PROJECT FINAL REPORT

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Project acronym: NAPANIL

Project title: Nanopatterning, Production and Applications based on Nanoimprinting Lithography

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Period covered: from 1 May 2008 to 30 April 2012

Name of the scientific representative of the project's co-ordinator[1], Title and Organisation:

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Contents

Executive summary

NaPANIL (Nanopatterning, Production and Applications based on Nanoimprinting Lithography) is a large scale collaborative project in FP7 focussing on development of manufacturing processes based on nanoimprinting. Altogether 19 groups have participated the NaPANIL consortium, with the total project volume of 15.9 M€ of which the EC grant covers 11.8 M€. The four year project started in May 2008 and finished in April 2012.

The concept of the project is to realise three industrial demonstrators as manufacturing technology drivers of (a) the 3-dimensional nanopatterning manufacturing technologies, (b) the design, simulation and metrology aspects of these technologies and (c) the next wave of innovation in these and related applications, based on these processes. The three industrial demonstrators are Planar Diffractive Optical Element, Light Re-Directional Element and Emissive Head-Up Display, and the common property of all the three is controlling light at nanostructured surfaces. The project has focused to develop materials, processes and simulation tools to fulfil the requirements of the demonstrators and their fabrication processes. In addition, the potential to exploit the technology for the next generation sensor and biomedical applications has been investigated.

The main achievements include the first validation of production value chain for nanoimprinting by manufacturing and characterising more than 1000 pcs of diffractive optical back-light elements, validation of the flexible emissive head-up display demonstrator for automotive applications and demonstration of day-lighting effect on a window pane, thus fulfilling the goals set by the end-users. Other important outcomes from the project are the new dedicated materials for nanoimprinting, novel processes to realise true 3-dimensional surfaces not available before and process simulation software. 21 exploitable results were identified with TRL level ranging from 3 to 9. The project produced 13 patents and other foreground that is handled as trade secrets. Some of the results are already commercialised, while some are still looking for the route for exploitation. NaPANIL produced 38 peer reviewed articles and 123 conference contributions.

Specific efforts were used to disseminate the results. Two NaPANIL Industrial Days were organised in April 2011 and February 2012 in Berlin. About 80 people from industry and academia attended the both events with very positive reception. To address more the academia, a NIL Session was arranged within the SPIE Photonics Europe meeting in April 2012 in Brussels. NaPANIL had also a booth in the Innovation Village to disseminate with hands-on examples the results of the project. In addition, NaPANIL has produced 31 press releases and flyers, a video "**Nano Foil Brightens Screen"** (www.yourismediacenter.com, can be found also in YouTube), and a "Library of Processes" containing "recipes" for a wide variety of NIL processes and applications.

Project context and main objectives

The concept of the project is based on identified application fields with very high potential impact but with no mature production processes developed yet. A large number of the partners involved in this project took part in the European project NaPa – Emerging Nanopatterning Methods[2,3], which was an Integrated Project focussing on new nanopatterning methods with the largest sub-project concentrating on nanoimprinting lithography (NIL). Thus, NaPANIL partners have readily identified potential target applications for large-scale implementation and up-scaling to industrial production of tools, materials, processes and know-how developed in the field of nanoimprinting lithography.

To test the applicability of nanoimprinting in production, three industrially relevant applications were chosen as test vehicles. The three industrial demonstrators are **Planar Diffractive Optical Element**, **Light Re-Directional Element** and **Emissive Head-Up Display,** representing mobile, housing and automotive fields, all relevant for European industry. The applications chosen are based on the idea of controlling light at surfaces using nanoscale 3-dimensional surface structures. At the moment there is no efficient production method available for this kind of surfaces and the aim in this project was to develop and qualify processes that can produce such surfaces in small scale production environments. The focus of this project was driven by our end-user partners, originally on applications with surface areas in the range from a few mm to tens of cm. The project philosophy follows the 5-gated approach for technology implementation. The NaPANIL value chain is shown in Figure 1 below.

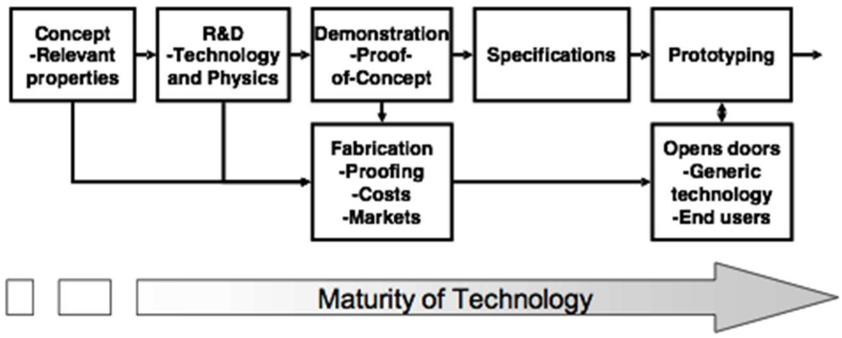

Figure 1. The value chain of the NaPANIL proposal. The chain extends from the concept, here controlling light at surfaces, via R&D step to demonstrating the proof-of-concept, checking the specifications followed by prototyping. To make this possible the manufacturing and qualification processes must be developed. When the technology is mature enough, it will be made available to other end-users outside the consortium

The applications contain generic aspects that can be regarded as common to the whole nanopatterning R&D field. The patterns utilised in these applications are truly 3-dimensional, ranging from 50 nm feature size up to several micrometres. The whole range of such feature sizes are combined at the same surface location, providing a great challenge to the fabrication processes. The patterns can be created in an efficient manner using different nanoimprinting approaches: Step&Stamp, large area parallel, thermal, UV, soft UV or roll-to-roll approaches.

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2 Integrated Project in FP6 (2004-2008), www.napaip.org
3 NaPa was selected as one of the Success Stories in FP6

The common feature here is that the fabrication and the subsequent duplication of the master stamp is crucial. Replicas are created in hard and in soft surfaces. The former requires dry or wet etching steps after nanoimprinting, while in the latter case the patterns can be directly moulded using imprinting. Technologies such as sol-gel, plasma treatments, atomic layer deposition, among others, will be used to complement the standard techniques. In addition to these well specified devices, development of exploratory processes for applications that are at in embryonic state but have potentially high impact, together with their manufacturing processes, have been carried out in the project. These include, in addition to advanced optical surfaces, applications in the fields of bioscience and health care.

Thus, the concept of the project was to realise three industrial demonstrators as manufacturing technology drivers of (a) the 3D nanopatterning manufacturing technologies needed to bring them to the market, (b) the design, simulation and metrology aspects of these technologies and (c) the next wave of innovation in these and related applications, based on these processes. The latter is crucial to consolidate the leadership in the market of adaptive optics in the medium and long term, having harnessed the current and near-term innovations in 3D surface nanostructuring. More specifically, the aim was to develop up-scalable manufacturing processes for master stamps and up-scaled replication processes for working stamps. The lack of masters and corresponding working stamps form the main bottle-neck to exploiting in production the novel nanopatterning methods based on nanoimprinting. The three industrial demonstrators, Planar Diffractive Optical element, Light Re-Directional Element and Emissive Head-Up Display are shown in the Figure 2.

