MINAM
Micro- and NanoManufacturing

Roadmap 2012

final version

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COOPERATION

MINAM Roadmap 2012

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1. Introduction

The requests of the 21st century society for solutions to the "grand challenges", for ever improving yet affordable health care, higher standards of living and quality consumer goods and to tackle the risks posed by increasing energy costs, depleting resources, and employment are intensified by the current international economic situation. These "grand challenges" have been recognised by the European Commission, and are addressed by the Europe 2020 strategy[1]. The urgency of addressing these challenges is a driving force to develop and exploit key enabling technologies that will facilitate new innovative products and systems.

MicroNanoManufacturing Technologies (MNMT) have become the "unseen helpers" of today's society and have an impact across a broad range of application areas. The trends towards personalised health care, minimal invasive surgery, and care in the community for an aging population will all be supported by MicroNanoTechnology (MNT) solutions. Across other application areas such as mobility, homeland security, energy storage and energy conversion MNT will prove to be key to further innovative products and has the potential to bring paradigm shifts to production processes. Innovative MNMT already reduces our dependence on fossil fuels (oil, gas, coal, etc.) and raw materials[2] (coatings, rare earth materials, etc.) and consequently reduces the carbon dioxide emissions, as well as the concentration of nitrogen oxide and sulphur oxide in the atmosphere.

In the mid to long term, advanced MNMT will lower energy consumption and reduce the use of resources; and will enable a further reduction of energy consumption in many of their application areas. They will also lead to the use of less materials and reduced waste due to the use of "additive processes" as opposed to "material removal processes" to obtain the end product.

Over recent years MINAM has invested significant efforts to harvest the community's opinion on the current status and foreseeable developments in MicroNano (MN) Manufacturing which we still expect to be one of the key technologies for advanced manufacturing and the development of next generation products in a wider sense.

The results from surveys, workshops with the European Technology Platforms, workshops with regional clusters, brainstorming events with transnational clusters have been summarized and merged into two documents:

- the *MINAM roadmap* summarizing the feedback of the MN related community regarding technological and non technological bottlenecks
- the *MINAM Strategic Research Agenda*, providing a summary of the roadmap findings and adding the strategic development of the MINAM community towards a strong umbrella organisation with dedicated services for its members.

[1] Europe 2020 is the EU's growth strategy for the coming decade, European Commission, 2011 (http://ec.europa.eu/europe2020/index_en.htm)
[2] The raw materials initiative - meeting our critical needs for growth and jobs in Europe, European Commission, 2008 (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2008:0699:FIN:en:PDF)

2. MicroNanoManufacturing Technologies (MNMT), a key enabler for European industries

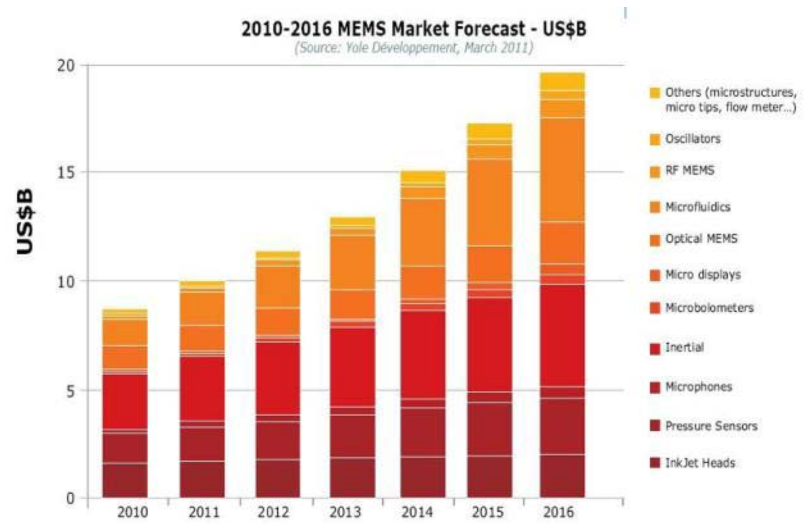

Fig. 1 MEMS Market forecast (Yole 2011)

The economic relevance of Micro components is confirmed by latest Market Reports, such as the ones from Yole or IHS iSuppli, which forecast a continuously growing market share for many areas that directly depend on MNMT. Components built through MNMT have already enabled new and more affordable products. Future MNMT-based technologies, products for health safety, ambient living, communication, and mobility will increase living standards and quality of life.

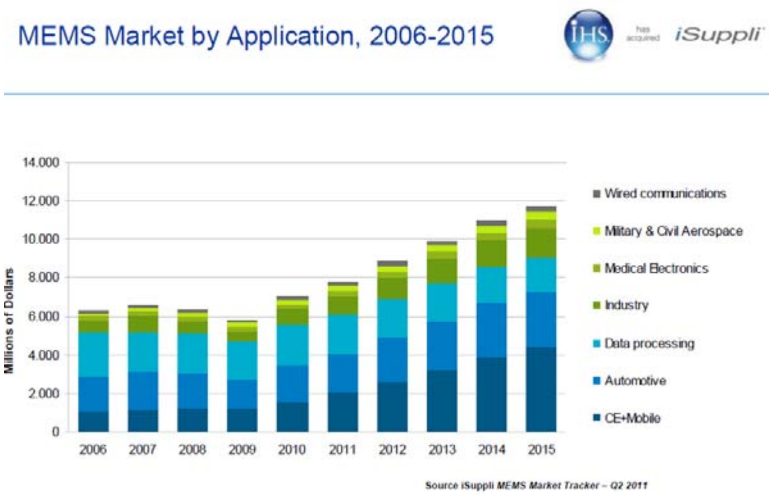

Fig. 2 MEMS Market forecast (IHS iSuppli 2011)

But rather than focus just on the MEMS and Micro components' markets[3], attention should be drawn to the multiplying effect of MNMT enabled "macro" products or systems, helping to ensure/improve Europe's competitiveness through advanced control, additional performance and monitoring functionality in many areas. Here, technological advances in miniaturisation, reduced power consumption of electronic components, new materials, and surface structure enabled functionalities have opened the way to new generations of products in a wide range of applications (Fig. 2), which, due to this multiplying effect, is also paving the ground for economic success in a much larger area of applications for the benefit of European society.

[3] See also Annex 1 with additional input from Yole and iSupply

2.1 Paving the ground for Europe’s competitiveness until 2030

From the classification of innovative products provided by **ManuFuture** (Fig. 3), it is obvious that MN enabled components play an important role. ManuFuture especially addresses the need for research in MNMT in its “emergent technologies”[4].

Not only new components and technologies, but also the further improvement of technologies assumed as mature will play a role in future innovation steps.

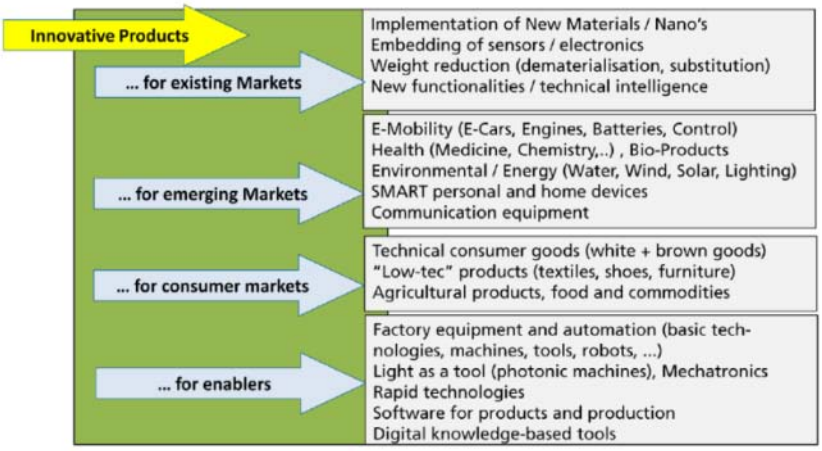

Fig. 3 Innovative application areas identified by ManuFuture

The ***“European Factories of the Future Research Association (EFFRA)”*** underlines the importance of Micro Nano-integrated devices in its strategic roadmapping document[5]:

- Most industrial sectors of importance to European manufacturing have a requirement to innovate through use of new materials and/or new functionalities, requiring manufacturing approaches that fully exploit the improved functionality and versatility of design. Embedded „smartness“ for condition monitoring, maintenance and in-situ repair are driving these developments.
- Integration of electronics, e.g. using improved sensing and control systems, and customisation of smart products, such as in intelligent packaging, also demand new manufacturing methodologies, e.g. an increased use of laser technologies and roll-to-roll manufacturing.
- Additional services associated to products will introduce more embedded (micro) mechatronics in the product’s components and consequently, change the design and production methodologies.
- Small-scale products or products requiring micro-manufacturing processes for advanced features, micro- and nanoproducts/electronics

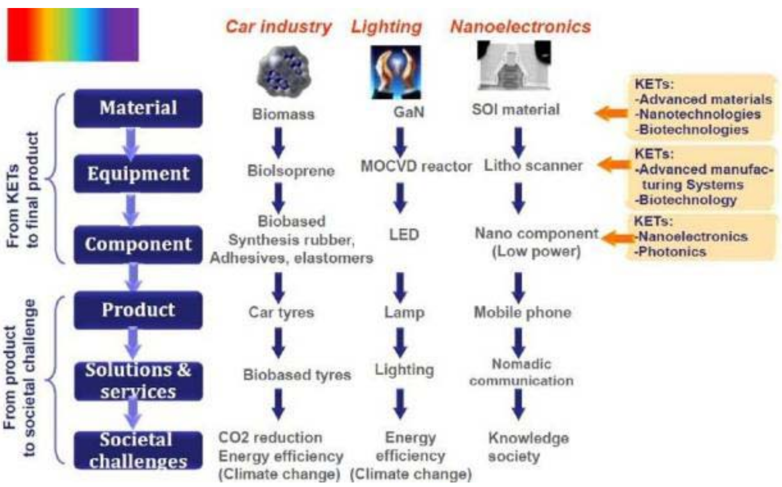

Fig. 4 KETs are strategic all along value chains (Source: KET HLG Report, 06/2011

The interdisciplinary ***Key Enabling Technologies (KET) High level group report***[6] initiated by the European Commission highlights the importance of a number of Key technologies with an estimated market volume of MN enabled products of more than 1200 billion Euros. All of these key

4 ManuFuture’s “Manufacturing 2030 in Europe” publication, July 2011, page 10
5 EFFRA Roadmap FACTORIES OF THE FUTURE BEYOND 2013, June 2011, EFFRA Roadmap Working document Status June/2012
6 KET HLG report, June 2011

technologies are well linked to, and many of them significantly dependent on MNMT as described further in chapter 3.

In particular the interface between nano and micro manufacturing is considered to be key to the successful introduction of nanotechnology into the marketplace. In addition the large market for intelligent manufacturing systems relies on MN based sensors and smart systems, making MNMT a (direct or indirect) key enabler for a vast number of industries and a key differentiator for the future workplace of large parts of our population.

2.2 Why do we need MINAM, when microsystems technology has matured in some application areas already?

MNMT enabled components are becoming established in all major areas of our daily life and can already be found across the broad spectrum of application areas[7],[8]. According to car makers and suppliers more than 200 micro actuators and sensor are integrated into modern automobiles. Well established in automotive technology, MNMT is now becoming more and more important in other application areas such as ICT, health, aviation, safety, or consumer goods. The influence of micro components is increasing rapidly, helping us to save energy, helping elderly people to live independently, or just making our lives more comfortable. The following use cases for the three (for the MINAM community) most relevant "energy", "health" and "production" illustrate existing Success Stories of MNMT enabled products and systems ***"Made in Europe"*** and give an outlook into further successes possible in the near future:

Considering the fact that microsystems technology somewhat rules our lives through the automotive and ICT industries it is sometimes hard to imagine that there are also plenty of opportunities in other application areas, where microsystems can help to improve our life and save energy. There are a few aspects people should be aware of when discussing the microsystems technology:

The world wide ICT and manufacturing communities put enormous efforts and generated significant investments into building up a robust and almost mature "silicon-based" ICT industry over decades.

Looking at the ongoing developments in the field of multimaterial micro manufacturing it is obvious that other MNMT related developments offer a similar potential to rule our daily lives again, but are lacking in terms of maturity and funding so far.

Printed electronics is a good example, which will gain more and more importance in several application areas such as energy or health as soon as the manufacturing problems are solved; similarly, micro optics will pave the ground for the next revolution in ICT, and polymer microfluidic systems will help us to bring the lab closer to the patient.

