular and Nanoscale Chemistry Symposium*	*22nd May 2013*	*Durham University, UK*	*Scientific Community*		*All*
46	*Conference*	*M. Ersoz (SU)*	*WG2, WG3 & WG4 meeting: Functionalized Surfaces and Nanobiocomposites, COST CM1101 – Workshop*	28th May, 2013	Szeged, Hungary	*Scientific Community*		*All*
47	Conference/Workshop	UCC-TNI/ Intel, all partners	Euronanoforum 2013/ Directed Self Assembly of Materials for Devices workshop	18-20 June 2013	Dublin, Ireland	*Scientific Community, Industry, Policy makers*	1500	*All*

All partners attended a number of conferences (Table A2) that addressed mainly the scientific community. UCC-TNI held a booth presenting the LAMAND project as a whole at the Industrial Technologies 2012. The event, the largest European Commission industrial technologies event of the year gathered the scientific community, the industry and policy makers such as the EU commission, and was a great opportunity to advertise the research done within Lamand to the companies present at the event. Among the events organized by the consortium was the Intel workshop on Patterning by Self Assembly and Advanced Self Assembled materials for CMOS applications (1-2 October 2012), and the Intel/CRANN workshop on Directed Self Assembly of Materials for Devices (20th of June 2013) and The first workshop took place in Intel Ireland, Leixlip, Kildare, Ireland. It was centred on identifying challenges, solutions and long term requirements for the use of directed self-assembly towards extending silicon devices towards their ultimate dimension and performance. There were sessions on industry requirements, self-assembled material requirements, nanofabrication methodologies and new directions/self-assembled materials for advanced CMOS applications. This workshop event had the following objectives :

- A review of the state of the art in the topic in Europe
- A discussion on BCP scaling / technology challenges / industry opportunities
- Look to identify collaborative opportunities for European partners
- Understand current and future EU program opportunities for patterning by self-assembly and advanced self-assembled materials for CMOS applications
- Create more of a focus on the challenges from the research community

The event was very successful. DSA has progressed a lot, many companies are interested in developing it on industrial scale. However a few problems remain. There is a need to improve on defects, solvent annealing (not environmentally friendly), brush deposition (extra step added), need new BCPs,as alternative to PS-b-PMMA.

The second workshop was a part of Euronanoforum 2013 and took place in the Convention Center in Dublin. The focus was on identifying challenges, solutions and long term requirements for the directed self-assembly of materials towards ICT, energy and emerging applications, as well as the metrology of self-assembled systems. Experts from across Europe will be invited to participate in this workshop and showcase the newest developments in this field as European groups continue to demonstrate world-class leadership in this research area. The event articulated around a series of lectures, and a DSA poster session. All the LAMAND partners attended the workshop along with other European academics. Many partners presented a poster (UCC-TNI, ICN, LTM), and Prof M. Ersoz (SU) gave a talk. The event was once again very successful. Interests for DSA is not limited to ICT applications, but is extending to energy applications, and other fields. Both workshops were chaired by M. Shaw (Intel).

TEMPLATE B1: LIST OF APPLICATIONS FOR PATENTS, TRADEMARKS, REGISTERED DESIGNS, ETC.					
Type of IP Rights[6]:	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Application reference(s) (e.g. EP123456)	Subject or title of application	Applicant (s) (as on the application)
Patent	*yes*	*Published on 23/05/13*	*PCT/EP2012/072935*	*NANODOTS –A method for providing a nanopattern of metal oxide nanostructures on a substrate.*	*Michael A. Morris, Dipu Borah, Tandra Ghoshal, Parvaneh Mokarian-Tabari*
Patent	*yes*	*Filed, not published yet*	*P10939EP00*	*An antimicrobial food package*	*Michael A. Morris, D Borah and J Kerry*
Patent	*yes*	*Being filed*	.	*Image analysis of one- and two- dimensional structures: morphology analysis and order quantification.*	*W. Khunsin, C. Simão, D. Tuchapsky, A. Amann, M. A. Morris and Clivia M. Sotomayor*
Patent	*yes*	*Being filed*		*In line detection and real time analysis of sub-50 nm size features formation and defectivity on top of micron periodic gratings for block copolymers nanopatterns and/or nanogratings from nanoimprint lithography.*	*J. Gomis, C. Simão, T. Kehoe, C. Sotomayor Torres*

[6] A drop down list allows choosing the type of IP rights: Patents, Trademarks, Registered designs, Utility models, Others.

Type of Exploitable Foreground[7]	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application[8]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
Commercial exploitation of R&D results	NANODOTS –A method for providing a nanopattern of metal oxide nanostructures on a substrate.	*yes*		*Superhydrophobic surfaces for use as oleophobic surfaces in touch screens for phones and tablets*	*Glass Coating*	*2016*	*Patent to license to a company in this sector*	*UCC-TNI(owner)* .
Commercial exploitation of R&D results	NANODOTS –A method for providing a nanopattern of metal oxide nanostructures on a substrate.	*yes*		*Nanopatterning method for creating active nanopatterns for the semiconductor industry*	*Semiconductor Industry*	*2016*	*Patent to license to a company in this sector possibly Intel*	*UCC-TNI(owner)*
Commercial exploitation of R&D results	COATINGS - A method to develop patterned block copolymer (BCP) films over large area substrates using conventional coating methods to create	*yes*		Large area coating to generate large area nanostructured surfaces to create superhydrophobic surfaces, used as oleophobic surfaces for use in touch screens on phones and tablets	*Glass Coating Metrology companies Foodpackaging industry*	2016	POSSIBLE PATENT *licensing to a company in this sector.*	UCC-TNI/KAN(OWNER)

[19] A drop down list allows choosing the type of foreground: General advancement of knowledge, Commercial exploitation of R&D results, Exploitation of R&D results via standards, exploitation of results through EU policies, exploitation of results through (social) innovation.
[8] A drop down list allows choosing the type sector (NACE nomenclature) : http://ec.europa.eu/competition/mergers/cases/index/nace_all.html

Type of Exploitable Foreground[7]	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application[8]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
	superhydrophobic surfaces							
Commercial exploitation of R&D results	An antimicrobial food package	*yes*	31/12/13	Uses the patterns developed on nanodots patent to create antimicrobial patterned surfaces for food packaging	*Foodpackaging industry*	2016	*Patent P10939EP00 filed on 28/06/13. To license to a company in foodpackaging*	*UCC-TNI (OWNER)*
Commercial exploitation of R&D results	Image analysis of one- and two-dimensional structures: morphology analysis and order quantification.	*yes*		Nanometrology software for BCP self-assembled structures	*Metrology companies*	2013	*Patent being filed to licence to a metrology company*	*UCC-TNI/ICN/ICREA(OWNER)*
Commercial exploitation of R&D results	In line detection and real time analysis of sub-50 nm size features formation and defectivity on top of micron periodic gratings for block copolymers nanopatterns and/or nanogratings from nanoimprint	*yes*		Nanometrology development for BCP self-assembled structures	*Metrology companies*	2013	*Patent being filed to licence to a metrology company*	*ICN/ICREA(OWNER)*

Type of Exploitable Foreground[7]	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application[8]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
	lithography.							
Commercial exploitation of R&D results	Provision of a material-based and a process technology-based process for nano-patterning at 22nm.	*yes*		Generation of highly ordered active nanopatterns for the semiconductor industry, and small electronic device companies.	*Semiconductor Industry*	UNKNOWN	*License to a company from the semiconductor industry*	*UCC-TNI, LTM, ICN, PRO, UOI*
Commercial exploitation of R&D results	Desk top multipurpose nano-imprint lithography module	*yes*		*A desktop imprinting tool capable of imprinting a thin polymer player in three different modes.*	*Universities-Research laboratories Research Institutes Research and development companies printing electronics industry, Universities*	UNKNOWN	*Possible patent, if patented try to license*	*ICN/ICREA (OWNER)*
Commercial exploitation of R&D results	Large scale production of POSS (polysilsesqui oxane) resists	*yes*		*Multifunctional POSS resists, adapted to the requirements of the client PRO is only lab scale production provider would need large scale to be done by another company*	*Printing electronics industry, Universities*	*2016*	*Licence to a company such as Microresists Technology GmbH*	PRO (OWNER)

8 exploitable results were identified (see template B1 and B2). The organization of the exploitation Strategy Seminar by S. Pastor, ESS coach in Barcelona in July 2012 was of a great help to identify them.