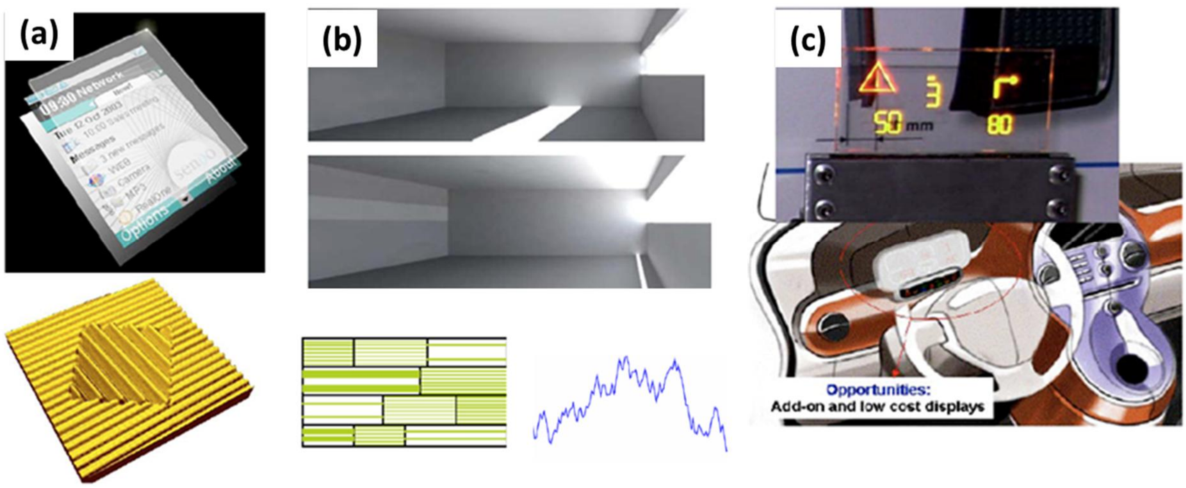

Figure 2. The three industrial demonstrators of the NaPANIL project. (a) Planar diffractive waveguide for backlight and frontlight applications. (b) Light re-directional elements for efficient day-lighting. (c) Emissive head-up display for cars and other vehicles.

To achieve the goals, the work was divided into four sub-projects to make the use of resources and the interaction between the different parts of the value chain most effective. The project structure is shown in Figure 3. The demonstrators form their own sub-project Applications&Demonstrators with supporting sub-projects Modelling&Metrology and Manufacturing Technologies. The former focussed on developing simulation tools for nanoimprinting, especially for true 3-dimensional structures and on developing metrology tools for complicated surfaces and structures with the residual layer remaining. The latter was developing the required materials, stamps and processes for the qualification of the demonstrators and their production. To investigate the potential of nanoimprinting technology developed in NaPANIL for emerging applications, the sub-project Research into Exploratory was established. This sub-project looked into the next-generation reconfigurable optical surfaces and sensor and bio applications.

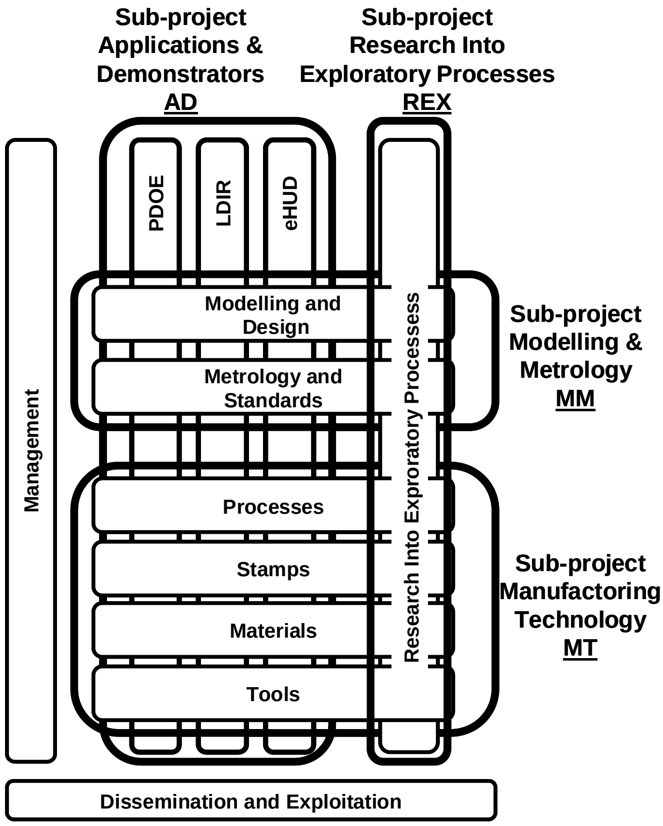

Figure 3. Structure of the NaPANIL project. The project consisted of four sub-projects and the supporting Management and Dissemination and Exploitation workpackages. The sub-projects Modelling&Metrology (MM) and Manufacturing Technology (MT) supported the qualification of the Demonstrators (AD) and the emerging applications (REX).

Main S/T results and foreground

In the following the main results of the NaPANIL project are given per sub-project, starting from the Applications&Demonstrators, followed by Modelling&Metrology and Manufacturing Technology. Finally, the results on next generation applications realised in Research into Exploratory Processes will be described. The list of results below is by no means exhaustive. The project produced large amount of knowhow which is described in more detail in the NaPANIL Library of Processes.[4]

Sub-project Applications&Demonstrators

In AD sub-project one of the main outcome was the demonstration of pilot production of light-guide devices by Roll-to-Roll nanoimprinting.[5] More than one thousand light-guides were imprinted and characterised. The important result was that all the devices were of commercial quality, proving that even with a lab-scale system small scale production id possible. The results of the piloting experiment are shown in Figure 1. The depth of the diffractive grating was measured by confocal microscopy and showed some variation of the imprinted depth among the samples. This scatter partially arises from the small bending of the waveguides during the measurements.

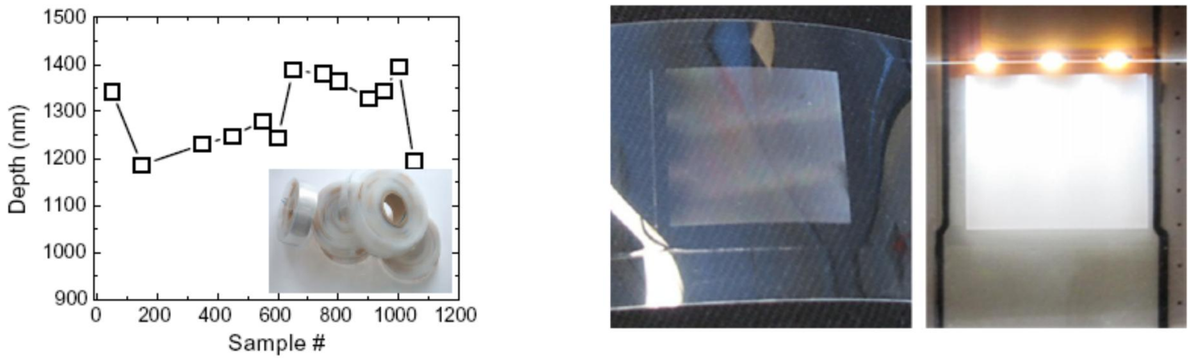

Figure 1. Pilot production of back-light waveguides by Roll-toRoll nanoimprinting. More than one thousand devices were produced and all of them had quality high enough for commercial use. The depth of the imprinted diffractive patterns was measured by confocal microscopy. The optical properties were tested in a test bench for backlight devices.