2.2.1 Market introduction of microsystems strongly depends on the continuous/disruptive improvement of manufacturing technologies

Keeping in mind that the development of silicon-based microsystems from the lab to a high-volume production technology took over 30 years, it is obvious to mention that the continuous improvement of technologies is one of the biggest challenges in micromanufacturing. Tab. 1 shows the progress in technology development for the silicon-based acceleration sensor, which represents a mix of "continuous improvement within a single technological step" and "disruptive improvements" whenever new application areas were targeted. The accelerometer is a perfect example of the fact

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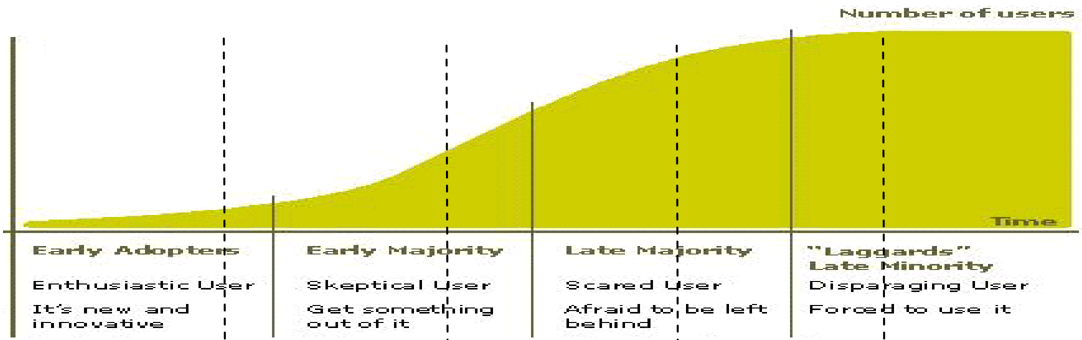
7 GlobeMST - Linking microtechnologies with emerging applications - a meta analysis of publicity available studies in the field. 4M/ICOMM 2009 : The Global Conf. on Micro Manufacture, 2009

8 MINAM 2009 Roadmap (http://www.minamwebportal.eu/downloads/roadmaps)

that Microsystems technologies are continuously developing and requirements regarding robustness and scalability change during the diffusion into new markets (See Tab. 1).

Similar to development in other areas this observation shows the necessity to support technological development, not only in the start up phase of new technologies but throughout their development. Micro technology needs support in a continuous way similar to what is done in the “well established” technological areas such as replication, tooling or others.

Fig. 5 Sequence of Rogers innovation adaption diffusion curve (remark: the “innovator” group on the left was removed from the graph since it represents only indirectly a user group)



1980	1990	2000	2005	
high precision engineering	Piezo	Bulk micromachining	Surface micromachining	CMOS
luxury class cars	Upper middle class cars	Automotive, all areas	Entertainment electronics	All types of entertainment electronics White goods
		Hard drive protection	Mobile communication	Communication

Tab. 1 Disruptive development of manufacturing technologies for accelerometers preparing the next level of component diffusion into the market (See parallels to the innovation adaption curve)

Microsystem manufacturing technologies change during the diffusion of MN enabled components into new markets. To ensure availability of robust technologies the continuous adaptation / development of new disruptive technologies is essential for the future success of MN enabled products.

In conjunction with the progress in all application areas a continuous improvement and adaptation of all kind of manufacturing technologies is required.

It is expected that for MNMT new developments (continuous and disruptive) will furthermore enable/accelerate technical and commercial breakthroughs in other application areas such as organic photovoltaics, fuel cells, etc.

Even those MNMT which seem to have achieved a mature state will be able to benefit from the new developments in the materials sector, adopting the new advantages and leading to new opportunities (e.g. higher function integration) in manufacturing the next generation of products utilizing the enhanced properties of composites, coatings, etc.

In this context Technology Maturity and Technology readiness and the potential of technologies have been analyzed in detail. A detailed analysis exists for all 79 technologies and can be downloaded from the MINAM web portal[9]. As a consequence out of these findings we can state that the MINAM community is still concerned about weaknesses in the transition of R&D results into mature processes and their application in an industrial scale for both the development of production technologies as well as the related design of new applications.

> The expected transition time from advances in technologies at lab scale towards mature technologies ready to be used in industry needs to be shortened through the full support of technology, product and production developments - from basic research to the scale up of production.

2.2.2 Are MicroNano enabled components already state of the art?

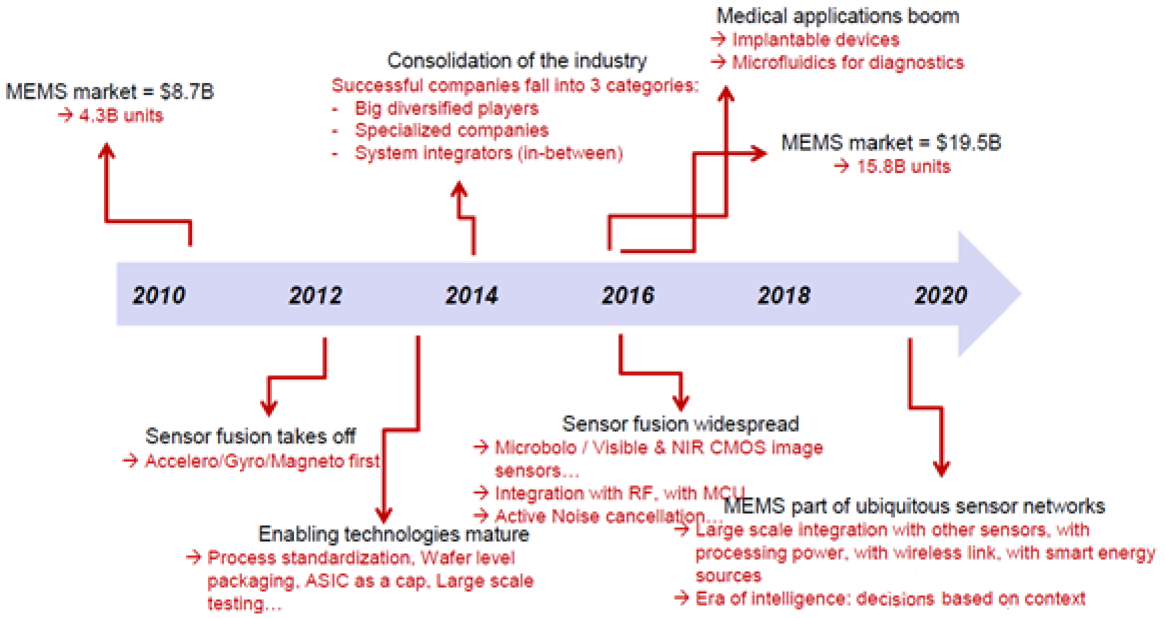


Fig. 6 MEMS Industry Evolution 2010 – 2020 (Source: Yole)

Fig. 6 illustrates the ongoing evolution in MEMS based products and new application areas over the current decade (existing and projected), based on a mix of continuous and disruptive development cycles. MNMT has contributed to these application developments but will also contribute further in the years to come. While some MNMTs can already be considered "quite" mature, some will still need to be taken from lab to production, and others still need to be discovered.

[9] MINAM 2009 roadmap www.minamwebportal.eu

2.3 MINAM roadmapping

MIMAM has invested a lot of efforts over the last 5 years to analyze strengths and weaknesses as well as the threats and opportunities in this still promising field of advanced manufacturing technologies. Additionally, several consultations were conducted with experts from players in this area. MINAM conducted three surveys targeted at individuals from R&D and industry as well as with representatives from the regional clusters, European technology platforms (ETP) and networks of excellence (NoE).

The results from these activities have been analyzed and interpreted in several documents, most of which have already been made available on the MINAM website (www.minamwebportal.eu). All surveys were designed to address specific targets to contribute to this roadmap from a different viewpoint:

- MINAM/Micro-Sapient studies and MINAM SRA (2008-2009) – identification and assessment of causal chains from technology to product and vice versa. More than 230 participants from 29 countries provided 10.000 datasets allowing for an assessment of technologies' relevance and maturity with respect to the 17 application areas investigated.
- 2010/2011 Interviews with clusters / ETPs / NoEs[10] - harvesting the expectations from different players in the MN community. With the growing relevance of regional cluster activities and the experience of the ETPs interviewed, MINAM validated its earlier results to enlarge the base of its assessments.
- 2011/2012 More detailed interviews with stakeholders from R&D and Industry (which have been included in this roadmap). To update the initial findings from 2009, individuals from industry and R&D were interviewed again.

Market/Application Pull (Technology Push) approach

→ *application* related aspects (Markets, Applications, MN-Functional elements)

linked with

→ *technology* related aspects (Production technologies, Production processes, Materials, System Integration aspects)

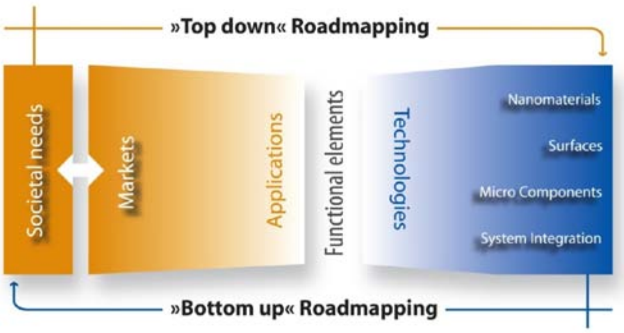


Fig. 7 MINAM roadmapping approach

[10] Internal Report MINAM 2.0 SRA

In 2009 more than 230 participants from 29 countries provided more than 10.000 individual statements.

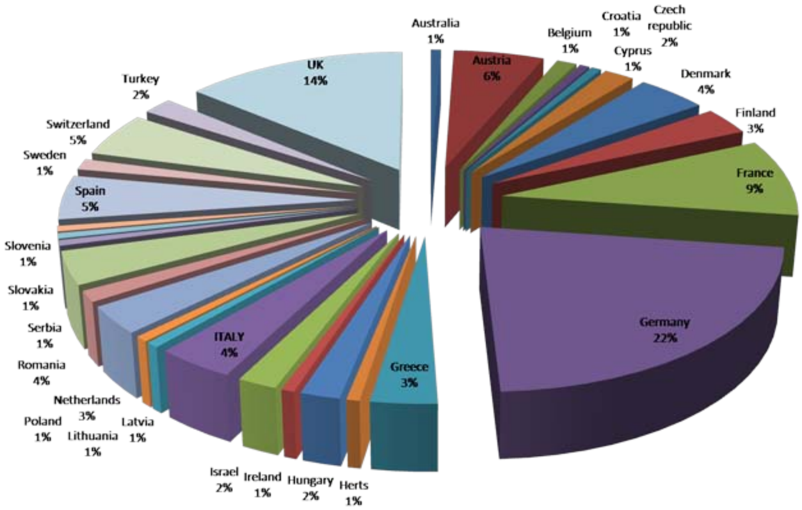


Fig. 8 Origin of 2009 survey participants by countries

In addition to conducting surveys the MINAM team is continuously screening literature in the MN related scientific and industrial area. MINAM's ultimate goal is to overcome the limitations referring from a narrow view on individual aspects and provide a holistic picture on all aspects influencing the MN manufacturing process.

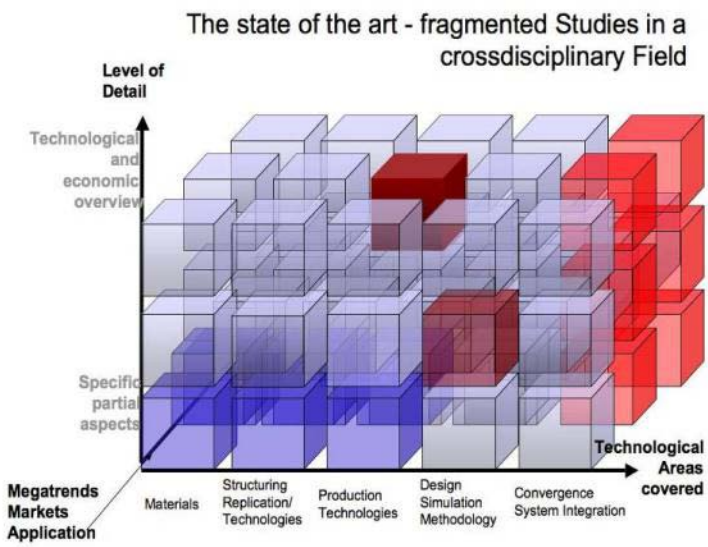


Fig. 9. Analysis of studies in a fragmented and multidisciplinary field such as MNMT

Both results led to an integrated approach for 76 technologies and their relevance in 17 application areas. The application area “energy” is a good example for this approach.