Exploitable result 1 : NANODOTS –A method for providing a nanopattern of metal oxide nanostructures on a substrate (UCC-TNI) + COATINGS - A method to develop patterned block copolymer (BCP) films over large area substrates using conventional coating (UCC-TNI/KAN)

The invention on nanodots is based on selective incorporation of a metal oxide precursor into one polymer of a phase separated di-block copolymer film, and the subsequent oxidation of the precursor and removal of the polymers to leave a nanopattern of metal oxide nanostructures. The process can be depicted as follows :

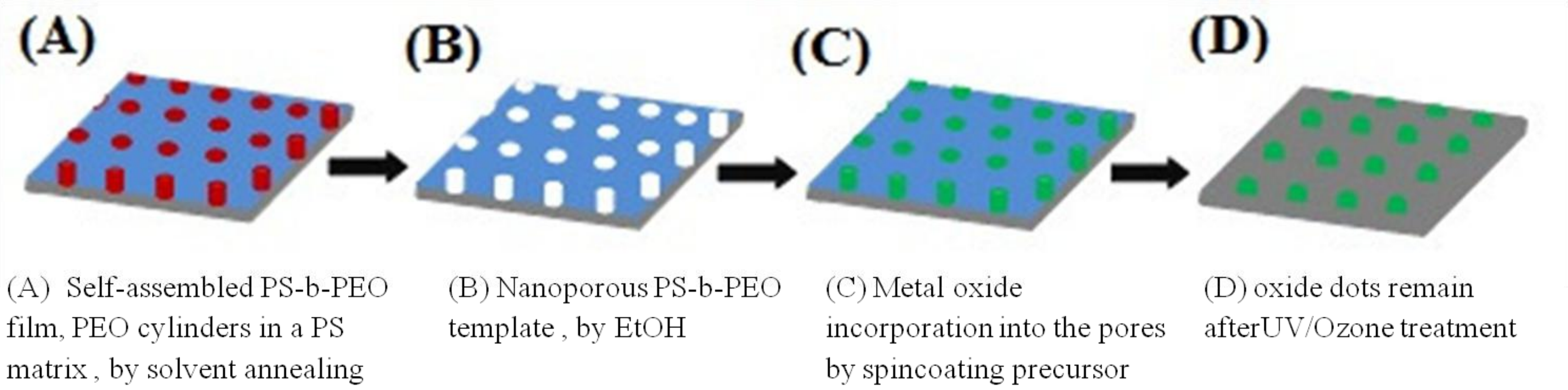
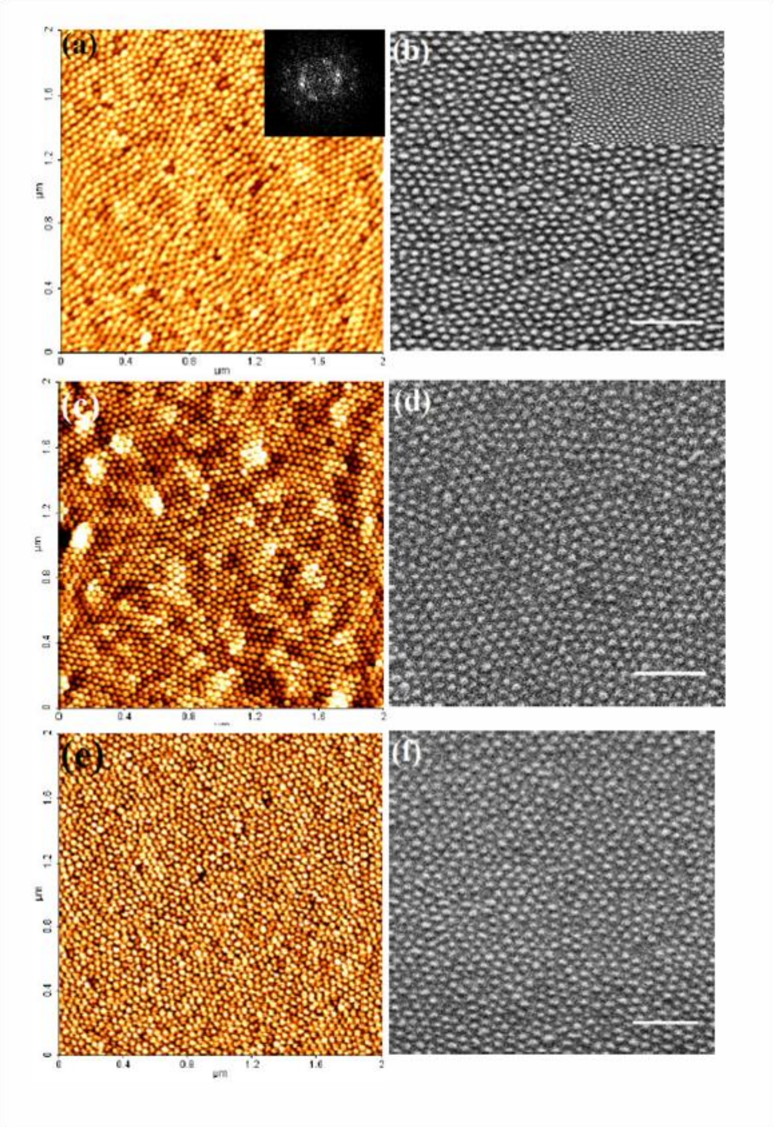
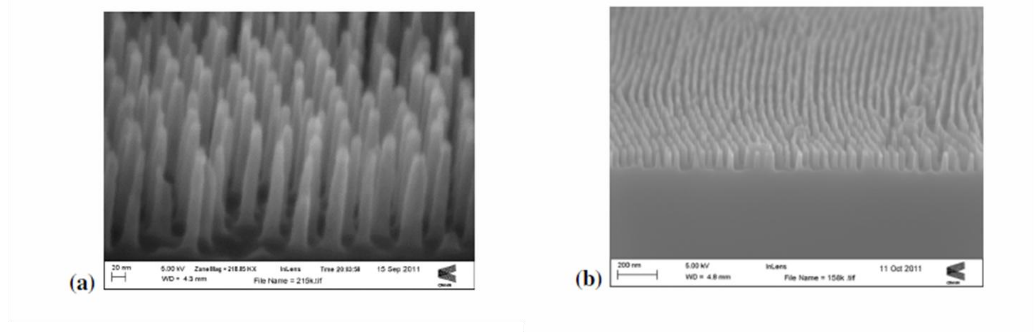


Figure 10 : Schematic illustration of the fabrication of oxide nanodots

The nanostructures are generally nanodots or lines on a substrate (such as silicon). Various metal oxide nanodots can be obtained as shown on figure 11A. Metal oxide nanopatterns can be transferred to the underlying silicon as shown on figure 11B.