The light re-directional element for day-lighting applications is extremely demanding because human eye is very sensitive to variations and defects, setting high demands to the quality of gratings to be integrated into building window panes. Here the challenge is to operate with glass panes of the size of square metres, glass being hard and fragile and the human eye being very sensitive. The aim in NaPANIL was to realise a re-directional element of size of 10 by 10 centimetres on glass to proof the concept. This was eventually possible by optimising the step&stamp NIL process to make a large area mold for soft stamps from the original master and using the soft stamp to transfer the pattern onto a glass pane. An example of a final demonstrator pane is shown in Figure 2.

[4] www.napanil.org

[5] T. Mäkelä, T. Haatainen, Roll-to-roll pilot nanoimprinting process for backlight devices, Microelectronic Engineering, 2012.

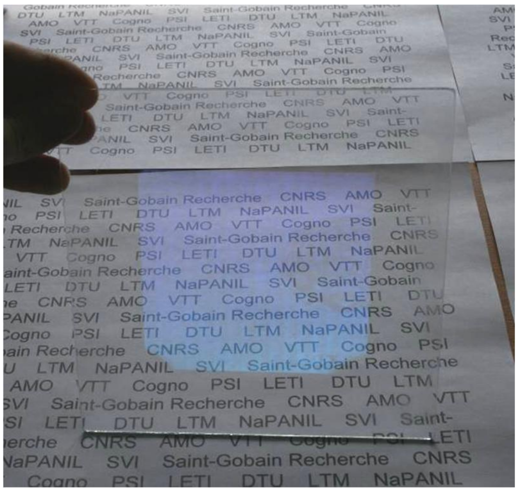

Figure 2. 10 by 10 cm² light re-directional element integrated into a glass pane.

The main goal for the head-up display for automotive applications has been development of a small-volume active device with the production costs low enough that the display can be made available to mid-price mid-size range cars. The device is rather complicated containing anti-reflective surfaces, microhollows for LEDs, transparent and bendable wiring and all this joined into one device. In Figure 3 are shown examples of rigid and conformal head-up displays.

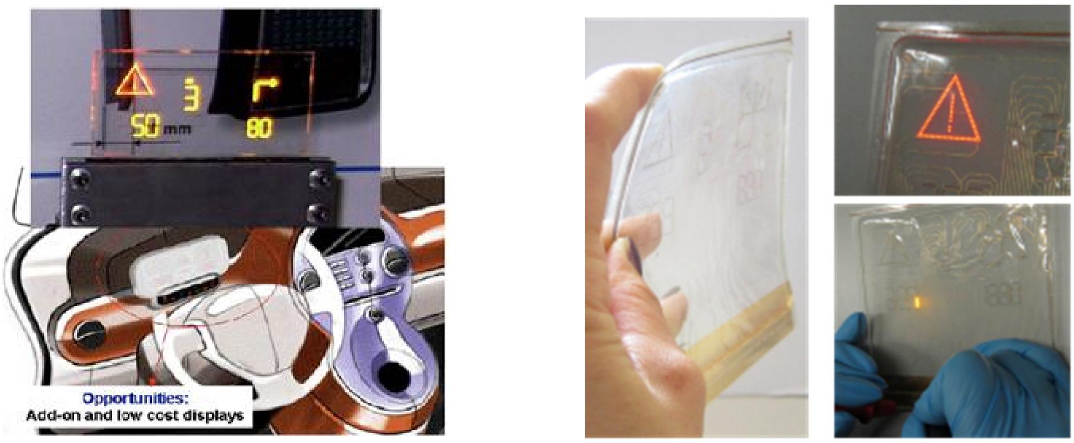

Figure 3. Emissive head-up displays developed in NaPANIL. In addition to glass-based display, also a conformal demonstrator was realised.

Sub-project Modelling&Metrology

Simulation of the nanoimprinting process is very challenging due to complicated relationships between the process parameters, such as temperature, pressure, imprinting speed etc,, and the behaviour of the resist material. Issues like stamp bending, the residual layer, the residual stress remaining in the resist and dependence on the feature size pose extra difficulties for simulation. Another big challenge is the size of data files needed to represent the design of the stamps, especially those with true 3-dimensional features, such as cones, lenses and tiered structures. The size of the files can easily reach TBit level, meaning that operating with laptops becomes impossible.

NS Suite developed in NaPANIL tackles both of the problems.[6] A test version can be downloaded from the project web site.[7] A full version is available from Cognoscens.

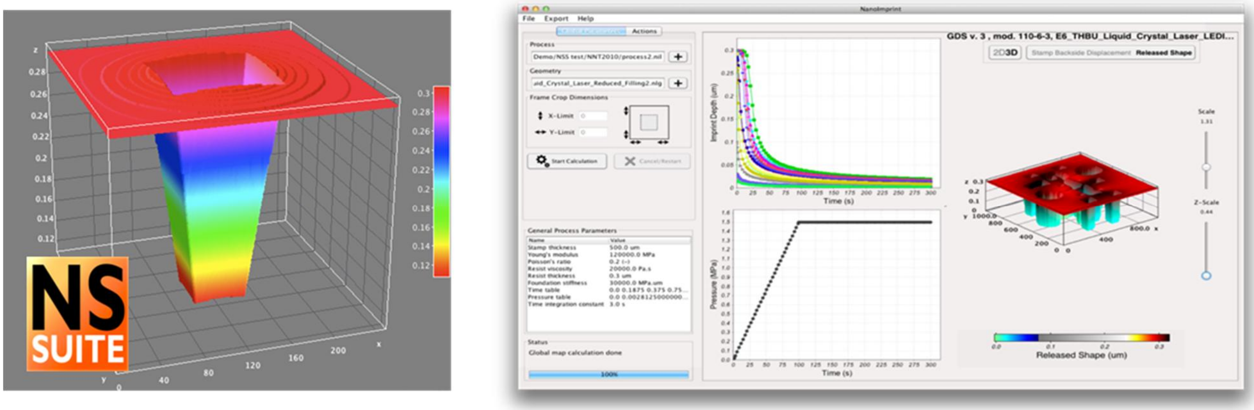

Figure 4. Nanoimprinting simulation suite is an easy to use simulation tool for testing and optimising the imprinting process. The software is real 3-dimensional, compact and fast.