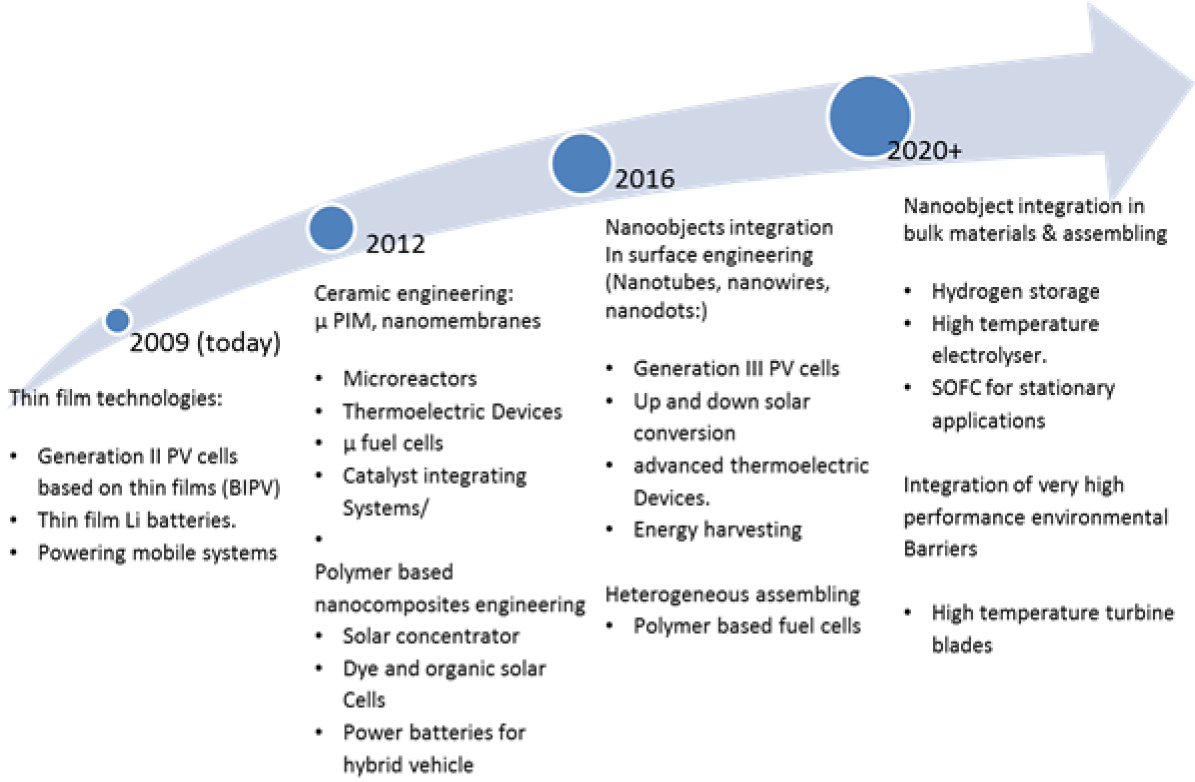


Fig. 10 Example roadmap for „Energy“

In addition to the MNT related questions, other, more production oriented questions were posed to the community. All results can be downloaded from the MINAM web portal (www.minamwebportal.eu).

> While MINAM 1 built on more than 600 individual persons or companies, MINAM 2 enlarged the basis for its decision (indirectly) by linking to “multipliers” in this area. In particular the regional clusters expressed their clear interest to bundle activities and to join forces through MINAM in order to show, that Micro Nano manufacturing is a true transnational European community building on thousands of companies that are organised in regional clusters (the amount of companies organised in clusters exceeds 3000, many of those being SMEs that are hard to reach directly through a European activity).

2.3.1 MINAM2.0 - Collecting the knowledge of multipliers

To gather further feedback from the European Micro&Nano community in regard to MINAM, its application areas and technologies, semi structured interviews have been conducted with representatives from selected key player organisations using tailored survey formats for the three targeted groups (Networks of Excellence (NoEs), Technology Clusters, and European Technology Platforms (ETPs).

Fig. 11 ECommunities in contact with MINAM

A representative amount of organisations participated in this survey.

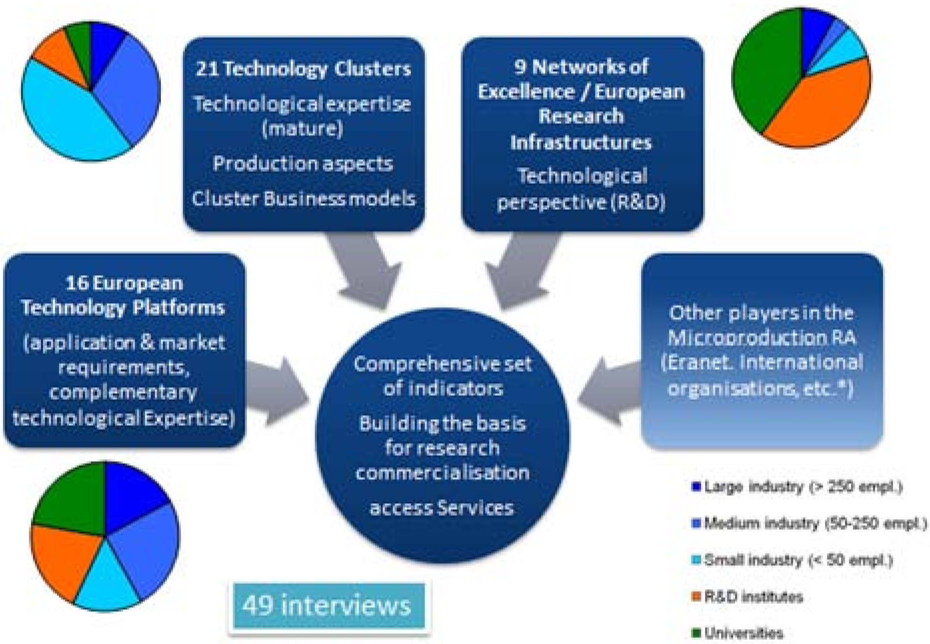


Fig. 12 MINAM 2 survey and roadmapping approach

From the feedback gathered from those communities through different channels, the clear analysis is that MN manufacturing is a significant issue for all of these organisations. However, quite a number of these organisations have priorities that cannot be solved through technical aspects only.

MINAM also took comments from the respective communities from earlier publications[11] into account. Especially for the ETP´s there was -not surprisingly- a focus on applications, markets, innovation, and non technological bottlenecks such as standardisation. Nevertheless technology related bottlenecks are and will remain the main critical issue for the majority of these organisations over the next years. Advanced Macro, as well as typical Micro, manufacturing related topics are seen as critical in an almost identical way.

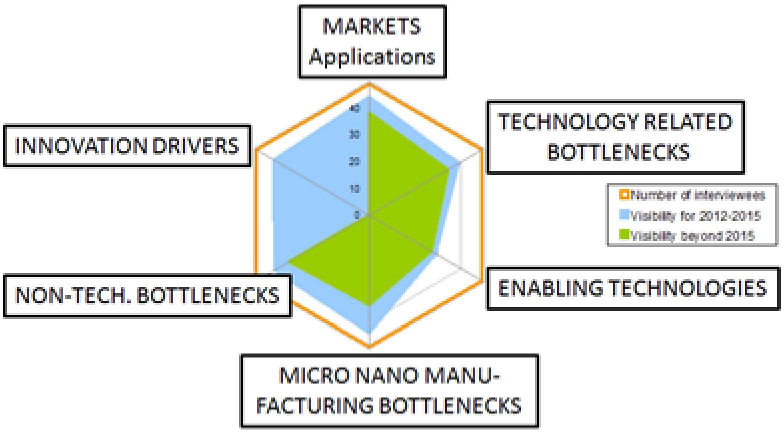


Fig. 13 Feedback from MINAM 2 survey – main topics

2.3.2 MINAM2.0 Phase 2: Feedback from individual European players 2012

As one might have expected, most feedback was given from the countries with the largest MNMT base, Germany and France. Additionally The Netherlands have been strong in contributing and also Switzerland and a few of the NAS countries such as Romania, Bulgaria and Czech Republic. From outside Europe, inputs were generated from Australia and Israel. Despite some efforts by MINAM, not much response was generated from the UK/Ireland and Scandinavian countries.

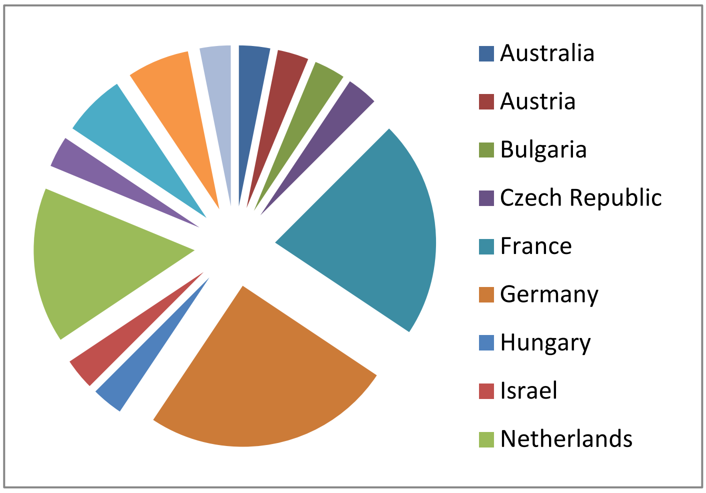


Fig. 14 Origin of MINAM 2 survey participants by countries

[11] MINAM position paper (2011), MINAM report on feedback from clusters (2011), MINAM report on feedback from ETP´s (2011)

3. Markets / Components

The ongoing development of intelligent and highly integrated products (e.g. lightning, optical or identification systems) requires the assembly of devices smaller than 500µm (e.g. LEDs, RFID chips and lenses). It is not possible to handle the required components with conventional handling- and assembly-hybrid techniques anymore, as conventional handling- and assembly techniques are limited when it comes to an increasing degree of miniaturization. New methods, based on self-assembly methodologies are required and need to be made available for industrial applications. Nanometer-scaled structures on the substrate surfaces provide the basic technology and cause a reliable positioning, interconnection and electrical contacting of the devices. Research is especially needed for the handling and feeding of micro-parts using self organisation. E.g. new methods will be needed for generating localised nanometer-scaled surface structures on free-form surfaces of geometrically complex or flexible substrates and methods for self-alignment of micro-parts on pre-structured free-form surfaces of geometrically complex or flexible substrates. Additionally methods for self-organised interconnection and the contacting of mounted micro-parts with very small pitches are a missing feature. Novel assembly processes for the integration of micro parts into geometrically complex or flexible substrates will give an enormous push to realising highly-integrated products at small- and medium scale production.

MNMT-enabled components today have started to break through into all major areas of our daily life. They can already be found in nearly all application areas. As an example, according to car makers and suppliers more than 200 micro actuators and sensors are integrated into modern automobiles. Well established in automotive technology, MNMT is now becoming more and more important in other application areas such as ICT, health, aviation, safety, or consumer goods. The influence of micro components is increasing rapidly, helping us to save energy, to help elderly people or just make our lives more comfortable. Overall the influencing effects of MNMT enabled “macro” products or systems are estimated to multiply the above mentioned achievable (MEMS) markets by a factor of 100-1000.

Since MNMT is an enabling technology designed for the integration of functionalised micro surfaces and micro components in macro products, it is not surprising that many application areas are the subject of MN related research and will benefit from ongoing improvements in this advanced manufacturing area. As stated in chapter 1 expected breakthroughs do not take place consistently in all areas at the same time. To gain a better understanding of what we can expect to see next, MINAM also asked the community their opinion on application areas for micro components in macro applications.

Fig. 15 provides an overview on where MINAM members expect significant contributions thanks to new developments in MN manufacturing

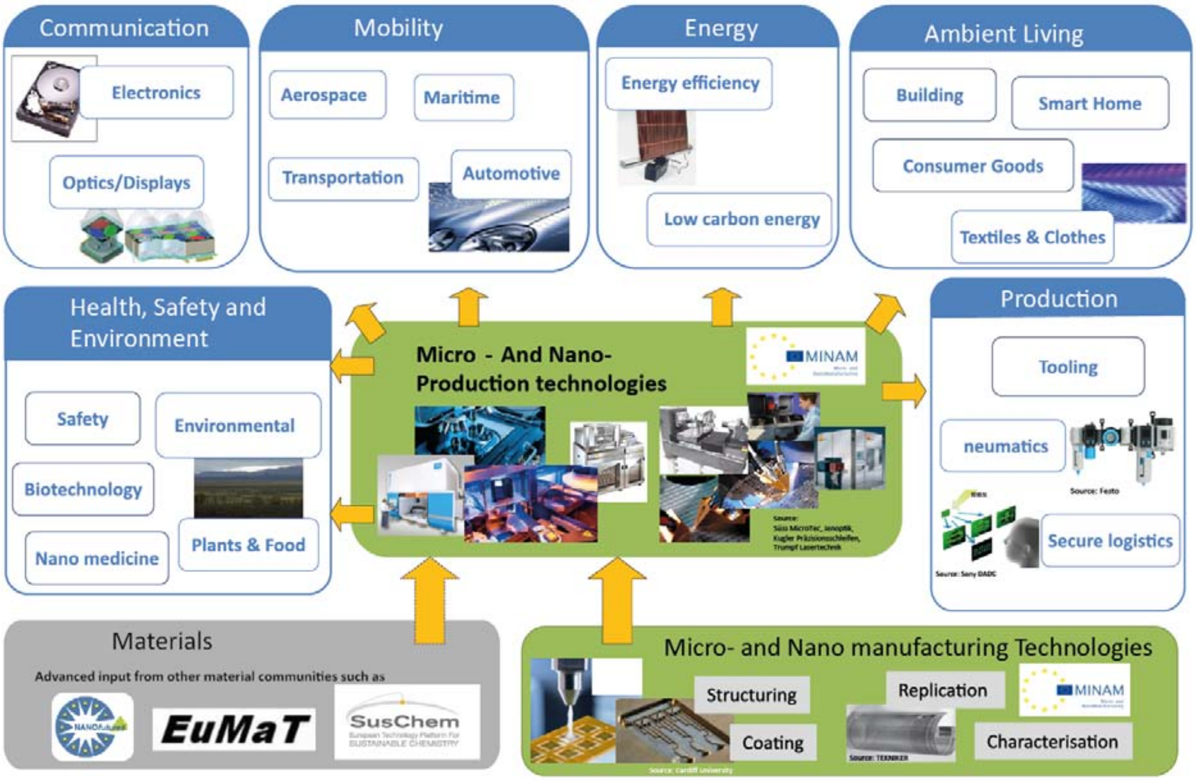


Fig. 15 MN manufacturing - an enabling technology for many application areas

3.1 Main future markets for MN manufacturing

To better understand where the MN user community sets its priorities of the next years, survey participants were asked to estimate where we might see the next revolution – made by micro manufacturing. The following feedback including its prioritisation had been harvested from the different surveys. According to the surveys in 2011/2012 three major application areas were identified.