(A)



(B)

Figure 11 : (A) AFM and SEM images of hexagonal ordered different oxide nanodots after UV/Ozone treatment. (a) and (b) iron oxide; (c) and (d) cerium oxide; and (e) and (f) copper oxide nanodots. Insets of (a) shows the corresponding FFT pattern. Inset of (b) shows iron oxide nanodots annealed at 8000C for 1h, Scale bar: 200 nm and (B) SEM images of silicon substrates that have been subject to pattern

transfer via formation of iron oxide nanostructures formed by the method described previously (a) vertical cylinders formed from a nanodot pattern and (b) lines from a lamellar structure.

In order to produce nanopatterns over very large area (10 cm x10 cm), coating methods had to be developped. The coating method is based on the inkjet printing of tipycally 1wt% of PS-b-PEO solution (anisole, nitrobenzene, THF, toluene…) on glass/silicon or polymer substrates (polyester, polyimide….). After solvent annealing (toluene at 50^{0}C for 1h), and EtOH restructuring, the film microphase separates in nanoporous dot patterns of PEO dots in a PS matrix over very large areas. The Incorporation of iron oxide should be possible. The fitted image used for inkjet printing is as follows :

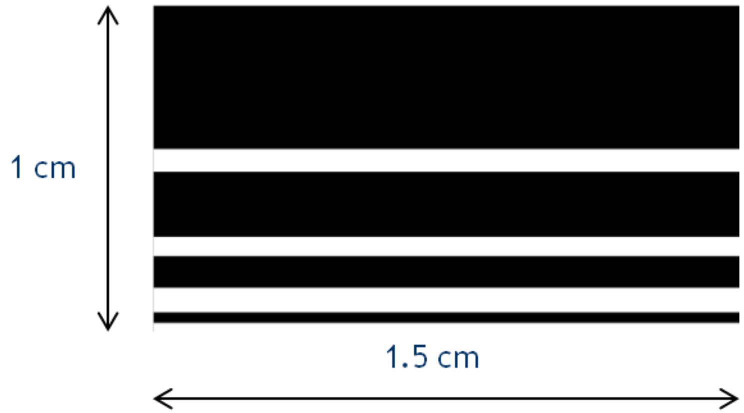


Figure 12 : Fitted image used for inkjetprinting; the black part indicates the polymer while the white indicated spacing (no polymer)

PS-b-PEO inkjetprinted films are shown on picture 13, nanopatterns are formed over very large area. PS-b-PEO can be injekprinted on glass/ silicon substrates as well as on polymer substrates such as polyimide or polyester.

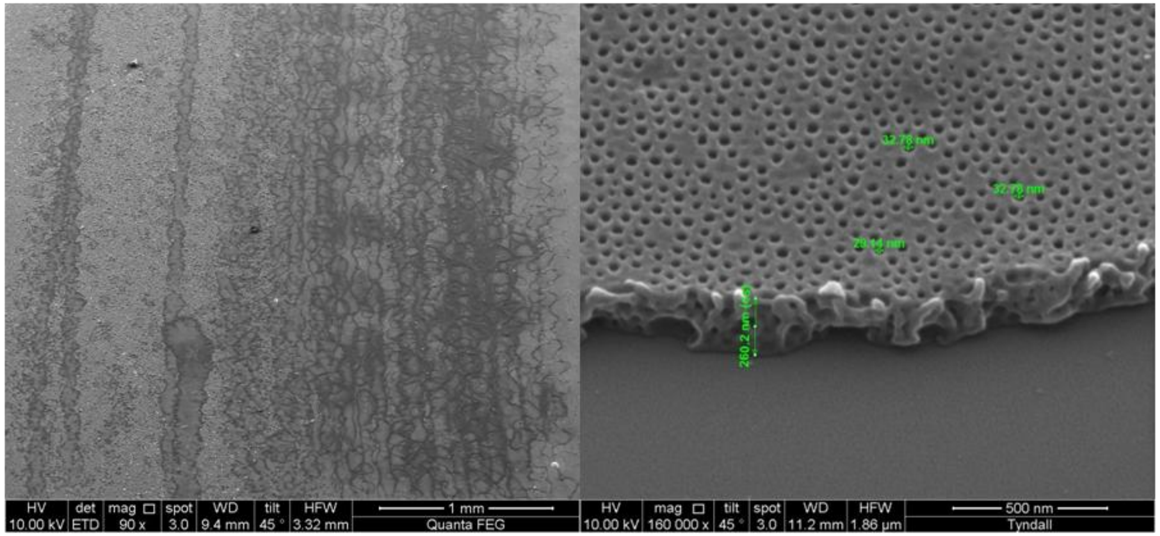


Figure 13 : PS-b-PEO inkjetprinted films 1wt% THF, on silicon substrates (2cm x 3 cm), film thickness = 260 nm, after solvent annealing with toluene at 50 ℃ for 1h

These nanostructured surfaces display superhydrophobicity that could be used as olephobic surfaces for use in touch screens on phones and tablets (thus keeping them grease free). Additional IP protection will be required, and an extension of patent on nanodots to coated methodology developped by KAN could be envisaged. Optimization of these coating method would be needed and inclusion of metal oxide will be investigated. UCC-TNI contributed to the BCP self assembly work while Kanichi contributed to the coating methodologies. UCC-TNI is the sole owner of patent on nanodots and is seeking to licence it to a companies involved in glass coating. Patent on nanodots n° PCT/EP2012/072935 (11189329-2222) received Enterprise Ireland Feasibility Funding (15k) to do a market survey, opportunity and route to market report. UCC-TNI is awaiting for the report. The cost of implementation before exploitation is estimated to be in the region of 300000€, and time to market around 2 to 3 years. UCC-TNI and KAN are expecting license revenues. A source of financing after the project ends would be Commercialisation development grants.

Moreover, Intel is potentially interested in the results on nanodots for a different application. Internal discussions are on-going'. This could be used as a nanopatterning method for creating active nanopatterns for the semiconductor industry.

<u>Exploitable result 2</u> : An antimicrobial foodpackage Patent n° P10939EP00 (UCC-TNI)

This invention provides novel antibacterial 'smart' packaging materials to improve the safety, quality and shelf-life of dairy and meat products. Active antibacterial packaging is produced by incorporation of antimicrobial/antibacterial particles of both inorganic and organic nature into conventional polymers (PVC, PP, PE and PTFE). This invention relates to the maximization of microbial activity of the packaging material whilst allowing minimization of particles needed so that shelf or storage life can be increased without exposure of users to undue toxicological risks. Very briefly, this invention extends previous work by carrying out detailed testing and assay to show:

a) that efficacy (antimicrobial activity) is strongly related to particle size
b) that there are minimal risks to users (consumers) through the addition of these small particles

Patterns developed on the previous patent would be used to create antimicrobial patterned surfaces by the formation of silver oxide nanodots. This could be used in food processing and packaging. The market size could be several tens of million. UCC-TNI is the sole owner of this patent.
The patent n^0 P10939EP00 has been filed, and received Enterprise Ireland Feasibility Funding (15k) to do a market survey, opportunity and route to market report. The study is being carried out by Jeff Brandenburg of the US Food Materials Consultancy Panel. UCC-TNI is awaiting full report soon. It Looks very promising in a number of applications. The cost of implementation before exploitation is estimated to be in the region of 300000€, and time to market around 2 to 3 years. UCC-TNI is expecting license revenues. A source of financing after the project ends would be Commercialisation development grants.

Exploitable result 3 : Image analysis of one- and two- dimensional structures: morphology analysis and order quantification (UCC-TNI/ICN)
The invention proposed consists in a new software devoted to the identification and analysis of block copolymer (BCP) self-assembly nanostructures (2D and 1D features), defectivity and order quantification, by means of two main code applications, which allow extensive defect control of nanostructures, a strong requirement in the semiconductor industry. BCP are emerging as potential rivals to conventional and short wavelength photolithography as a means to create nanodimensioned substrate features, with a potential to reach sub 10 nm structures. The code is capable of identifying circular (Figure 14) and linear features (Figure 15) of microphase segregated block copolymers (with hexagonal and lamellar packing, respectively) and extract features about dimension, regularity, anisotropy, and an extensive analysis of specific defects such as dislocations, disclinations, missing elements and curvature. Additionally, the code is also capable of quantifying order and periodicity of the assembled structures, estimating line widths and line-edge roughness, pivotal parameters for industrial applications. Advantages and improvements of this invention over existing methods/ materials/ devices/current state of the art: this code has been exclusively developed for BCPs, so it is highly specific.