Nanoimprinted structures are also challenging to metrology. Destructive methods can give information of the thickness of the residual layer and the angles of the slopes of the imprinted features, but it is difficult to find a non-destructive method to obtain this information. Scatterometry has been used to characterise line and space structures, including the residual layer.[8] In NaPANIL scatterometry has been further developed to be able to characterise pillar structures and tiered structures, providing information of the thickness of the residual layer, features sizes and the slopes of the walls of the structures, all information inherent and crucial for nanoimprinted surfaces.

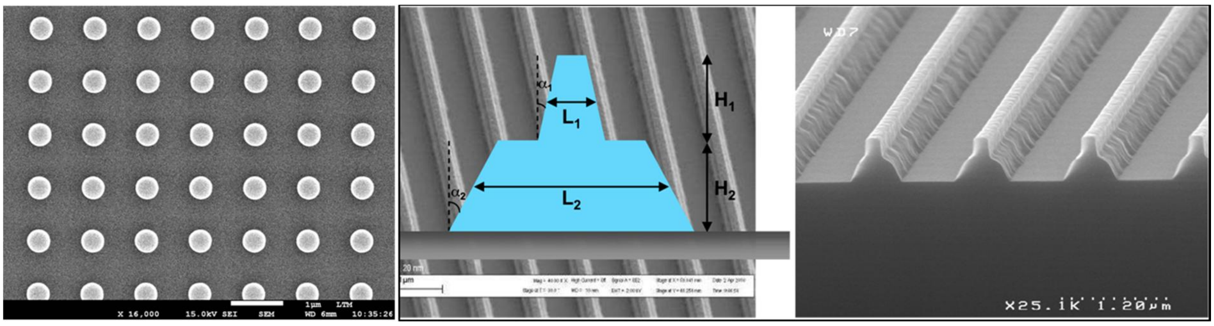

Figure 5. Scatterometry tools are now available, in addition to line and spaces, also for pillar arrays and for multitiered structures with tilted walls.

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[6] D.-A. Mendels, Mechanical Proximity Correction Using the NIL Simulation Suite, NNT 2010 9th International Conference on Nanoimprint and Nanoprint Technology (NNT 2010), Oresund & Copenhagen, October 13-15, 2010.

[7] www.napanil.org

[8] C. Gourgon, A.K. Ferchichi, D. Pietroy, T. Haatainen, J. Tesseire, Scatterometry analysis of sequentially imprinted patterns: influence of thermal parameters, Microelectronic Engineering, 2012.

Sub-project Manufacturing Technologies

The development of the processes and materials needed for the proofing of the demonstrators and needed in the next generation processes and applications were mainly developed in this sub-project. The activities concentrated on master stamp fabrication, stamp reproduction and enlargement to make working stamps for the production processes and testing the relevant part of the values chain for production. One of the main focii in sub-project Manufacturing Technology was the fabrication of master stamps. Stamps with binary gratings or arrays of pillars are relatively straightforward to make by optical, e-beam or interference lithography. To exploit the full potential of nanoimprinting, one would also produce true 3-dimensional structures with tilted surfaces or tiered profiles. Here the challenge is to realise the master stamp with all the desired properties. The master can be the transferred to working stamps by reproducing techniques. Below are some examples of the processes developed in NaPANIL.

One of the potential advantages of nanoimprinting is the ability to produce true 3-dimensional surfaces, which are advantageous for example for photonics and optics applications. The problem is the fabrication of the master stamp with all the desired features. Once made, the master can be used to produce the working stamps for Step&Stamp imprinting, large area parallel processes and for Roll-to-Roll manufacturing. NaPANIL has developed three approaches to realise the complicated stamps. Tiered structures can be made using fine optical lithography and dry etching. Examples of tiered ridges on a 300 mm wafer are shown in Figure 6.

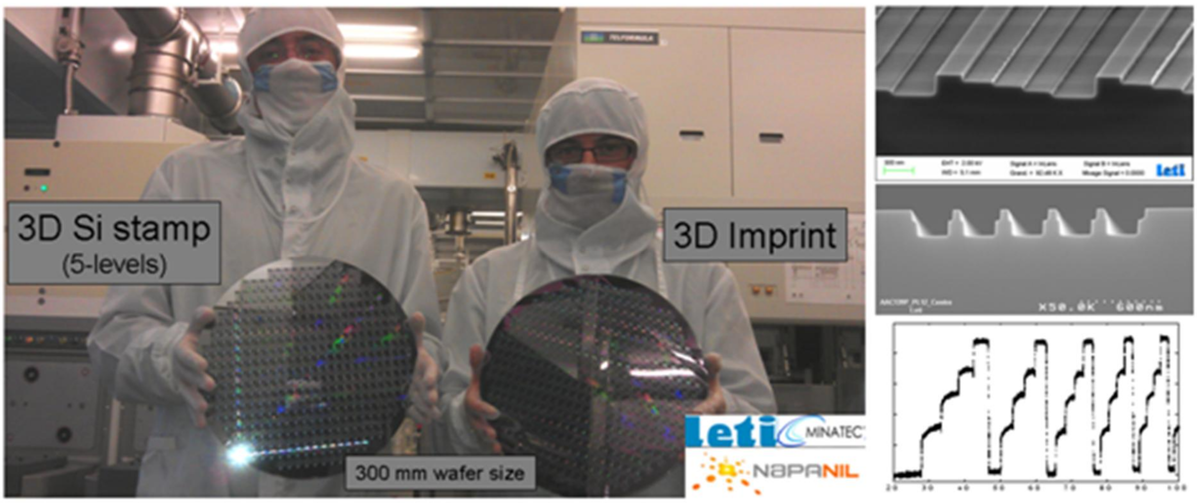

Figure 6. 300 mm Si stamp with 5-level tiered patterns and the corresponding imprinted replica..

A modulated dose, or grey-scale, e-beam process was developed to obtain smooth tilted surfaces. The TASTE process utilises the tunability of the glass transition temperature of polymers. In Figure 7 are shown SEM images of structures realised by the TASTE process. The maximum slope angle approaches 45 degrees which is enough for many applications.[9]

[9] A. Schleunitz and H. Schift, Fabrication of 3-D pattern with vertical and sloped sidewalls by grayscale electron-beam lithography and thermal annealing, Microelectronic Engineering, 2011.