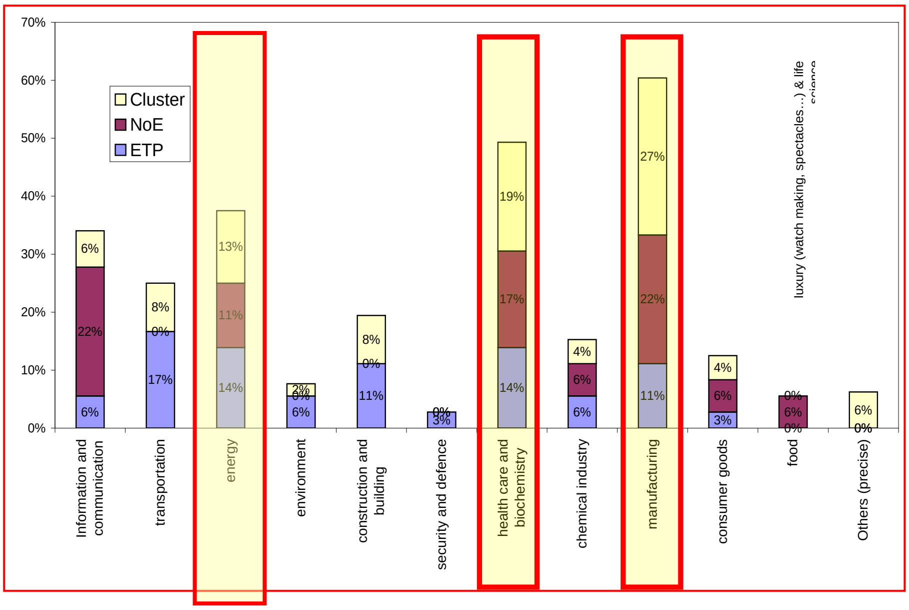


Fig. 16 Main markets identified (2012-15)

For the timeline 2012-2015, manufacturing has been identified as the most important sector, followed by health care and biochemistry and energy. ICT, transportation and construction were also important but not the major issues.

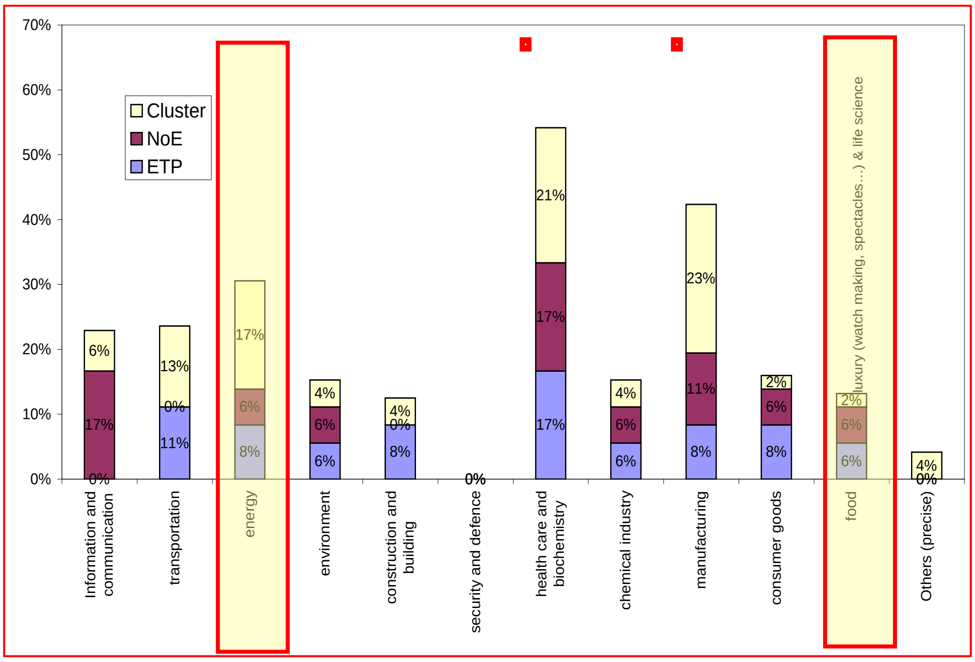


Fig. 17 Main markets identified (beyond 2015)

For the timeline beyond 2015, however, health care and biochemistry have taken the lead, leaving manufacturing the second most important sector, followed by energy. Transportation and ICT also remain strong, but environment and food in particular seem to be gaining in importance.

The following use cases illustrate existing success stories of MNMT enabled products and systems “Made in Europe” and successes that seem possible in the near future. Following the prioritisation done in the surveys, examples for the three major application areas are also given.

3.1.1 Energy

The photovoltaic energy is considered to be one of the most promising technologies in this sector and encompasses a huge market growth. Manufacturing photovoltaic systems requires a wide use of both thin film deposition and surface micro-texturation. The impact of micro-nanotechnologies on this industrial sector has impressed energy production experts and led to the opinion that MNMT will have a decisive role in the manufacturing of energy mass production and management systems.

Today the main developments are undertaken in the following fields:

One of the major concerns of the global warming is on how to achieve energy mass production with zero carbon emission. Up to now energy mass production by conventional technologies was rarely using MN manufacturing in its core processes.
However, this behaviour is changing fundamentally because both diminishing oil reserves and the public mistrust of nuclear energy have pushed the development of alternative renewable energy production.

Technology experts estimate new micro- and nanotechnologies can enable (with new developed processes and components) a profitable value chain from the development of primary energy sources over the conversion, storage, transport and utilisation of energy.

Exploitation of primary energy sources: The European Union has the ambitious goal to cover at least 20% of the whole energy consumption in Europe with renewable energy by the year 2020. Furthermore the aim is a decrease of 20% in greenhouse gases as well as an increase of 20% in energy efficiency. Potential innovations within exploitation of both conventional (fossil and nuclear fuels) and renewable energy sources (geothermal energy, sun, wind, water, tide or biomass) are fuelled by micro- and nanotechnologies.

In particular the use of sunlight by means of photovoltaics has enormous potential. Photovoltaic energy is considered as being one of the most promising and encompasses a huge market growth. Today photovoltaic technologies based on thin semiconducting films have more and more complex architectures (e.g. a-Si, µ-Si, CIS) to match as closely as possible the solar spectrum. Another example is quantum based photovoltaic cells by using nano structuring of dots or wires to adjust light absorption.

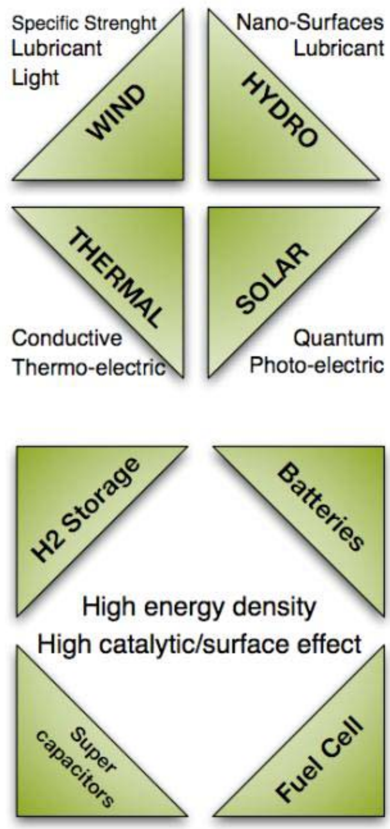


Fig. 18 Energy technologies

Today, the technology dominating the markets is using expensive mono- or rather multi-crystalline silicon, and cost reduction is a major challenge. Basically there are two main approaches to achieve this:

1. By reducing the amount of raw materials required with new technologies e.g. concentrator lenses[12]
2. By replacing silicon with alternative materials, e.g. polymers.

New developments include alternative cell types such as thin film solar cells, dye solar cells or polymer solar cells. A recently started project, for example, is a NASA contract with Kopin Corp. which has been awarded a $ 600,000 for the production of nanostructured solar cells made from indium gallium phosphide (InGaP) materials.

Energy conversion: The highest achievable efficiency is targeted with the conversion of primary energy sources, heat and kinetic energy, into electric power. Another significant trend these days is to generate electricity in a more environmentally friendly manner. Improvements could be introduced via heat and anti corrosion coatings on the nanoscale, which will improve the efficiency based on higher operating temperature or the usage of light materials. Innovation potential in the field of hydrogen oxygen fuel cells will derive from nano-structured electrodes, catalysts and membranes used in the chemical energy conversion to achieve a higher electricity efficiency. In coal burning power plants, membranes with new materials encourage the separation and climate neutral storage of carbon dioxide; this will, in the long term, lead to more environmentally friendly methods of electric power generation.

Energy transport: Low-loss power transmission and intelligent electricity networks aim at using the remarkable electrical conductivity of nanomaterials such as carbon nanotubes in power cables. Moreover there are new approaches for the optimisation of superconductivity materials. Long-term options are wireless energy transport by laser, microwaves or electromagnetic resonance. Micro- and nanotechnologies will deliver urgently needed contributions to these visions by means of nano-based sensors and electronic power components to handle the complex steering and monitoring of those huge electricity networks.

Storage of energy: Energy harvesting by thermoelectric devices, where nano-structuring has already helped achieving a significant increase in conversion efficiency. Devices using electrochemical reactions to produce or store energy may also be strongly impacted because the energy density is directly related to the density of the active surface. And it is obvious that MNMT can offer a great breakthrough perspective by increasing the active surface by orders of magnitude. With the help of nanotechnology, Lithium-Ion batteries will improve the capability and functional safety, for example, with new ceramic, heat consistent, but flexible separators as well as high potential electrode materials. Additionally, hydrogen as an energy storage system seems a promising possibility in the long-term perspective.

Utilisation of energy: Besides improving the production of renewable energy there is also an enormous energy saving potential in minimising the energy consumption with new MN technologies in several areas. The most important impacts are seen in the automobile sector with light weight construction materials, and in buildings with heat insulation or energy saving through LED lightning concepts.

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[12] An example is the ASPIS project which develops a Parallactic Tracking technology concept that supports flat, fixed solar panels with internal concentration and dynamic suntracking http://www.aspisproject.eu/index.html

In summary, the potential impact of MN technologies on this industrial sector is impressive; energy production experts acknowledge that MN technologies will have a decisive role in the mass production of energy and in energy systems. The implementation of nanotechnology innovations needs to keep track with the macroeconomic and societal context. The planning of prospective energy systems requires long-term investments in research activities and infrastructures, which are based on a realistic assessment of potential innovations. A dialogue overlapping in sectors and disciplines between all actors is essential to get the new nanotechnology innovations into practice as soon as possible, especially in such a broad and “society-impacting” field like the energy sector.

Applications	Benefits of micro- & nanomanufacturing technologies
Electrochemical storage for ICs, Electrical Vehicle and Smartgrids	• Higher power & energy densities batteries • More durable batteries • Safer batteries
Electricity production & conversion	• Bulk nanostructuring for high power factor thermoelectricity conversion • Surface micro- & nanostructuring for light management in 3G photovoltaic • Smart micro-designs for CPV optics • New materials and processes for Organic electronics and OPV
Hydrogen production & storage	• Higher performance materials and processes for Electrode Membrane Assemblies of electrolysers and fuel cells • Micro and nano-fractionated materials and compounds for fast and reversible H_2 storage in solid phases • Catalysts for gas reforming
Heat exchange, harvesting & insulation	• Surface micro- & nanostructuring for improved heat transfer in pool and convecting boiling • Surface micro- & nanostructuring for improved heat harvesting in CSP • Bulk micro-structuring for low heat conductive materials
Lighting	• Energy efficiency brought by MN-enabled LEDs sources and optics. • Micro-integrated electro-photonic features enabling active and passive light components (emission, guiding, detection) for ultra-high speed communication
Fossil fuel efficiency	• Nanoparticle fuel additives for lower fuel consumption and better local air quality • Solid lubricant nanomaterials for reduced friction losses • Surface micro- & nanostructuring for hydrophobic functionality to reduce icing on wind turbine blades • Micro- and nanomaterials to improve heat resistance of aeroplane turbine blades allowing the engine to run at higher temperatures
Biomass	• Nanocatalysts for highly efficient chemical pathways for 2G fuels

Tab. 2 Applications of MNMT in energy efficient systems for energies production, conversion and storage

A few examples will provide an insight into ongoing activities in this area:

Photovoltaic technologies based on thin semiconducting films are being developed with more and more complex architectures to match as closely as possible the solar spectrum and quantum based photovoltaic cells by using the nano structuring of dots or wires to adjust the light absorption. R&D activities and first solutions show a clear trend from Si-based Photovoltaics to organic Photovoltaics (OPV).