- It is a lighter code compared with existing software applications, so it affords a faster analysis (minutes vs hours).

- Compatible with soft materials.

- Large area analysis and no real size limitation.

- Suitable for cross sample comparison.

- Robust against image contrast and how images we taken.

- Versatible for post-processing.

- Compatible with semiconductor industry standards.

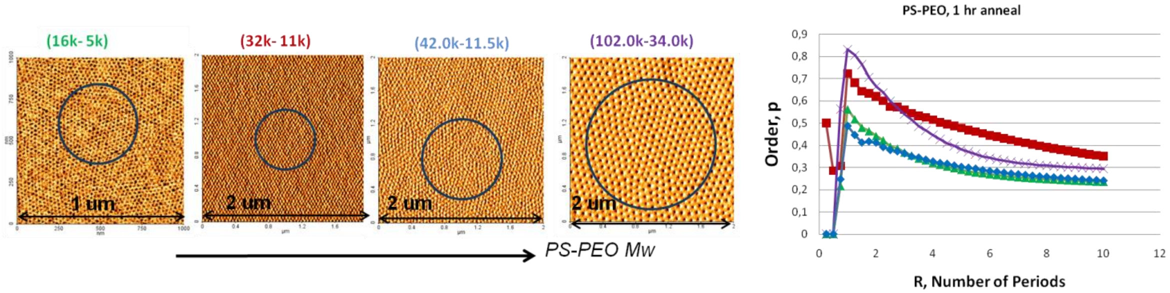


Figure 14. Circular patterns formed from self-assembled block copolymers with four different molecular weights order quantification by AFM images analysis.

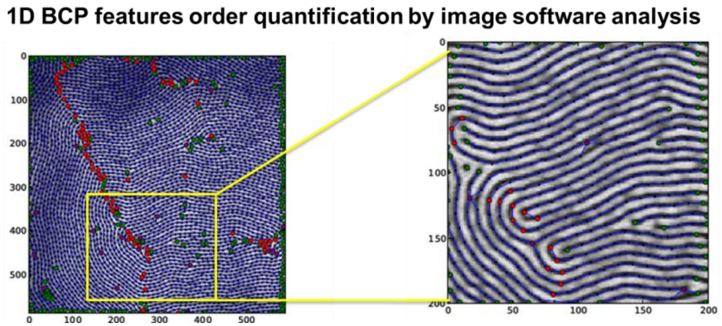


Figure 15. SEM images of linear patterns formed from self-assembled block copolymers: linear elements and defects identification and analysis.

This software image analysis will be presented as a metrology tool which has been especially designed for the analysis and quality control of subnanometric features, thus aimed at the semiconductor industry and other industrial fields related nanofabrication, in which controlling the quality of the materials obtained is essential. UCC-TNI, and ICN/ICREA co-owns this IP. The prototype is in the process of being patented. Once the patent is in place, ICN/UCC-TNI will try to license it to a metrology company. The cost of implementation would be around 5000 €, and time to market would be immediately after the end of the project. A source of financing after the project ends would be through licence agreement or alternatively, under a collaborative project (private-public funding) leading to a subsequent transfer agreement.

<u>Exploitable result 4</u> : In line detection and real time analysis of sub-50 nm size features formation and defectivity on top of micron periodic gratings for block copolymers nanopatterns and/or nanogratings (ICN).

ICN has applied subwavelentgh diffraction to detect the formation process of sub-50 nm features over gratings with periodicities in the range of microns to tens of microns. The apparatus has compactness, ease of operation and integrable with any production line. It provides sensitivity to ratio changes below 1 percent and has a cycle of operation (measurement and analysis) below the second, what allows *in situ* measurement of the transitions undergone in the self-assembly of block copolymer for semiconductor lithographic masks, or made from conventional semiconductor fabrication techniques.

Sub-wavelength diffraction, the technique that we have implemented for this duty (in situ sensitiveness to sub-50 nm feature changes) is contactless, non-destructive and fast, characteristics that allow its addition to industrial or experimental environments as a continuous process check tool. The prototype has been used to monitor cylindrical and lamellae self-assembled structures over conventional blazed gratings.

The landmark is to be able to characterize complex 3D structures with features below 50 nm in all three spatial directions. The apparatus provides data for a rapid analysis that allows real time measurements of ordering, identification of the supra-structures assembled and validation of the fidelity of the process.

The resolution limit of any optical measurement is set by diffraction to half the wavelength of the light used. In our case with the wavelength used set in the visible range (400-650 nm), sub 50nm features seem out of our scope. However, in particular cases the sub-50 nm features lay on top of gratings with periods of 1 to 10 μm. These micron-period gratings do diffract the visible light. The sub-wavelength diffraction technique consists in a careful characterization of the intensity of the diffracted orders and allows tracking back the changes in the diffractogram to the sub 50 nm scale.

A good example is Direct Self Assembly (DSA) of Block Copolymers over nanoimprinted trenches (graphoepitaxy). The trenches guide the self-assembly and lead to ordering the supra-structures generated after the block copolimers dissociation. The trenches form the grating with 1 to 10 μm period that we need.

In the past, Sub-wavelength diffraction has been used as an ex situ metrology tool. Several factors prevented its inline implementation:

- The collection of the angle dispersed light into an automated collection system, i.e. a CCD camera.

- The light that illuminates the zone of interest must be a plane-wave, as the diffraction pattern is critically affected by the angle accuracy of the excitation.
- The spot size should be in the range of hundreds of microns, to integrate several grating periods but keeping the lateral spatial resolution high.
- The laser that provides the light must be compact and compatible with an industrial environment.

In the following, we describe the implementation of the apparatus that solves the restrictions commented.

The setup is shown in figure 16 and starts with an achromatic fiber collimator on top of it. The collimated beam has a gaussian shape and a waist of 4 mm. The counterpart of the gaussian beam approach is the space left to work with a collimated beam: the Rayleigh zone. The smaller is the beam waist the shorter is the space the beam propagates without meaningful divergence. For a 135 um waist, this distance is reduced to few cms.

We use the last lens of the beam expander as collector, this lens is chosen to have a big numerical aperture, and determines the highest angle of collection.

The system is complete with two cameras and the appropriate optics to image simultaneously in one camera the sample (inspection) and in the other the far field (diffractogram). A 12 bit depth is chosen for the far field camera.

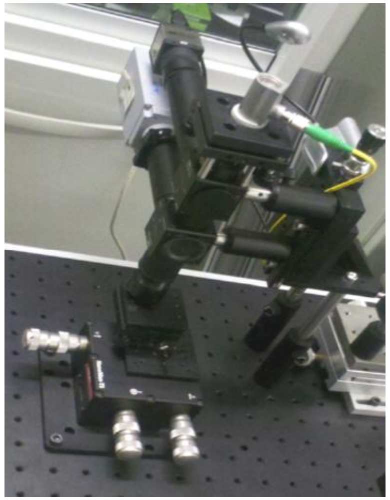


Figure 16 Online Sub-wavelength diffraction setup

This technique will be used as a metrology tool to study BCP self-assembled structures, thus aimed at the semiconductor industry and other industrial fields related nanofabrication. ICN/ICREA are the sole owner of this IP. The prototype is in the process of being patented. Once the patent is in place, ICN/ICREA will try to license it to a metrology company. The cost of implementation would be around 15000 €, and time to market would be immediately after the end of the project. A source of financing after the project ends would be through licence agreement or alternatively, under a collaborative project (private-public funding) leading to a subsequent transfer agreement.