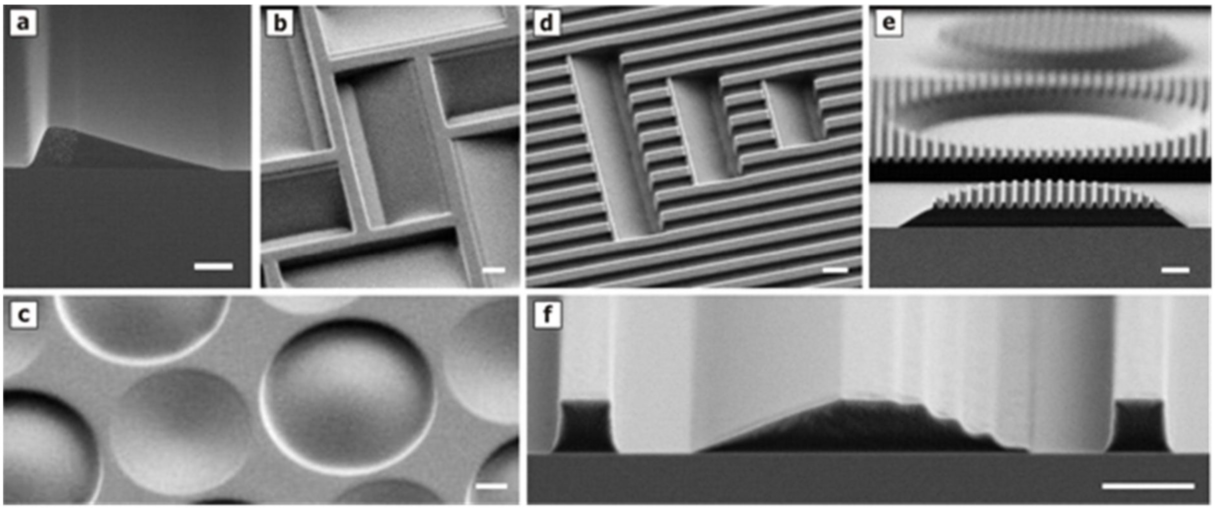

Figure7. SEM images of 3-dimensional structures in PMMA made by the TASTE process.

To achieve even steeper slopes, X-ray lithography can be used. In Figure 8 is shown the master made by X-ray lithography and electroplating. The master is replicated several times into PMMA and after the second electroplating step, used again to enlarge the stamp area.[10] The structure can eventually be transferred on a Ni-shim that can be used in Roll-to-Roll fabrication.

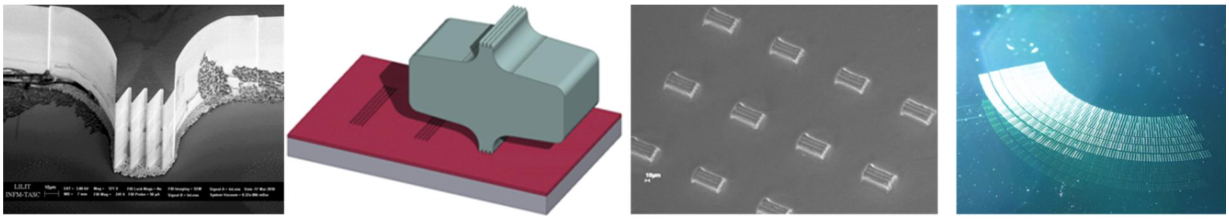

Figure 8. A signle electroplated saw-tooth stamp made by X-ray lithography is used to make a larger stamp by Step&Stamp nanoimprinting. The working stamp can them be used to create rather complicated surfaces. These can be transferred to the Roll-to-Roll process for high throughput manufacturing.

The Roll-to-Roll fabrication of back-light devices was piloted by the bench-top size machine shown in Figure 9. Although the tool has not been designed for production, the piloting experiment showed that Roll-to-Roll nanoimprinting can really provide a process for low cost and high throughput manufacturing.

[10] T. Haatainen, T. Mäkelä, A. Schleunitz, G.Grenci, and M. Tormen, Integration of rotated 3-D structures into pre-patterned PMMA substrate using step & stamp nanoimprint lithography, 37th International Conference on Micro- and Nano-Engineering (MNE 2011), Berlin, Germany, September 19-23, 2011.

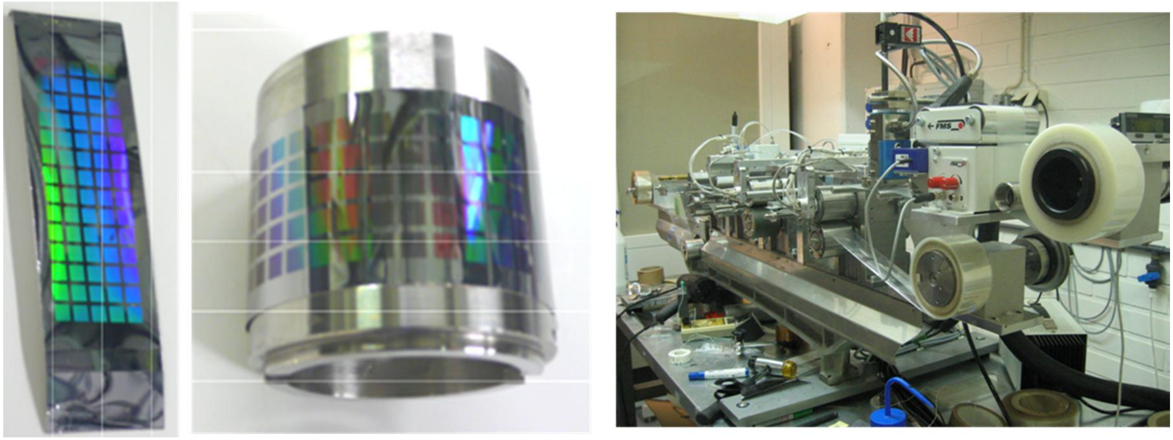

Figure 9. Nickel shim is made by using Step&Stamp nanoimprinting with a small master stamp and electroplating. The shim is attached to a roller which is used in Roll-to-Roll nanoimprinting process capable for small scale production.

The development of the Roll-to-Roll process led to foundation of a spin-off company PTMTEC Oy producing table-top machines, both for thermal and UV NIL, to academia, research institutes and industry. In Figure 10 is shown a table-top NIL tool for thermal Roll-to-Roll nanoimprinting.[11]

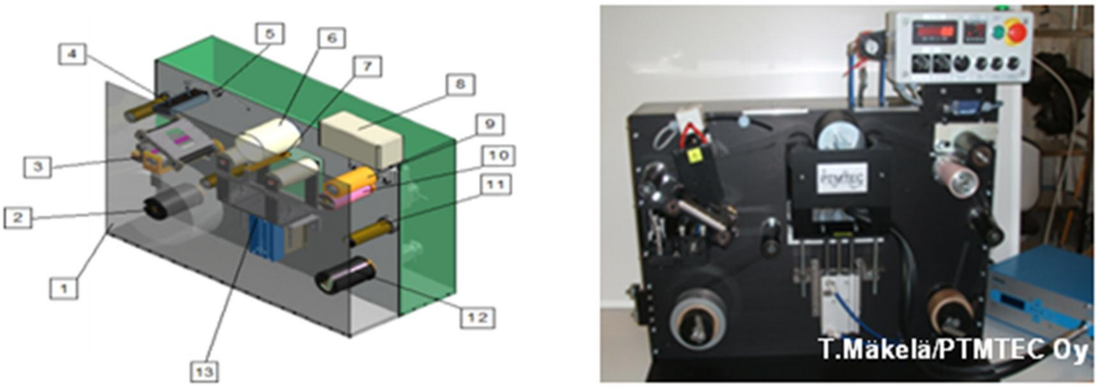

Figure 10. Schematics and a photograph showing the PTMTEC tool for thermal NIL. Another version is available for UV-NIL.