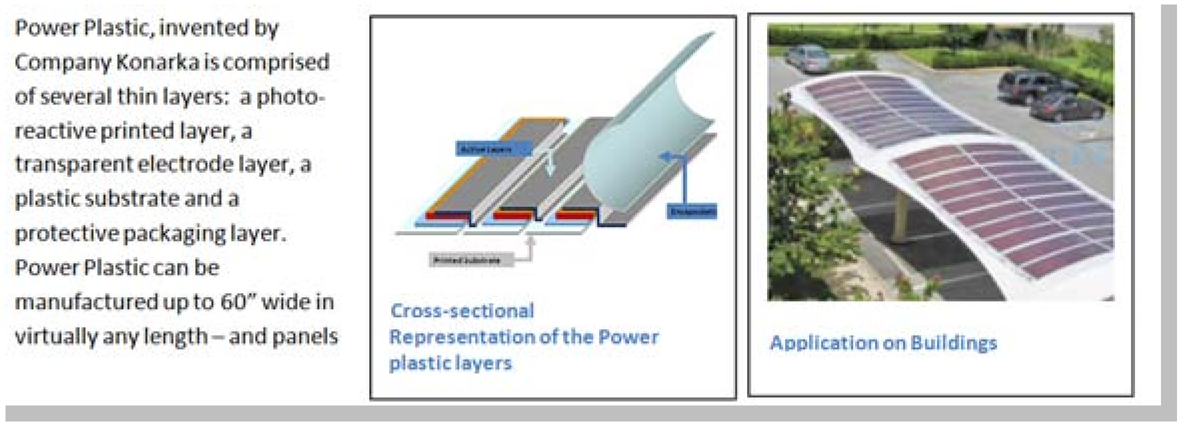


Fig. 19 Organic Photovoltaic cells (Source: Konarka)

Energy harvesting by thermoelectric devices where nano structuring has been employed has driven a significant increase of the conversion efficiency. Devices using electrochemical reactions to produce or store energy can also be strongly impacted because the energy density is directly related to the amount of active surface. And it is obvious that micromanufacturing can offer a great breakthrough perspective by increasing the active surface by orders of magnitude. Two technologies are concerned:

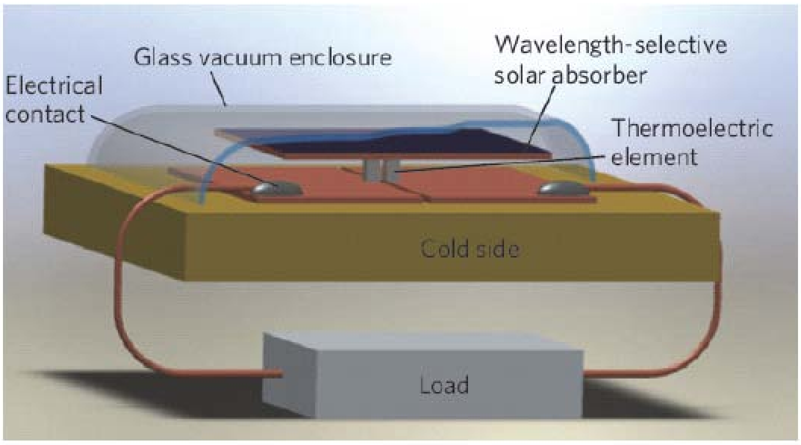


Fig. 20 Solar electric generator (Source: Nature Materials 10, 532 (2011 copyright by Maximilian Publishers Ltd.)

Fuel cells

In addition to the use of fuel cells in the automotive sector, in which the extension of the range is still the limiting factor, the use of micro fuel cells for a larger variety of applications is a relevant topic. Besides the challenges related to the development of catalysts, function integration is also addressed by the MINAM community.

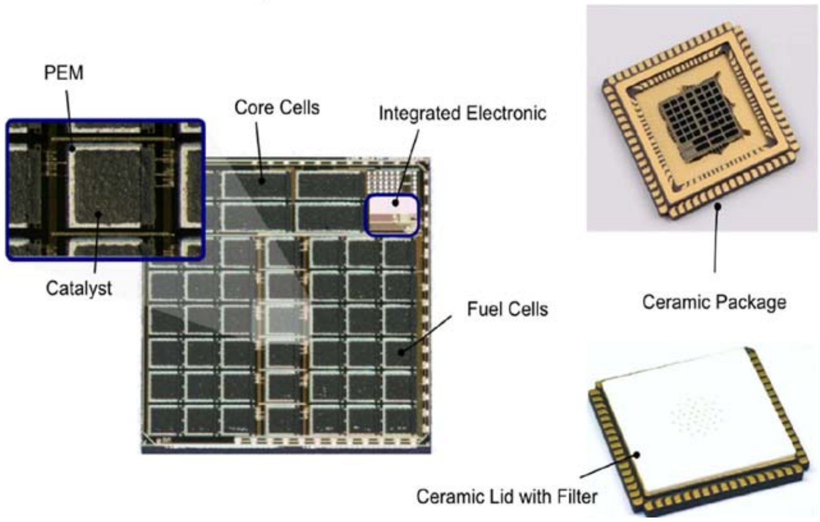


Fig. 21 Micro Fuel Cell - Integrated System (Source: Imtek/Microtec Südwest)

Batteries

In both cases, specific power can be increased by MN structuring of the active areas.
In the field energy mass production, the common challenge is to develop very high productivity MN manufacturing tools because whatever the physical concept of energy conversion, a very large active area is needed when considering energy mass production. Typically applying MN fabrication on a square meter surface at high throughput is mandatory for all the applications mentioned above.

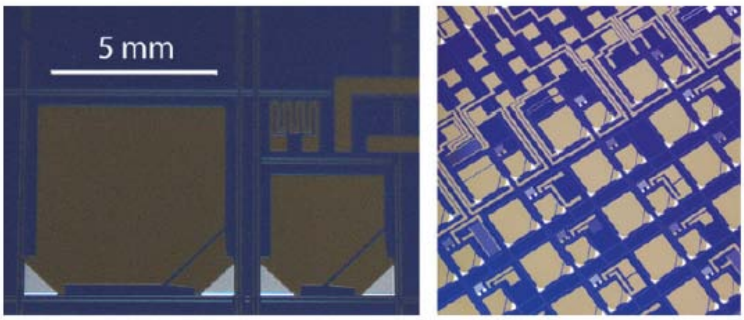


Fig. 22 Topology of the micro battery developed by ST Microelectronics (Source: Journal of Power sources 196, 10289 (2011) (c) Elsevier).

New generation of batteries, enabled by advances in micro laser technologies

The development of high performance and cost efficient energy storage systems such as lithium-ion batteries is a new global scientific and economic challenge. There exists an increasing demand for powerful rechargeable battery systems suitable for automotive applications as well as for temporary storage of electrical energy provided by wind generators or solar power plants. It is assumed that new technical approaches for laser processes such as rapid laser cutting and laser surface structuring/modification will enable new architectures of battery materials for improved energy power density and battery lifetime (cycle stability).

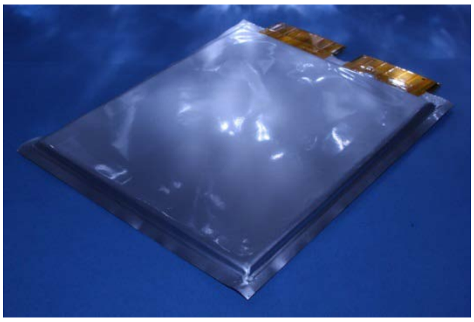


Fig. 23 battery with laser modified surface for improved power density and lifetime (Source: KIT)

In very recent research results it was demonstrated that 3D battery architectures were realized by direct laser material processing of electrode materials and that a significant improvement of battery cycle stability, especially for high loading/discharging currents, was obtained. The economic scale-up for these prospective processes, the development of ultra fast laser processes for reducing thermal damages as well as the damage-free rapid laser cutting of electrode sheet materials are future research topics in battery technology which could create a significant added value.

3.1.2 Health

MNMT plays a key role in developments of relevance for the health sector. Nearly all areas of Health are affected by new developments on the way to their market introduction. Despite many developments taking longer than expected, the trends toward a more personalised medicine and personal health are about to pave the ground for a wealth of applications enabled by MNMT. Microfluidics-based diagnostics, minimally invasive surgery as well the monitoring and conditioning of body functions (e.g. intracorporeal through new generations of pacemakers or extracorporeal through telemedicine) are topics benefitting from further continuous development of the enabling MNMT towards a higher degree of miniaturisation in parallel with an increasing maturity of technologies in terms of manufacturability, reliability, cost and time to market.

The following paragraphs provide an overview on where we can see ongoing improvements in the health sector enabled by micro components in the near future.

Drug delivery

MN manufacturing will improve the delivery of drugs, starting with intracorporeal particles up to the optimization of drug consumption, e.g. through optimised droplet size leading to a reduced intake of drugs.

Example for HEALTH: Inhaler for Respiration

The Respimat Soft Inhaler was developed by the German SME Microparts founded in 1990, now Boehringer Ingelheim Microparts, a subsidiary of Boehringer Ingelheim, one of the largest pharmaceutical companies in the world.

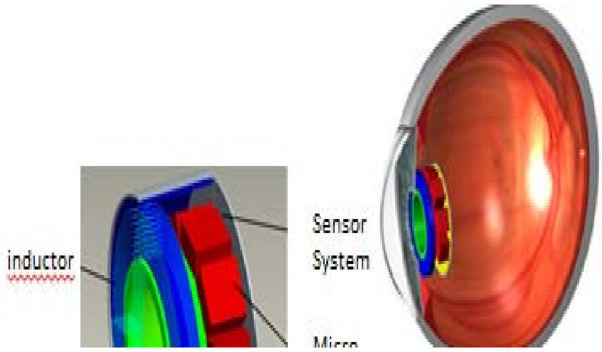
This product represents an excellent example for an MNT success story in the field of medical healthcare leading to a smaller intake of drugs in combination with significant improvements of drug inhalation enabled by a core micro component (etched micro diffuser).

Fig. 24 Respimat Inhaler production (Source Boehringer Ingelheim Microparts)

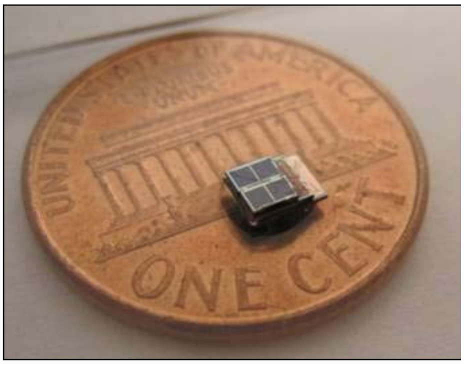
Next generation of smart implants

Major challenges in this area are the development of manufacturing technologies for coating of surfaces (e.g. sensors) and the assembly of the discrete parts to produce micro components. In this context new strategies for smart system integration, e.g. modularisation and new integration approaches, are required.