<u>Exploitable result 5 </u>: Provision of a material-based and a process technology-based process for nano-patterning at 22nm (UCC-TNI)

The invention under study consists of a technology based process for nano-patterning at 22nm that allows the creation of uniform active nanopatterns that are equally spaced and periodically ordered on silicon substrates, over a large area. Parallel lines and hexagonally packed nanopillars of active material can be obtained with easily tunable feature size. The process is based on the use of block copolymers (BCPs) that display the capability of self-assembling into ordered nanostructures, and that are used as a template to create active nanostructures. It consist of 3 main steps (see schematic Figure 17) :

1) Development of patterned substrates (Intel, LTM, ICN)
2) BCP deposition/direct self-assembly (DSA) (UCC-TNI, LTM, ICN)
3) Active nanopatterns formation via 3 different methods (UCC-TNI, LTM)

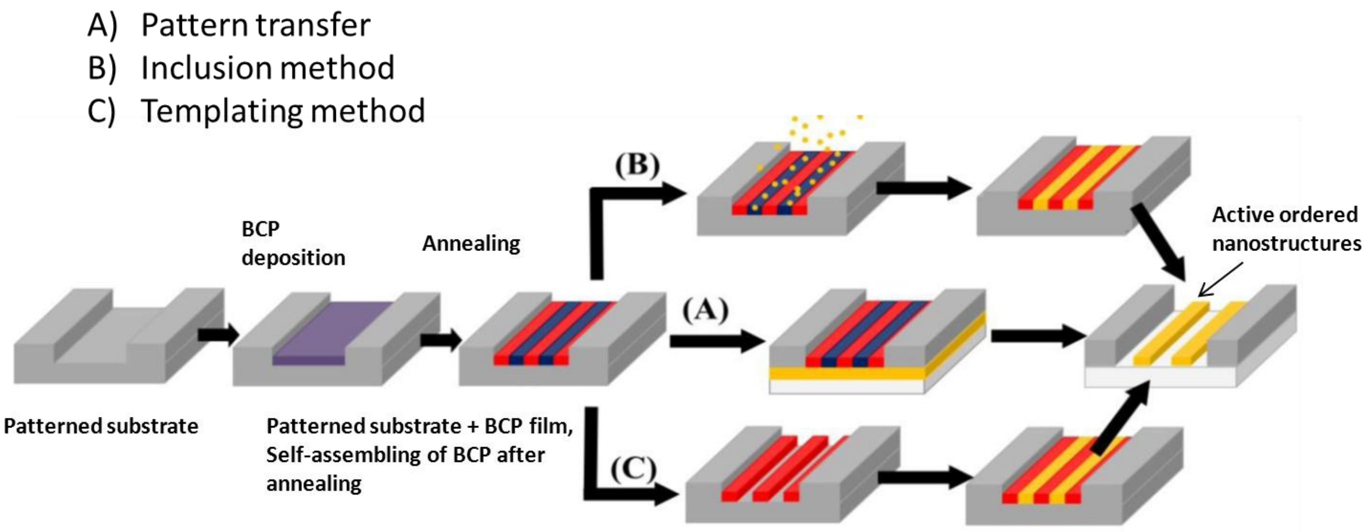


Figure 17 : Process flow of ordered active nanostructures using direct self-assembly of BCPs : A) Pattern transfer, B) Inclusion method, C) Templating method

Example of nanostructures obtained via pattern transfer :

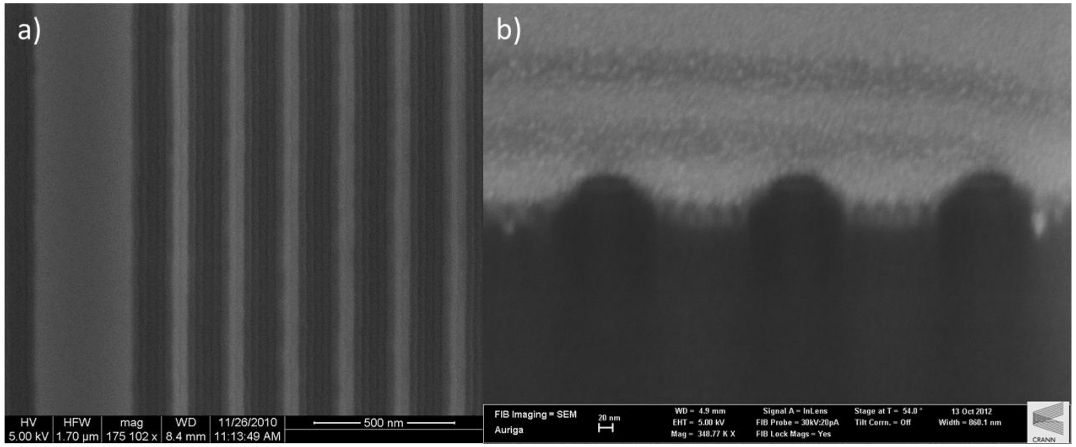


Figure 18 : Parallel silicon nanowires on Si_3N_4 patterned substrates, using PS-b-PMMA(18k-18k)

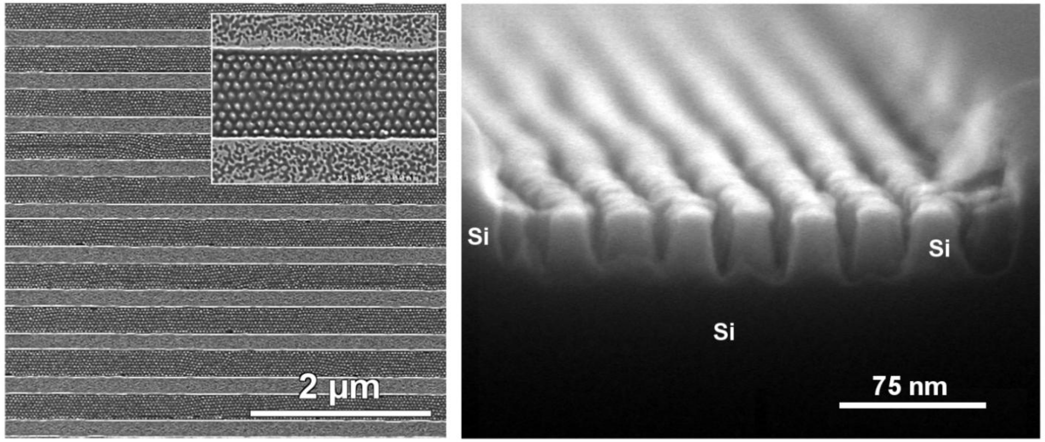


Figure 19 : Silicon nanopillars within 6E2F-POSS resist lines, using PS-b-PDMS (31k-11k)

This process can provide highly ordered active nanopatterns for the semiconductor industry, and small electronic device companies. DSA is a simple and cost effective method that offers an alternative to current lithography used in the semiconductor industry. Moreover it has the potential to be integrated in existing facilities. The product foreseen are aligned active nanowires (10-30 nm in width) on a substrate for production of transitors for the ICT sector. UCC-TNI, ICN, LTM, PRO, UOI co-owns this IP. ICN and LTM contribute to development of patterned substrates for know-how, patents. UCC-TNI , LTM, ICN for BCP nano-patterning/etching for know-how, patents, PRO supplied the POSS materials and UOI the BCP material. No patent is envisaged, but the consortium could try to license the know-how to a company from the semiconductor industry such as Global foundaries. Intel has shown no interest in this IP as their 22nm technology is already in production. There might be a need to reformulate this IP, as it did not get a great feedback from partners.