Materials form a crucial part of the nanoimprinting process. Thus, it is essential to develop polymers and resists optimised to fulfil the demands of the processes. The properties to be optimised include the glass transition temperature, demoulding properties and etch resistance, among others. NaPANIL project has been developing and testing new resists dedicated for nanoimprinting. Good examples are the modified materials now including the fluorinated release agent to enhance the anti-sticking properties and to improve reproducibility.[12]

[11] tapio.makela@vtt.fi.

[12] H. Atasoy, M. Vogler, T. Haatainen, A. Schleunitz, D. Jarzabek, H. Schift, F. Reuther, G. Gruetzner, Z. Rymuza, Novel thermoplastic polymers with improved release properties for thermal NIL, Microelectronic Engineering 88 (2011) 1902–1905.

Sub-project Research into Exploratory Processes

The role of this sub-project was to look into potential next generation versions of the applications developed in NaPANIL, with a special focus on reconfigurable and functionalised surfaces. In addition, the aim was to look for processes and applications important to environment and health.

Colour filters based on sub wavelength arrays of sub wavelength slits etched in an aluminium membrane were developed. The cross hole geometry was found to be most efficient by simulations. The silicon stamps, shown in Figure 11, were fabricated by e-beam lithography and dry etching. The process is such that the filters can be integrated directly on top of CMOS devices. [13]

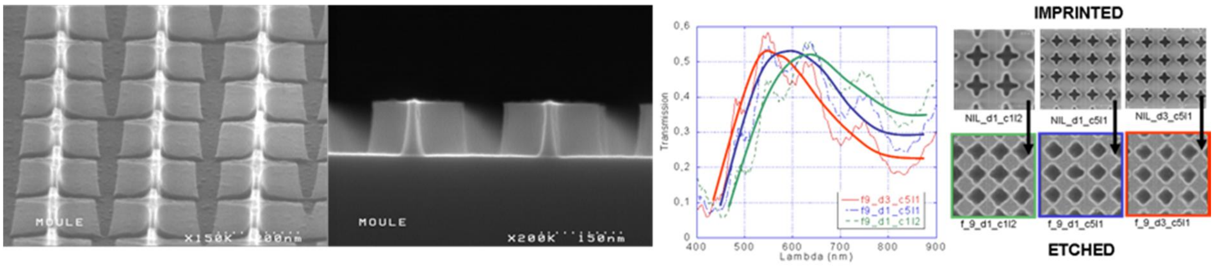

Figure 11. SEM images of Si stamps for colour filters. Measured transmission spectra and the corresponding imprinted and etched devices.

Enhancement of luminance and light out-coupling from organic LEDs is important for more efficient lighting. In Figure 12 is shown a process for OLED fabrication by imprinting, targeting to enhanced light out-put in comparison to a similar device with ITO top electrode.[14]

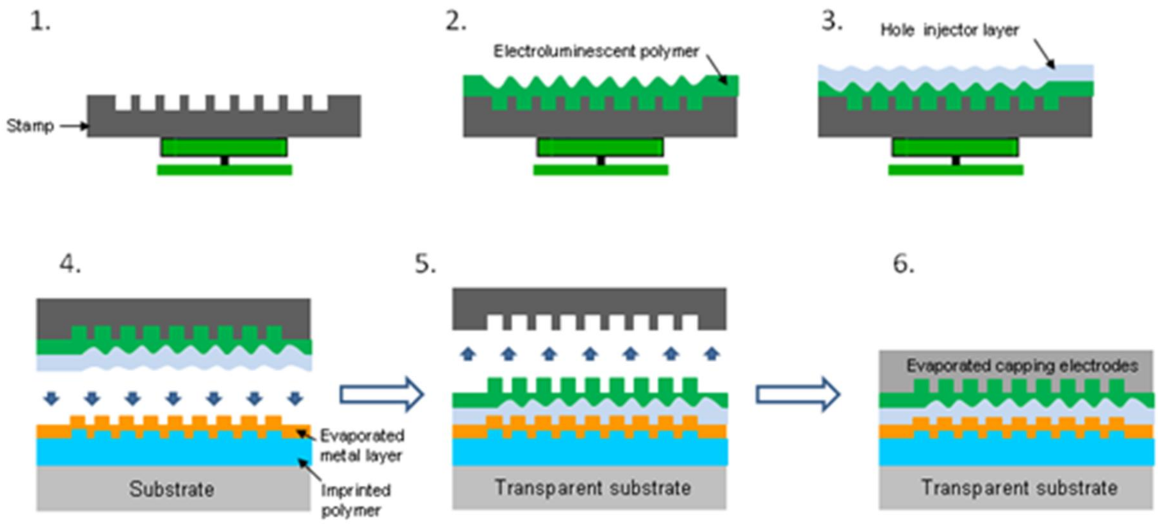

Figure 12. Fabrication process for independently imprinted OLED electrodes.

[13] S. Landis, N. Chaix, R. Espiau de Lemaestre, P. Brianceau, Fabrication of passive metallic photonic component nanostructures with 8" NIL processes, EIPBN conference, Florida May 26 - 29, 2009.

[14] V. Reboud et al., Enhanced light extraction in ITO-free OLEDs using double-sided printed electrodes, Nanoscale, 2012.

Hydrogels form an interesting family of “intelligent” materials that can be used in sensors sensitive to humidity, pH, temperature or ionic strength of the surroundings due reversible phase transition in the structure of the gels. The operation principle is shown in Figure 13. In the un-swollen state light is scattered out from the waveguide and is visible from the top of the waveguide. When reacting to the change in surroundings the gel becomes swollen and the light is guided through the waveguide and the amount of scattered light is largely reduced.[15]

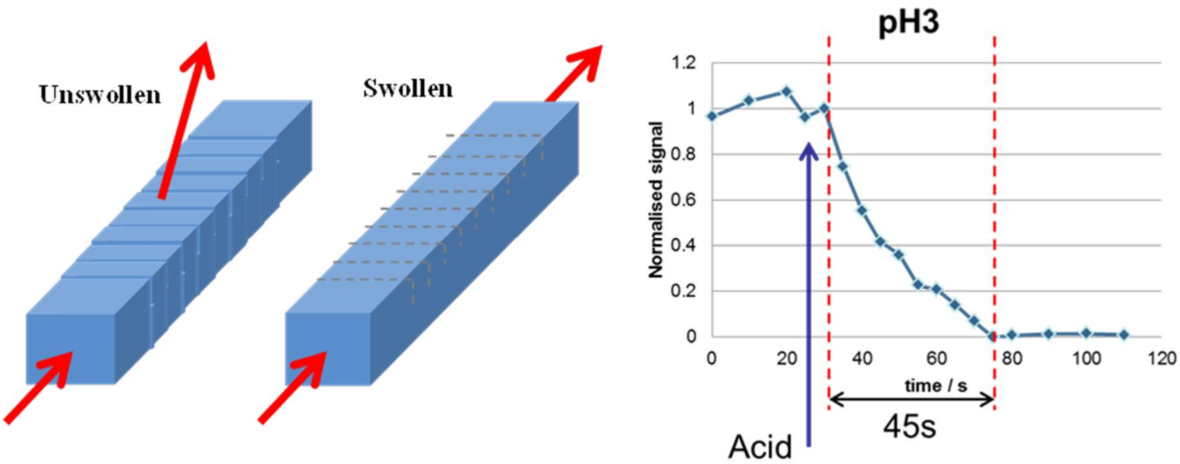

Figure 13. Operation principle of a hydrogel sensor and response to a change in pH.