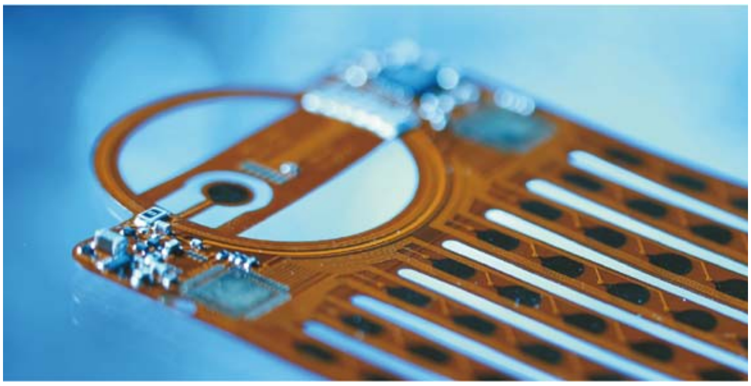
Mini-Pacemaker for Implantation into Heart muscle (Source: Medtronic)



Artificial accommodation system for eye implant (Source: KIT)



ARM Cortex-M3 Processor, Solar cell and Accumulator (Source: University of Michigan)



Prototype of a brain implant for Epilepsy (Source: NMI)

Fig. 25 Examples for MN manufacturing enabled advances in health implants

Advanced manufacturing technologies for production of small and high volume series of bio-analytical consumables

In Health industries currently at least two philosophies seem to compete against each other. On the one hand highest volume production at lowest cost is expected to be the only chance to replace the existing (macro) formats and structures in bio-analytics. On the other hand there is a need for medium series of specialised tests that have to be competitive regarding sensitivity and cost. MNMT technologies will in both cases be a key enabler for the introduction of these technologies into the market

Example: Use of embedded component technology for monitoring of health functions

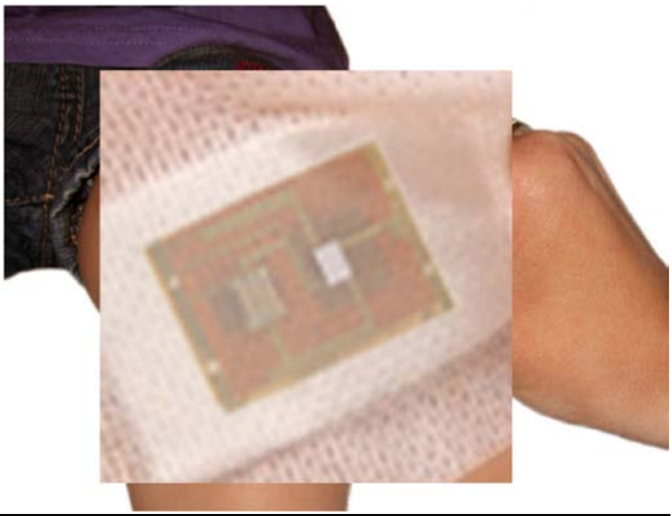


Fig. 26 "Intelligent Band-Aid" Source: Vision by Microtec Südwest,

Example: Use of embossing techniques for smart consumables for life science and in vitro diagnostic applications

Recent developments in the field of in-vitro diagnostics point towards parallelisation and miniaturisation of existing detection methods on a micro and sub-micrometer scale. The benefits of this trend are increased detection sensitivity, a reduction of sample material waste, faster test results and, last but not least, a reduction of cost. Furthermore by combining microfluidics with the array technologies, the "sample deployment" can drastically be simplified in comparison to traditional spotting technologies. E.g., Quanterix Corporation and Sony DADC have recently started to develop a new generation of diagnostic tests based on a Single Molecule Array (SiMoA™) detection technology. With this technique individual enzyme-associated paramagnetic beads are placed in an array of femtoliter-sized wells, fabricated in a DVD-like disc of cyclo olefin polymer.

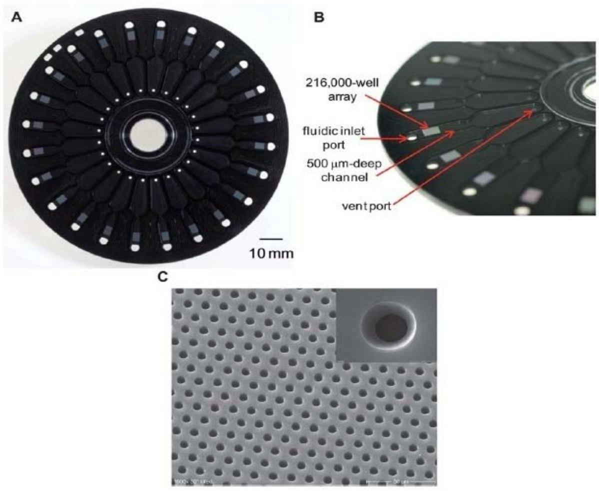


Fig. 27 Source: Lab Chip, DOI: 10.1039/c2lc20744c (Sony DADC)

Flexible and scalable production of smart consumables for life science and in vitro diagnostic applications

Rapid prototyping technologies will allow for a scalable and flexible production of customised micro fluidic devices up to a volume manufacture of 500,000 parts year. Together with improvements in materials and system integration technologies printed bio disposables could become reality.

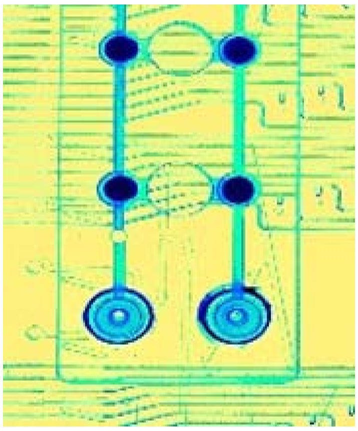


Fig. 28 Source: Aline. Inc.

Individualised production of cells

In order to make patient-specific production of cells available for a wide range of applications[13], patient-specific cell production is expected to gain in relevance. Bottlenecks identified so far include the lack of efficiency in production of personalised cells in terms of quality, throughput, and costs.

From the MNMT aspect this objective will be reached by combining several highly-sophisticated technologies such as

- a modular and scalable concept for the setup of cell production platforms, which is based on plug-ins and allows a flexible composition of functionalities, extension of capacities, as well as fast ramp up.
- a micro-fluidic component which provides a cell culture medium specifically customised for each cell culture.
- Bioreactors with integrated sensor technology, which are capable of highly automated processes as well as the associated incubation component
- the application of a low cost cleanroom and sterilisation concept to keep cell cultures free of contamination from the environment and between different cell cultures. This includes the development of flexible connectors between the fluidic component and bioreactors which have to fulfil sterility requirements.
- optical and biochemical inline monitoring methodologies, which enable the evaluation of cell status within the production process
- a MES (Manufacturing Execution System) with LIMS (Laboratory Information and Management System) functionalities for the control of the automation platform, which includes a self-learning knowledge-based cell behaviour model and advanced cell process control functionalities for self-optimization of cell production processes.

[13] ManuCyte (www.manucyte-project.eu) focuses on the development of an intelligent, modular manufacturing platform for flexible

Microsystems in food applications

The European food sector is the second biggest manufacturing sector in Europe with more than 300.000 companies employing around 4.3 million people and generating an annual turnover of around 1 trillion Euros. The sector is facing several simultaneous challenges that require innovation and new technological solutions: the food industry needs to guarantee food safety, improve process control and quality of the food products, and decrease its impact on the environment while continuing to provide affordable food supply to a growing population.

In the food industry, MNMT-based systems can be used as sensors and diagnostic systems that will detect and quantify a wide range of parameters, including chemical residues and micro-organisms. If necessary also sample preparation and multiplication (micro-organisms) modules can be included. MNT can significantly contribute to the economic benefit of European food industry by providing small and cost-efficient sensors, filters and other structures. They can also help to innovate and improve processes in the food industry, resulting in new opportunities for the industry, improved product specifications or increased sustainability of the sector. Despite this interesting potential, only a few applications have been developed so far.

An interesting example is the Lab-on-foil system that has been developed by IKERLAN within an EC FP7-funded project and is now being commercialised by POC MicroSolutions. The new device carries out sample preparation and detection using an automatic Lab-on-a-Chip based system. Raw samples are used in the verification of the system in order to detect different pathogens (Salmonella spp. Campylobacter spp. and Campylobacter jejuni). Besides the automatic DNA sample extraction, this system provides faster results (45 minutes) than culture systems since real time Polymerase Chain reaction is implemented. The system is currently being verified at a Chicken Farm.

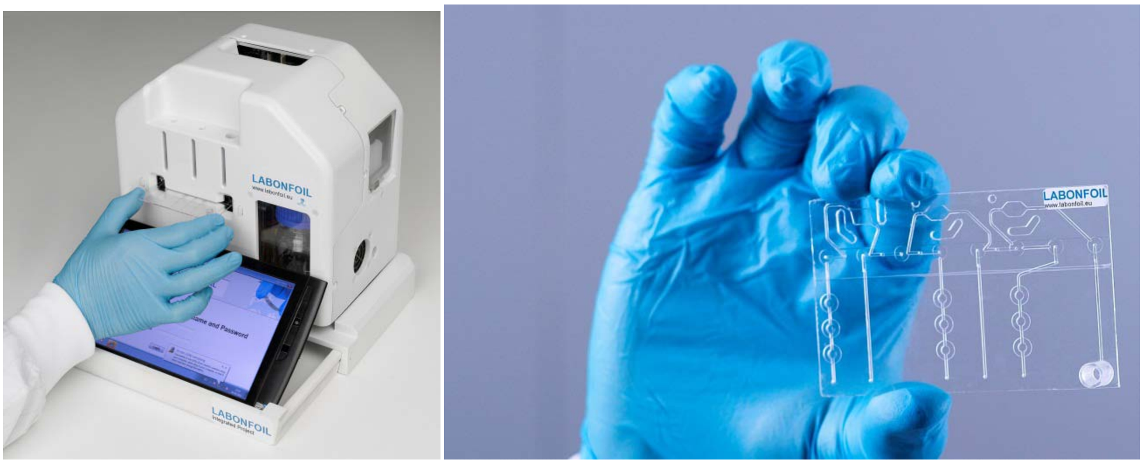


Fig. 29 Lab-on-foil system for pathogen detection in food application (Source: IKERLAN/POC)

Another example is INSION's monolithic spectrometer that combines micro-injection-moulding replication processes, high-end PVD and optical assembly processes. Its product platform is based on the LIGA-microtechnology and has its roots at the Karlsruhe Institute of Technology (KIT). This core technology generates sophisticated mould inserts for the production of injection moulded microstructures at large quantities with consistent quality. Specifically for food processing applications the spectrometer can be used to measure protein, fat, water, starch, vitamin, sugar, etc. Existing applications are in meat/sausage production, animal food quality, and in food safety. Standard commercial process analyzers typically integrate discrete functional modules and usually too large and expensive to do the analysis On- or In-Line with non-destructive methods, thus, a sample has to be taken and prepared for off-line measurements. The microspectrometer avoids sampling errors and allows direct on-line measurements by means of a miniaturized monolithical sensor. This concept delivers increased sensitivity, specifity and robustness and does not require periodical re-calibration.

Fig. 30 UV/VIS-microspectrometer-OEM-System (Source: INSION GmbH)

In 2011, an FP7 Coordination and Support Action „FoodMicroSystems (www.foodmicrosystems.eu)" has been launched to stimulate the application of microsystems and smart miniaturized systems in the food sector by aligning opportunities offered by suppliers and developers/users of microsystems for food/beverage quality and safety with the demands of the food sector. The project provides a review of the possibilities offered by microsystems to the food sector. In parallel, the specific needs of four food chains (meat, dairy, beverage, fruits and vegetable) have been identified and the perception of the consumers and the regulatory context has been analysed. Building on these results, three technological roadmaps will be developed – this will help identify new application opportunities for MNMT but also specify user needs and constraints.

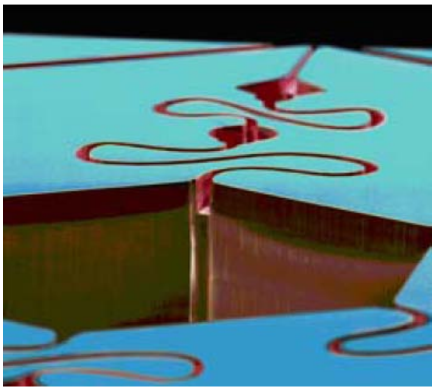
Fig. 31 Applications of different MNMT in the food sector (Source: enablingMNT and Wageningen University)

3.2 Microtechnologies - key enabling technology for next generation equipment and manufacturing of high-tech products

The production sector itself is to be considered as a major application. Applications of MNMT Systems range from specialised sensor developments to the application of advance structuring technologies for security labels with variable information for logistics.

Scalable flexible production of micro parts thanks to scale up of rapid prototyping technologies

In recent years many new developments for the production of small medium series of parts with micro functions have been launched. In most cases replication technologies could be reduced to a lot size of a few hundred of parts in an economic manner.



Meanwhile we see developments starting from the other side. Rapid prototyping technologies are advancing to a stage where it will become possible to produce parts in sufficient quality even for small medium series. First applications are available for less complex parts, but over the coming years we will see a development towards complex systems, building on the application of new printing technologies in combination with further improvements in state of the art technologies for structuring (e.g. laser technologies).

Fig. 32 State of the art Rapid Manufacturing microfluidic device (Source: microTEC)

Scalable flexible production of micro components with integrated functions

Like pictures are printed nowadays, the production of micro components and complete systems can be possible in both, in small and medium-sized enterprises and in home offices with adequate printing equipment. New production technologies building on new materials in combination with micro enabled manufacturing technologies, e.g. in print heads, will revolutionise the production of many Microsystems as well as macro products with functionalised MN surfaces in the near- to mid-term future.

Fig. 33 Printed Sensors for use in a manifold of application areas (Source: Optomec)

New specialised micro sensors for improved production control

Smart Sensors will -together with the latest developments in ICT- lead to new strategies for smart production of all kind of products.

Fig. 34 New Micro Flow Sensor for measurement of Airflow, integrated in a device for monitoring of compressed air (Source: FESTO)

The introduction of new sensors in production plant will lead to a significant increase of the yield thanks to early recognition of failure optimised control of the production process and improved monitoring of production conditions.

"Production" should in this context be regarded not only as manufacturing of parts. In a wider sense infrastructures or food production can benefit from new micro sensors, organised into grids. For the food sector, for example, micro sensors can lead to significant reduction of energy thanks to optimized usage of fertilizer, etc.