<u>Exploitable result 6</u> : Desk top multipurpose nano-imprint lithography module (ICN)

The desktop multipurpose nano-imprint lithography module is an artefact capable of nanoimprinting a thin polymer film. The module operates in three different modes, depending on the type of polymer to be processed: thermal, UV and solvent vapours assisted NIL,as descibed in Figure 20.

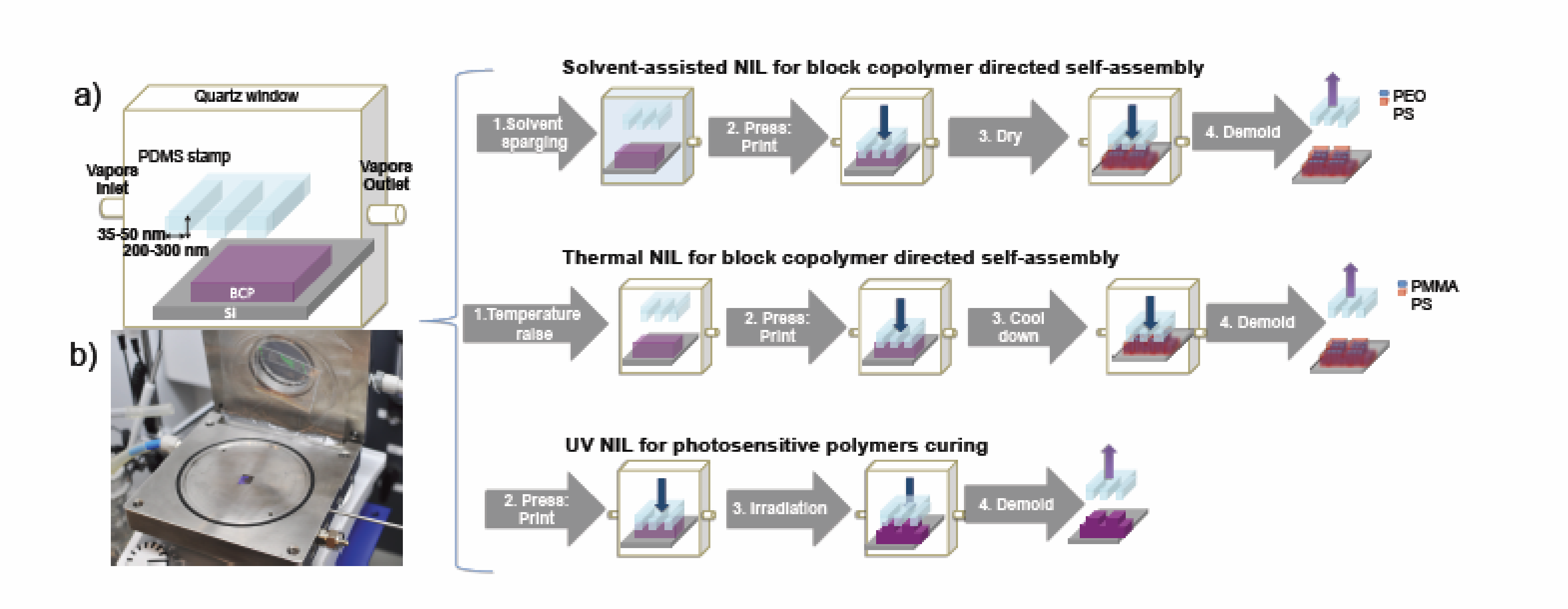


Figure 20. a) Process flow of nanofabrication using the desktop multipurpose nanoimprint lithography module nanostructures using direct self-assembly of BCPs to achieve sub 20 nm sized features in three operation modes: solvent vapours assisted, thermal and UV NIL.. b) Image of the module prototype in the ICN laboratories.

The prototype takes 4" wafers samples altough with a larger prototype samples can be bigger. The technique is not dependent on the size of the sample, due to the usage of PDMS stamp and a homogeneus polymer fluidization by a continous flow in the SVA mode and an all steel body with homogeneous heating (in thermal mode). The imprint process takes overall one hour and with the solvent vapors assisted NIL mode, low molecular weight block copolymers have been imprinted and their segregation returned features on the sub 20 nm.

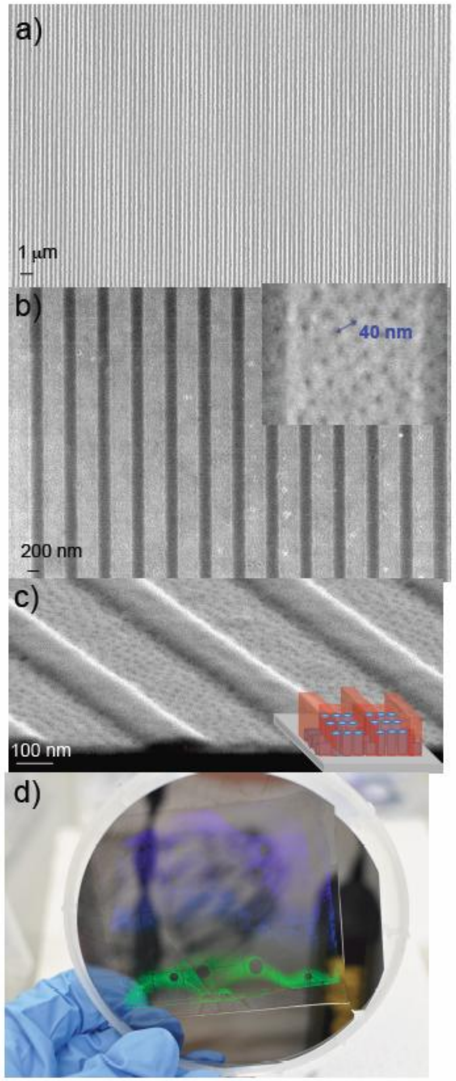


Figure 21. Sem images of the block copolymer PS-PEO 42-11 imprinted in the solvent vapors assisted NIL mode (a,b,c) shows high resolution registry of the replica of the stamp lines. Microphase segregation of the BCP originates 20 nm cylinders of PEO in a PS matrix with high ordering. d) Image of the 4" wafer imprinted.

This NIL module will be presented as a fabrication tool which has been especially designed for the fabrication of sub- 20 nm fabrication structures via BCP self-assembly integrated with conventional silicon lithography. Thus it is aimed at the semiconductor industry and other industrial fields realated to nanofabrication, in which reducing costs of fabrication of periodic structures is required. ICN/ICREA are the sole owner this IP. Pattenting this prototype is under consideration. If patented, efforts will be made towards various exploitation strategies such as licence agreement, technology transfer, publications. The cost of implementation before exploitation would be 10000 €, and the foreseen product price would be 20000€, potential customers are mainly universities and research institutions.

Exploitable result 7 : Large scale production of POSS (polysilsesquioxane) resists (PRO)
PRO has the capability of producing at lab scale multifunctional POSS material (see figure 22, chemical formula) adapted to the requirement of the customer (functional groups, layer thickness, hydrophobicity..).