When the portion of elderly people increases, the number of implants to repair hip and other bones will probably increase. It has been found that nanopatterning of the Ti implant surface enhances greatly the formation of bone tissue.[16] Direct nanoimprinting of Ti surface, also curved, was investigated in NaPANIL. The results are very promising and will be exploited in biomedical applications.

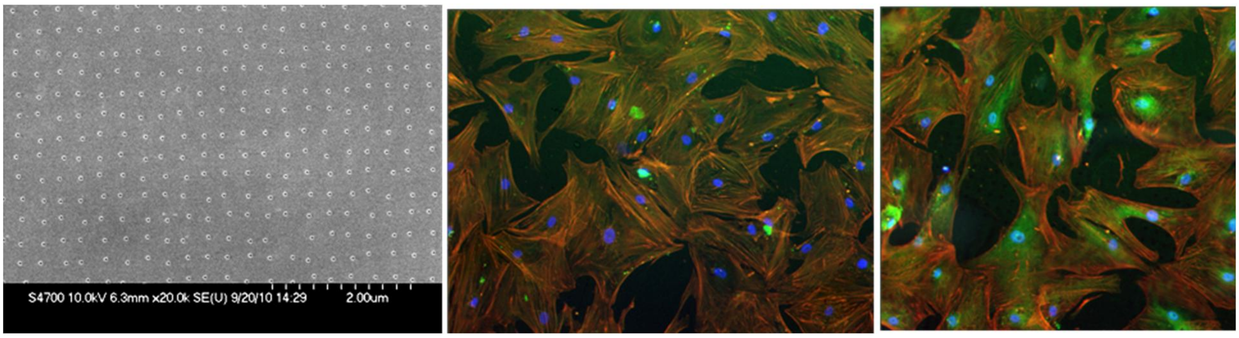

Figure 14. Titanium surface directly imprinted by a sapphire stamp. The patterned surface enhances the formation of bone cells (right) in comparison to flat Ti surface (middle). The direct nanoimprinting was done at one tons pressure.

[15] Ainhoa Gaston, Ali Z. Khokhar, Leire Bilbao, Virginia Sáez-Martínez, Ana Corres, Isabel Obieta, Nikolaj Gadegaard, Nanopatterned UV curable hydrogels for biomedical applications, Microelectronic Engineering, 2010.

[16] Rebecca J. McMurray, Nikolaj Gadegaard, P. Monica Tsimbouri, Karl V. Burgess, Laura E. McNamara, Rahul Tare, Kate Murawski, Emmajayne Kingham, Richard O. C. Oreffo and Matthew J. Dalby, Nanoscale surfaces for the long-term maintenance of mesenchymal stem cell phenotype and multipotency, Nature Materials, 2011.

Library of Processes

Most of the processes and applications are collected into the NaPANIL Library of Processes which is available from the project web site.[17] The Library consists of basics of nanoimprinting method, materials and tools, and a large number of recipes for various applications. The new volume contains more the 200 pages.

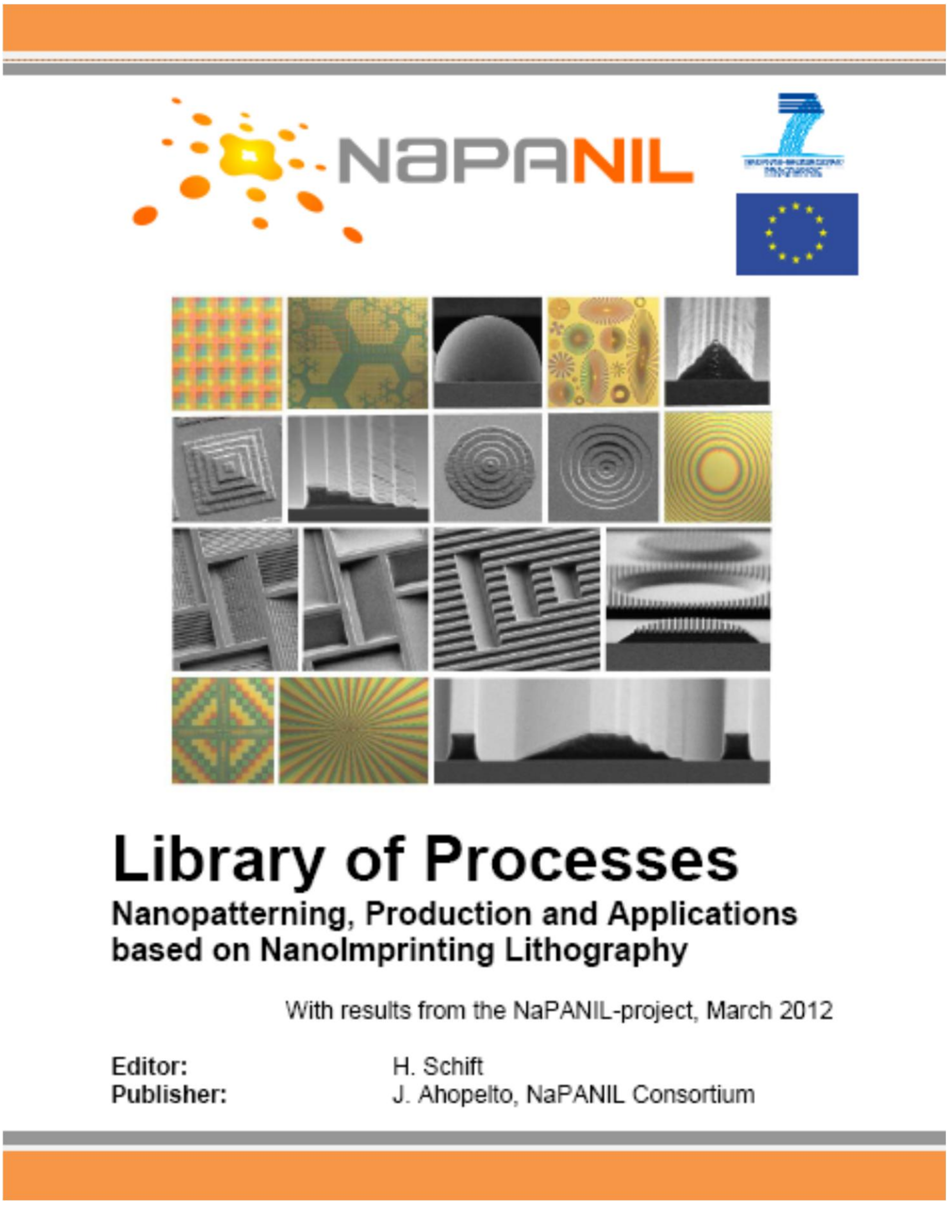

Figure 15. NaPANIL has published a Library of Processes consisting of basics of nanoimprinting and large number of recipes for various applications.It can be downloaded from the NaPANIL web site.