Safety in logistics thanks to MNMT

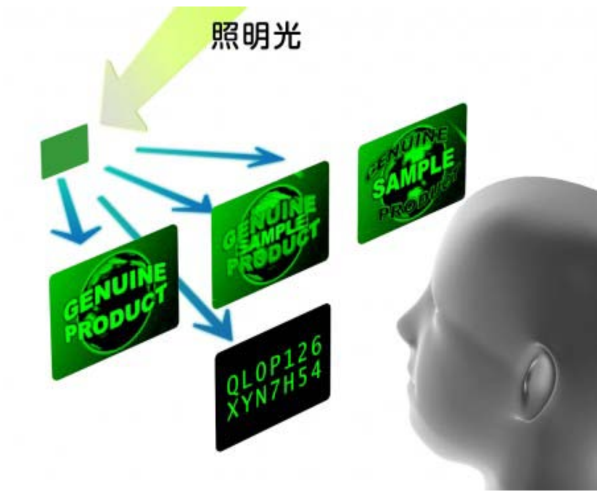


Fig. 35 3D Hologram (Source Sony DADC)

Outlook: MNMT enabled technologies leading to disruptive production approaches

Manufacturing of microproducts without product specific tools related to the production are going to such lengths, that in the future everybody could be able to fabricate their own micro technical product matching their own specific application. Thanks to the developments in printing technologies, coating, and beam based technologies, there exists a realistic chance to see first demonstrators in the next year followed by the development of robust processes by the end of this decade.

4. Roadmapping for manufacturing technologies

The 2011 MINAM survey asked Technology Clusters and European Technology Platforms (ETPs) to identify Technological Bottlenecks along the Supply and Value Chain. The result was quite a balanced distribution of importance of the bottlenecks New Materials, Manufacturing Capabilities, Integrated Products, Design/Simulation Software and Micro Components. Also, the distribution of the identified major challenges remains rather constant over the next 5 areas (which means for both periods 2012-2015 and beyond 2015).

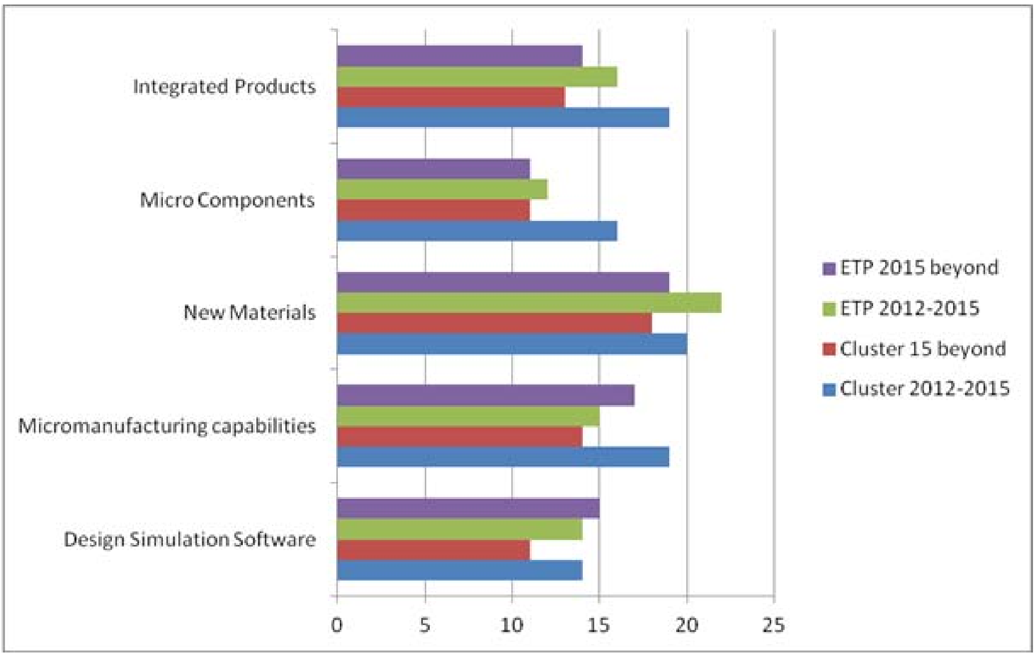


Fig. 36 Technological Bottlenecks along the Value Chain (results of 2011 – Phase 1)

The following chapters describe the identified bottlenecks in more detail.

4.1 Micro components

Micro components are representing the joining element between applications and technologies. From the application point of view they represent some of the enabling components providing essential or additional functionality. From the technological point of view microcomponents are representing the result of a single technology or a set of replication, structuring, coating and assembly technologies (a process chain).

MINAM asked both communities for the relevance of this joining element. On a scale between 0 and 5 the improvement of immature MN components has been considered as "critical" (scale 3-4) but not "very critical". This might result from the fact that for the techno push community the focus is more on the technologies, while the application community has to face other problems as well.

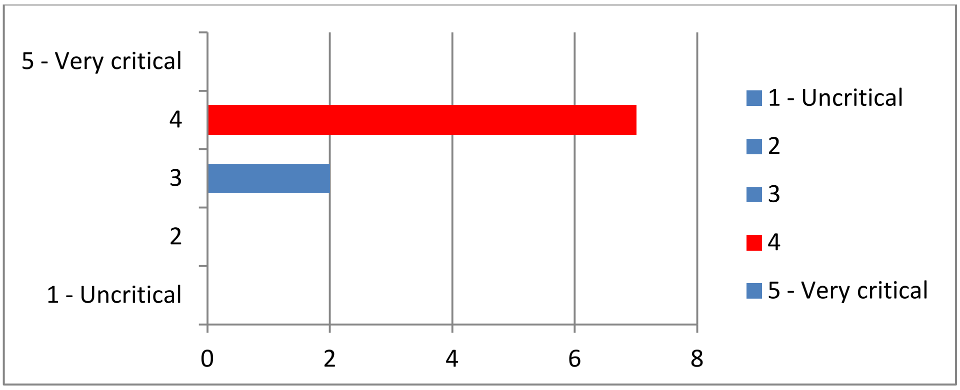


Fig. 37 Improvement immature MN components

When asked for a prioritisation of micro components, "microsensors" were identified as the major issue for now and also as a key issue for the future. The significance of "silicon or multimaterial MEMS" as a bottleneck will decrease, while "microfluidic devices" and especially "micro energy devices" will significantly grow in terms of being a critical bottleneck. Other components such as "RFID / transponders", MOEMS and Micromotors are critical to some but not to the majority of respondents.

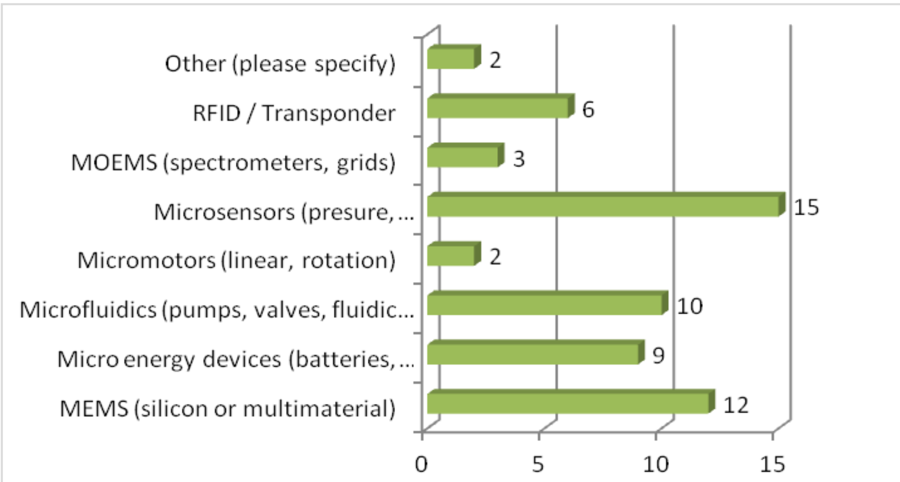


Fig. 38 Micro component bottlenecks (recent, total amount of mentions: 21)

Over the next years the micro energy devices will gain in importance followed by the microsensors remaining on a high level. Microfluidic devices seem to become more important which fits quite well to the forecasts by Yole (see chapter 1).

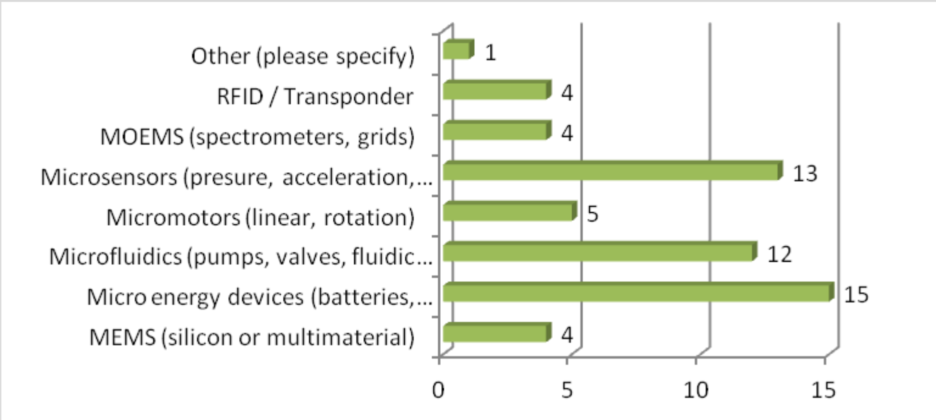


Fig. 39 Micro component bottlenecks (FUTURE, total amount of mentions: 21)

4.2 Materials

When asked for their "TOP 3 bottlenecks" with regard to materials, "nanomaterials" received highest marks, while "polymers", "materials for multilayers" and "composites" were next. Fluids, ceramics, metals and semiconductors were ranked much lower. Similar results were achieved in all three surveys so there seems to be an overall consistency regarding the needs of the developments over the last years. The high relevance of nanomaterials may be tackled by a close interaction with ETPs such as NanoFutures and EUMAT.

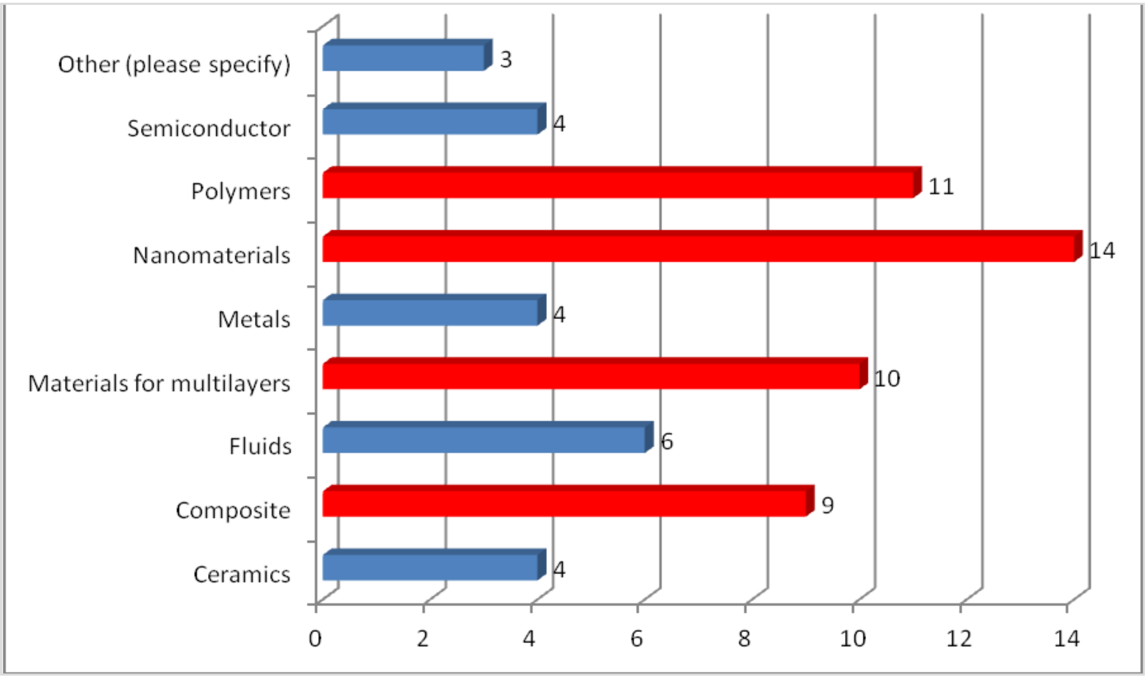


Fig. 40 Material bottlenecks

The more detailed results of the identification of "new materials bottlenecks", differentiated into bottlenecks 2012-2015 and "beyond 2015" show that overall the bottlenecks for materials should decrease over these two time lines, especially "polymers" (which for 2012-2015 is still named the key bottleneck) and "semiconductors". The significance of "metals" remains high with polymers, nanomaterials, multimaterials and composite materials all rather equal for the period 2015 and beyond. Ceramics and fluids are less significant bottlenecks in 2012-2015 and their “scores” will even decrease beyond 2015.