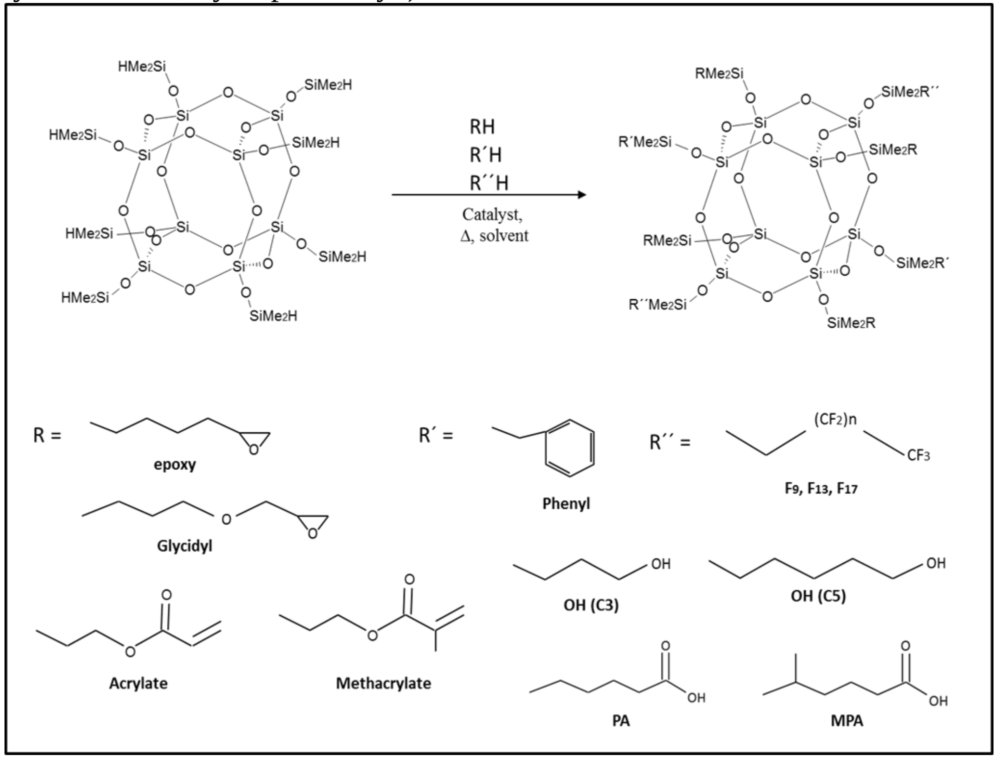


Figure 22 : Synthesis of POSS material with various functional groups, that provides various properties, e.g : Epoxy, glycidyl, acrylate, methacrylate are used as UV curable ligands, Phenyl for material toughness and patternability, Fluoro groups for low SFE (easy demolding), OH : groups for brush grafting, Pentenoic acid as ionic stamps.

There is a growing demand from the electronic industry for POSS resists, and multifunctional materials. Therefore PRO is seeking a company that would be able to produce POSS materials on a large scale. Patents exists on POSS precursor materials (Hybrid Plastics), but not on POSS resists. PRO is the sole owner of this IP. PRO is producing the POSS resists, and ICN, UCC-TNI and LTM are testing them. License agreement are envisaged with Microresist Technology GmbH. The foreseen price of these products at lab scale are 350 to 500€ for 100 ml at lab scale and 150 to 200€ for 100 ml at large scale. The source of financing foreseen after the project could be a bilateral collaboration with Microresists Technology GmbH, or could come from national funded projects.

As a conclusion, the LAMAND project has generated a number of IPRs. All of them were circulated to the industrial partners, PRO and KAN are not interested in commercializing them, however Intel may be interested in exploitable results on nanodots. Internal discussions are ongoing. 4 patents will be filed by the end of the project. IP owners are all interested in license agreement with either LAMAND industrial partners or other industrial partners.

4.3 Report on societal implications

Replies to the following questions will assist the Commission to obtain statistics and indicators on societal and socio-economic issues addressed by projects. The questions are arranged in a number of key themes. As well as producing certain statistics, the replies will also help identify those projects that have shown a real engagement with wider societal issues, and thereby identify interesting approaches to these issues and best practices. The replies for individual projects will not be made public.

A General Information *(completed automatically when **Grant Agreement number** is entered.*	
Grant Agreement Number:	245565
Title of Project:	LAMAND
Name and Title of Coordinator:	Prof. Michael Anthony Morris

B Ethics	
1. Did your project undergo an Ethics Review (and/or Screening)? • If Yes: have you described the progress of compliance with the relevant Ethics Review/Screening Requirements in the frame of the periodic/final project reports? Special Reminder: the progress of compliance with the Ethics Review/Screening Requirements should be described in the Period/Final Project Reports under the Section 3.2.2 *'Work Progress and Achievements'*	***No***
2. Please indicate whether your project involved any of the following issues (tick box) :	***No***
RESEARCH ON HUMANS	
• Did the project involve children?	No
• Did the project involve patients?	No
• Did the project involve persons not able to give consent?	No
• Did the project involve adult healthy volunteers?	No
• Did the project involve Human genetic material?	No
• Did the project involve Human biological samples?	No
• Did the project involve Human data collection?	No
RESEARCH ON HUMAN EMBRYO/FOETUS	
• Did the project involve Human Embryos?	No
• Did the project involve Human Foetal Tissue / Cells?	No
• Did the project involve Human Embryonic Stem Cells (hESCs)?	No
• Did the project on human Embryonic Stem Cells involve cells in culture?	No
• Did the project on human Embryonic Stem Cells involve the derivation of cells from Embryos?	No
PRIVACY	
• Did the project involve processing of genetic information or personal data (eg. health, sexual lifestyle, ethnicity, political opinion, religious or philosophical conviction)?	No
• Did the project involve tracking the location or observation of people?	No
RESEARCH ON ANIMALS	
• Did the project involve research on animals?	No
• Were those animals transgenic small laboratory animals?	No
• Were those animals transgenic farm animals?	No

• Were those animals cloned farm animals?	No
• Were those animals non-human primates?	No
RESEARCH INVOLVING DEVELOPING COUNTRIES	
• Did the project involve the use of local resources (genetic, animal, plant etc)?	**No**
• Was the project of benefit to local community (capacity building, access to healthcare, education etc)?	**No**
DUAL USE	
• Research having direct military use	No
• Research having the potential for terrorist abuse	No

C Workforce Statistics

3. Workforce statistics for the project: Please indicate in the table below the number of people who worked on the project (on a headcount basis).

Type of Position	Number of Women	Number of Men
Scientific Coordinator		1
Work package leaders	2	5
Experienced researchers (i.e. PhD holders)	6	24
PhD Students		3
Other	7	6

4. How many additional researchers (in companies and universities) were recruited specifically for this project?	
Of which, indicate the number of men:	

D Gender Aspects

5. Did you carry out specific Gender Equality Actions under the project?	○ X	Yes No

6. Which of the following actions did you carry out and how effective were they?

	Not at all effective				Very effective
❑ Design and implement an equal opportunity policy	○	○	○	○	○
❑ Set targets to achieve a gender balance in the workforce	○	○	○	○	○
❑ Organise conferences and workshops on gender	○	○	○	○	○
❑ Actions to improve work-life balance	○	○	○	○	○

○ Other:

7. Was there a gender dimension associated with the research content – i.e. wherever people were the focus of the research as, for example, consumers, users, patients or in trials, was the issue of gender considered and addressed?

○ Yes- please specify

X No

E Synergies with Science Education

8. Did your project involve working with students and/or school pupils (e.g. open days, participation in science festivals and events, prizes/competitions or joint projects)?

○ Yes- please specify

X No

9. Did the project generate any science education material (e.g. kits, websites, explanatory booklets, DVDs)?

○ Yes- please specify

X No

F Interdisciplinarity

10. Which disciplines (see list below) are involved in your project?

○ Main discipline[9]: Chemical sciences

○ Associated discipline[9]: Engineering and technology

○ Associated discipline[9]: Other engineering, sciences

G Engaging with Civil society and policy makers

11a Did your project engage with societal actors beyond the research community? *(if 'No', go to Question 14)*	○ X	Yes No

11b If yes, did you engage with citizens (citizens' panels / juries) or organised civil society (NGOs, patients' groups etc.)?