[17] www.napanil.org

Potential Impact

R&D competitiveness

The project NAPANIL, with its value-chain approach of technological R&D with a pull from industry needing 3D nanometre scale manufacturing, has shown that research leading to industrial innovation and more basic research can co-exist leading a mutually beneficial outcome: on the one hand real products and proof of concept developments, and on the other hand an insight in possible approaches to the next generation of those device applications. The project was an excellent experience of industry-research collaboration. With strong emphasis in 3D nanometre-controlled manufacturing, the results of NaPANIL are likely to contribute directly to the industrial competitiveness of Europe, in more than one area designated by the European Commission as Key Enabling Technologies (KET). In particular, the project falls in the remit of Advanced Manufacturing Technologies but also Nanotechnology, Photonics, Micro- and nanoelectronics and Biotechnology, when the researched applications are considered.

Innovations

The joint work with industrial partners led to several innovations being followed up some of which are:

* in *health*, such as ways to differentiate cells leading to artificial tissues;
* in the *automotive sector*, with light panel displays which are more user friendly to senior citizens;
* in *energy*, with more efficient living and working space lighting using day-light more efficiently, and
* All of these enabled by nanometre-scale patterning of diffractive optical elements in glass or polymer-based materials.

During the four-year project a research and innovation ecosystem was built and developed. Companies working with tools, novel materials, software for industrial process simulations and companies with a specific application in mind, worked closely with research organisations and universities to cover the value chain.

The work carried out in NaPANIL can be arguably said to have the potential to create jobs in Europe in the high-tech sector on nanomanufacturing. It has already demonstrated this by the spin-off the project and the expansion in the workforce of the industrial partners in the areas of work of NaPANIL. Furthermore, the project opened new research lines with its work in exploratory nanofabrication methods, which fall mainly in the medical area (artificial tissues and longer-life implants) and in the information technology area of future computing without using charge. Of particular relevance to manufacturing in Europe is the NaPANIL research on (nano)metrology methods and tools, which is a crucial step in the uptake of nanotechnology producst. NaPANIL made huge inroads in dimensional nanometrology applicable for flat and or curved nanopatterned surfaces. Moreover, this work would be crucial for setting Europe in a leading position in the discussion on the International Manufacturing Systems, to ensure global commerce.

Socio economic impact

Employment

The young researches and engineers who worked or were trained in the laboratories and companies participating in NaPANIL acquired unique expertise, which has ensured employment in industry and research organisations for many of them.
The project produced a “Library of (nanofabrication) Processes (using nanoimprinting)”, which can be of huge benefit to SMEs in enabling them to find ways on how to fabricate their new products potentially overcoming a bottleneck in the road of product development.

The training has not been just in the laboratories. The body of knowledge has become more structured and is now part of the curriculum of undergraduate and postgraduate studies in at least two academic institutions.

Health

The results on cell cultivation leading to cell differentiation and the realisation of, for example, bone cells in the laboratory, has the huge potential to replace tissue in case of accidents, for example. Furthermore, the discovery of longer-lived implants by using nanopatterning on metal surfaces, could do away with, for example, the need to have a second hip-replacement operation in the increasingly senior population of Europe.

Energy

Replacing normal room or office windows by windows incorporating passive diffractive optical elements (nano- and micropatterns) holds the promise of using day light over longer hours with a more even light level that here to fore. The challenging research demands to prove the concept were an integral part of NaPANIL: from design and realisation of large are master moulds to tests of reliable production.
A second example on the impact of NaPANIL results involving energy consumption, such as achieving higher contrast of e-book without increasing the power requirements, realised by pattering the plastic cover of electronic devices for which the sense of vision is needed, as in e-books.

In addition, the production methods are rather simple, energy efficient and environmentally friendly.

Transport

In between energy and transport are the research results on the emissive-Head-Up Display, suitable for insertion on the windshield of cars. This approach will increase safety as well enabling the senior citizens to use their vehicles more securely. The results pointed out to a much better design and realisation and looked further to the next generation of such devices based on new physical phenomena and novel nanofabrication processes.

Wider societal implications

The work of the RTD project NaPANIL was much appreciated in North America and in Asia, Japan in particular. Not only the outstanding technical and scientific work but the value chain approach of NaPANIL, were particularly mentioned. This is unusual in publicly funded research projects, and have raised the question of the short life of such endeavour. But perhaps tha major implication is the drive towards high-tech nano-manufacturing, which if continued and strengthened will create more jobs, commerce and the concomitant social stability to recover the social fabric of the communities making up Europe.

Dissemination

Industrial Days

Two NaPANIL Industrial Days were organised in April 2011 and February 2012 in Berlin. About 80 people from industry and academia attended the both events with very positive reception. The presentations were industrially oriented and given by the leading experts in Europe.
To address more the academia, a NIL Session was arranged within the SPIE Photonics Europe meeting in April 2012 in Brussels. NaPANIL had also a booth in the Innovation Village to disseminate with hands-on examples the results of the project.

In addition, NaPANIL has produced 31 press releases and flyers, a video "**Nano Foil Brightens Screen"** (www.yourismediacenter.com, can be found also in YouTube), and a "Library of Processes" containing "recipes" for a wide variety of NIL processes and applications. The book can be downloaded from www.nanpanil.org. The NaPANIL LoP is a follow-up to the famous NaPa Library of Processes.

Journal articles and conference contributions

The project has produced 38 peer reviewed journal articles, including papers in Nature Materials, Small and ACS Nano.

The partners in the NaPANIL consortium have had 123 contributions in various nanotechnology meetings, such as MNE, NNT, EIPBN and MRS, among others. These contributions include 23 invited talks.

Exploitation

The consortium has 13 patents accepted to protect the foreground created in the project. In addition, there are several trade secrets and software that are being exploited. The software on simulation of the NIL process is on the market, and so are the new resists containing anti-sticking agents.

The light-guide demonstrator has been integrated in a commercial product, the e-HUD demonstrator is being transferred to a subcontractor for potential production and the day-lighting elements are going through further development to enlarge the processed area to square meters. Thus, all the goals regarding the industrial demonstrators set in the beginning of the project are fulfilled.

Besides the demonstrators, 16 other exploitable results with TRL ranging from 3 to 9 were identified and the exploitation potential investigated. These include processes, sensor applications, biomedical applications and several applications for optics. These foreground results have been protected by patents or are trade secrets.

Two spin-offs have been established during the project. “ThunderNIL” (Italy) exploits the know-how on extremely fast nanoimprinting process and “PTMTEC” (Finland) the knowledge on Roll-to-Roll process to manufacture table-top size Roll-to-Roll tools.