○ No

○ Yes- in determining what research should be performed

○ Yes - in implementing the research

○ Yes, in communicating /disseminating / using the results of the project

[9] Insert number from list below (Frascati Manual).

11c	**In doing so, did your project involve actors whose role is mainly to organise the dialogue with citizens and organised civil society (e.g. professional mediator; communication company, science museums)?**	○ ○	Yes No

12. Did you engage with government / public bodies or policy makers (including international organisations)

- ○ No
- ○ Yes- in framing the research agenda
- ○ Yes - in implementing the research agenda
- ○ Yes, in communicating /disseminating / using the results of the project

13a Will the project generate outputs (expertise or scientific advice) which could be used by policy makers?

- ○ Yes – as a **primary** objective (please indicate areas below- multiple answers possible)
- ○ Yes – as a **secondary** objective (please indicate areas below - multiple answer possible)
- ○ No

13b If Yes, in which fields? Consumers, enterprise, research and innovation

Agriculture Audiovisual and Media Budget Competition Consumers Culture Customs Development Economic and Monetary Affairs Education, Training, Youth Employment and Social Affairs		Energy Enlargement Enterprise Environment External Relations External Trade Fisheries and Maritime Affairs Food Safety Foreign and Security Policy Fraud Humanitarian aid		Human rights Information Society Institutional affairs Internal Market Justice, freedom and security Public Health Regional Policy Research and Innovation Space Taxation Transport	

13c If Yes, at which level?

- ○ Local / regional levels
- ○ National level
- ○ European level
- ○ International level

H Use and dissemination

14. How many Articles were published/accepted for publication in peer-reviewed journals?	**21**
To how many of these is open access[10] provided?	**1**
How many of these are published in open access journals?	**1**
How many of these are published in open repositories?	**0**
To how many of these is open access not provided?	**20**
Please check all applicable reasons for not providing open access:	
✓ publisher's licensing agreement would not permit publishing in a repository ❑ no suitable repository available ✓ no suitable open access journal available ❑ no funds available to publish in an open access journal ✓ lack of time and resources ✓ X lack of information on open access ❑ other[11]: ……………	

15. How many new patent applications ('priority filings') have been made? *("Technologically unique": multiple applications for the same invention in different jurisdictions should be counted as just one application of grant).*	**4**

16. Indicate how many of the following Intellectual Property Rights were applied for (give number in each box).	Trademark	
	Registered design	
	Other	

17. How many spin-off companies were created / are planned as a direct result of the project?	**0**
Indicate the approximate number of additional jobs in these companies:	

18. Please indicate whether your project has a potential impact on employment, in comparison with the situation before your project:

❑ Increase in employment, or	❑ In small & medium-sized enterprises
❑ Safeguard employment, or	❑ In large companies
❑ Decrease in employment,	❑ None of the above / not relevant to the project
✓ Difficult to estimate / not possible to quantify	

19. For your project partnership please estimate the employment effect resulting directly from your participation in Full Time Equivalent (*FTE = one person working fulltime for a year*) jobs:	*Indicate figure:*

[10] Open Access is defined as free of charge access for anyone via Internet.

[11] For instance: classification for security project.

Difficult to estimate / not possible to quantify	✓ ❑

I Media and Communication to the general public

20. As part of the project, were any of the beneficiaries professionals in communication or media relations?

○ Yes X No

21. As part of the project, have any beneficiaries received professional media / communication training / advice to improve communication with the general public?

○ Yes X No

22 Which of the following have been used to communicate information about your project to the general public, or have resulted from your project?

❑	Press Release	X	Coverage in specialist press
❑	Media briefing	❑	Coverage in general (non-specialist) press
❑	TV coverage / report	❑	Coverage in national press
❑	Radio coverage / report	❑	Coverage in international press
X	Brochures /posters / flyers	❑	Website for the general public / internet
❑	DVD /Film /Multimedia	❑	Event targeting general public (festival, conference, exhibition, science café)

23 In which languages are the information products for the general public produced?

❑	Language of the coordinator	X	English
❑	Other language(s)		

***Question F-10*:** Classification of Scientific Disciplines according to the Frascati Manual 2002 (Proposed Standard Practice for Surveys on Research and Experimental Development, OECD 2002):

FIELDS OF SCIENCE AND TECHNOLOGY

1. NATURAL SCIENCES
1.1 Mathematics and computer sciences [mathematics and other allied fields: computer sciences and other allied subjects (software development only; hardware development should be classified in the engineering fields)]
1.2 Physical sciences (astronomy and space sciences, physics and other allied subjects)
1.3 Chemical sciences (chemistry, other allied subjects)
1.4 Earth and related environmental sciences (geology, geophysics, mineralogy, physical geography and other geosciences, meteorology and other atmospheric sciences including climatic research, oceanography, vulcanology, palaeoecology, other allied sciences)
1.5 Biological sciences (biology, botany, bacteriology, microbiology, zoology, entomology, genetics, biochemistry, biophysics, other allied sciences, excluding clinical and veterinary sciences)

2 ENGINEERING AND TECHNOLOGY
2.1 Civil engineering (architecture engineering, building science and engineering, construction engineering, municipal and structural engineering and other allied subjects)
2.2 Electrical engineering, electronics [electrical engineering, electronics, communication engineering and systems, computer engineering (hardware only) and other allied subjects]
2.3. Other engineering sciences (such as chemical, aeronautical and space, mechanical, metallurgical and materials engineering, and their specialised subdivisions; forest products; applied sciences such as

geodesy, industrial chemistry, etc.; the science and technology of food production; specialised technologies of interdisciplinary fields, e.g. systems analysis, metallurgy, mining, textile technology and other applied subjects)

3. MEDICAL SCIENCES

3.1 Basic medicine (anatomy, cytology, physiology, genetics, pharmacy, pharmacology, toxicology, immunology and immunohaematology, clinical chemistry, clinical microbiology, pathology)

3.2 Clinical medicine (anaesthesiology, paediatrics, obstetrics and gynaecology, internal medicine, surgery, dentistry, neurology, psychiatry, radiology, therapeutics, otorhinolaryngology, ophthalmology)

3.3 Health sciences (public health services, social medicine, hygiene, nursing, epidemiology)

4. AGRICULTURAL SCIENCES

4.1 Agriculture, forestry, fisheries and allied sciences (agronomy, animal husbandry, fisheries, forestry, horticulture, other allied subjects)

4.2 Veterinary medicine

5. SOCIAL SCIENCES

5.1 Psychology

5.2 Economics

5.3 Educational sciences (education and training and other allied subjects)

5.4 Other social sciences [anthropology (social and cultural) and ethnology, demography, geography (human, economic and social), town and country planning, management, law, linguistics, political sciences, sociology, organisation and methods, miscellaneous social sciences and interdisciplinary , methodological and historical S1T activities relating to subjects in this group. Physical anthropology, physical geography and psychophysiology should normally be classified with the natural sciences].

6. HUMANITIES

6.1 History (history, prehistory and history, together with auxiliary historical disciplines such as archaeology, numismatics, palaeography, genealogy, etc.)

6.2 Languages and literature (ancient and modern)

6.3 Other humanities [philosophy (including the history of science and technology) arts, history of art, art criticism, painting, sculpture, musicology, dramatic art excluding artistic "research" of any kind, religion, theology, other fields and subjects pertaining to the humanities, methodological, historical and other S1T activities relating to the subjects in this group]

2. FINAL REPORT ON THE DISTRIBUTION OF THE EUROPEAN UNION FINANCIAL CONTRIBUTION

This report shall be submitted to the Commission within 30 days after receipt of the final payment of the European Union financial contribution.

Report on the distribution of the European Union financial contribution between beneficiaries

Name of beneficiary	Final amount of EU contribution per beneficiary in Euros
1.	
2.	
n	
Total	