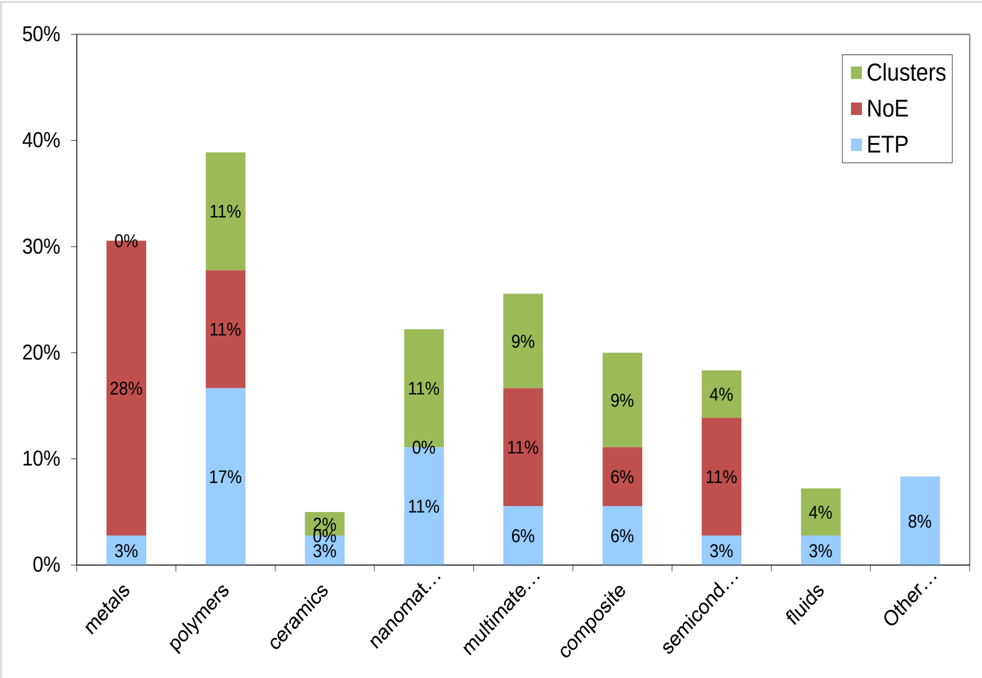


Fig. 41 New materials’ bottlenecks 2012-2015

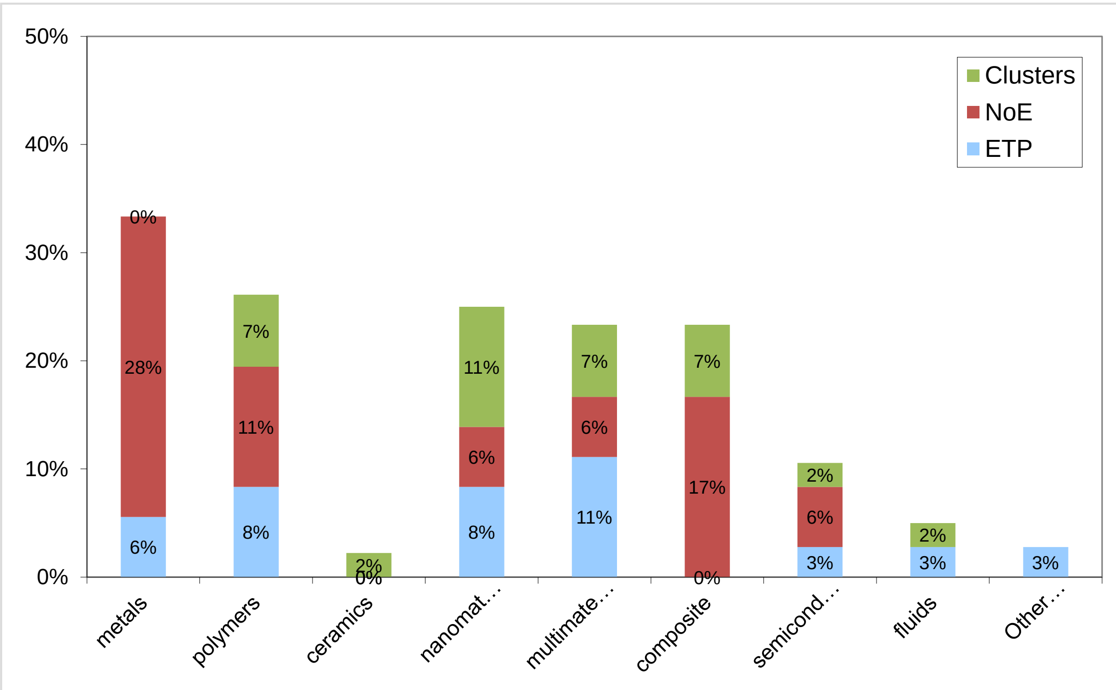


Fig. 42 New materials bottlenecks “Beyond 2015”

Both graphs show a clear focus on metals, polymers and multi (nano)enabled composite materials. New materials are expected to gain importance for the use in MNMT. These overall developments seem to underpin the trend towards advanced material designs and multi-material composites, e.g. „metals-polymers“, as it has been observed over the last years.

Nanotechnology and -materials (NANOfutures roadmap)

While MINAM focuses mainly on manufacturing technologies, scale-up and industrialization issues, another EC-funded Coordination Action (CA), called “NANO*futures*“, addresses the “nano” value chain more from materials’ point of view, aiming to:

- deliver a focused implementation plan up to 2020 within a longer term horizon of actions (>2025);
- address European cross-cutting key nodes in terms of cross-sectorial research, technology and innovation issues;
- cover broad socio-economic challenges to the implementation and commercialisation of sustainable and safe nanotechnology enabled solutions;
- have a market-driven value chain approach with a set of tech and non-tech actions along the identified nano-enabled value chains.

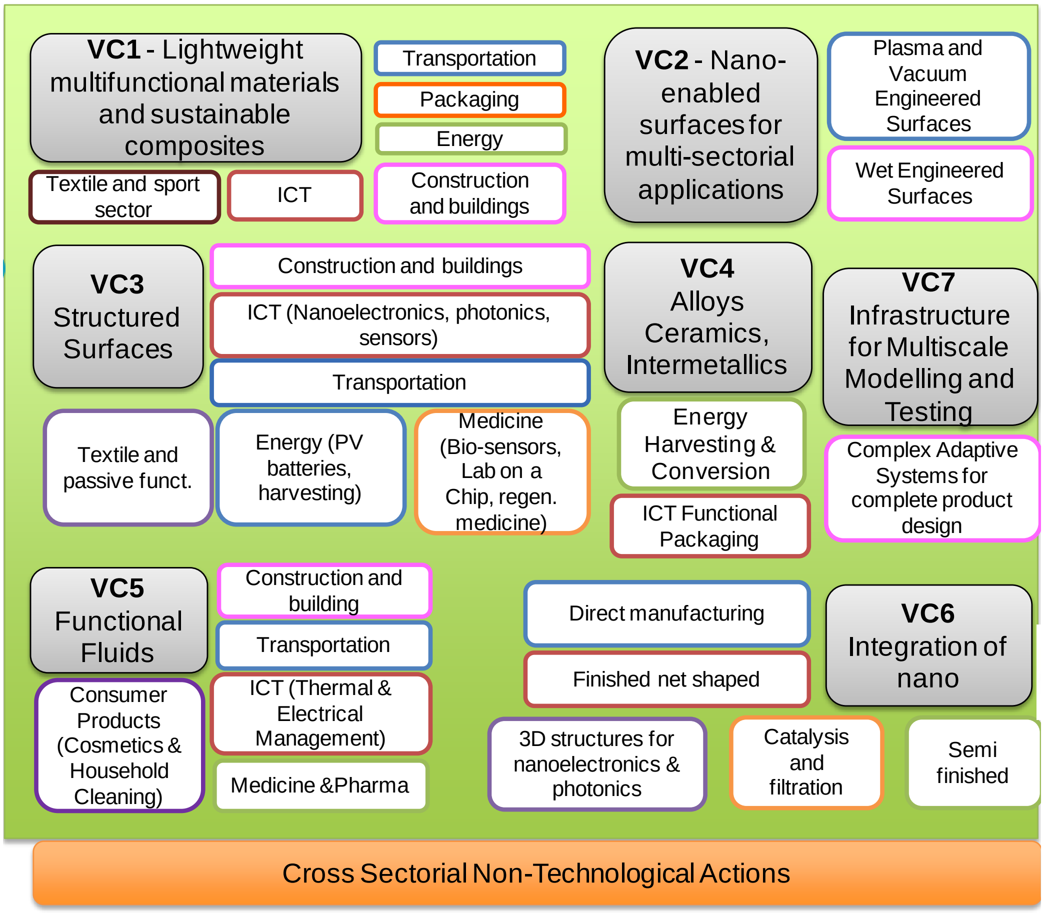


Fig. 43 Overview of the NANOfutures’ nano-enabled value chains and lead markets

The figure gives an overview of the NANO*futures* Roadmap, focused on nano-enabled value chains (grey boxes), which include actions to address industrial needs and research and innovation challenges for the successful development of safe and sustainable nano-enabled products. For each nano-enabled value chain, one or more production chains were detailed, identifying examples of possible lead markets.

The next table summarises the impact of the roadmap, in terms of possible, final nano-enabled products for each industrial sector. See also www.nanofutures.eu

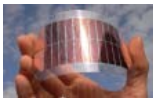
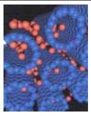
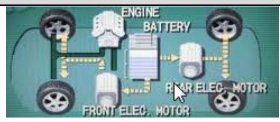
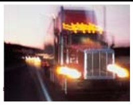
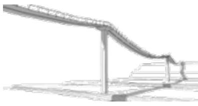
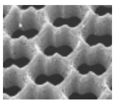
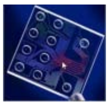
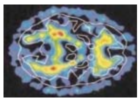
Examples of final nano-enabled products	
ENERGY	     *Advanced Solar cells (Including organic & hybrid PV)*; *solid state lighting (LED, OLED, PLED)*; *Efficient catalysis & carbon capture and storage -CCS (pollution control in fuels, in geothermal etc.)*; *Storage technologies (hybrid batteries, gas, hydrogen). Power electronics for industrial applications and engine management)*
TRASPORTATION	      *Long time, low cost fuel cell membranes and batteries; Low friction engines & lubricants; Smart glass surfaces; Lightweight metal or plastic sheet for chassis; efficient tires, wiper blades, seals; sustainable lightings and heating systems; smart sensors and radar systems*
CONSTRUCTION & BUILDINGS	 *High durability & high productivity infrastructure*; *Self-cleaning/Anti-microbial/solar reflective paints for building envelopes or indoor environment (e.g. HVAC)* ;  *Advanced insulating systems for new and existing building envelopes*;  *Green high performance concrete (CO2 trapping) & recycled building composites*; *Smart integration of technologies (incl. Sensors) at building level* 
MEDICINE & PHARMA	      *Scaffolds and coatings for regenerative medicine (implants, engineered cartilage, vessels, bone)*; *biosensors, like lab-on-chip and micro-TAS, smart pills*; *Nano-pharmaceuticals, biomarkers and contrast agents for theranostics*; *Diagnostic tools (CT, NMR, PET, optical), portable point-of-care devices and nano-imaging*
ICT	 *Lasers (optical communications, medical diagnostics and treatments, manufacturing tools, printers)*;  *ink-jet printers*;  *LCD-, silicon-, LED- and OLED-based Displays and Photovoltaics*;   *Consumer Electronics (smart phones, TV set, digital cameras etc.)*

Fig. 44 NANOfutures Impact – examples of final nano-enabled products , for each target market

4.3 Micro manufacturing technologies

MNMT is considered critical to very critical by most respondents of the survey, whereas some regard this topic as not very critical or even as uncritical. However, looking at the overall amount of mentions MNMT seems to be one of the more relevant topics.

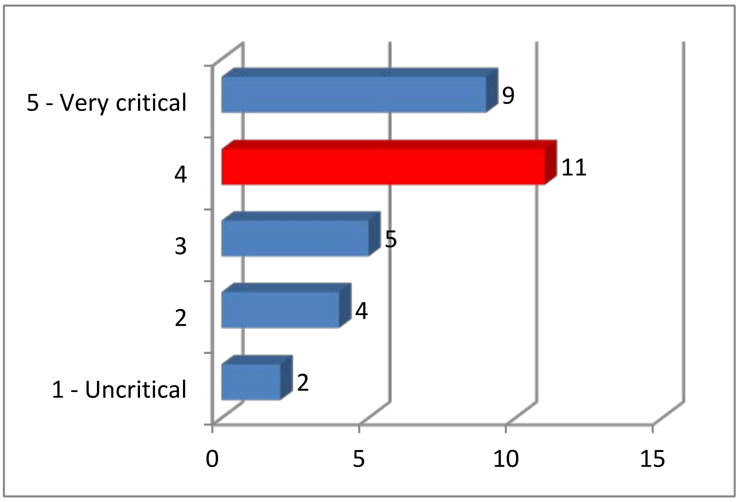


Fig. 45 Micro manufacturing in general

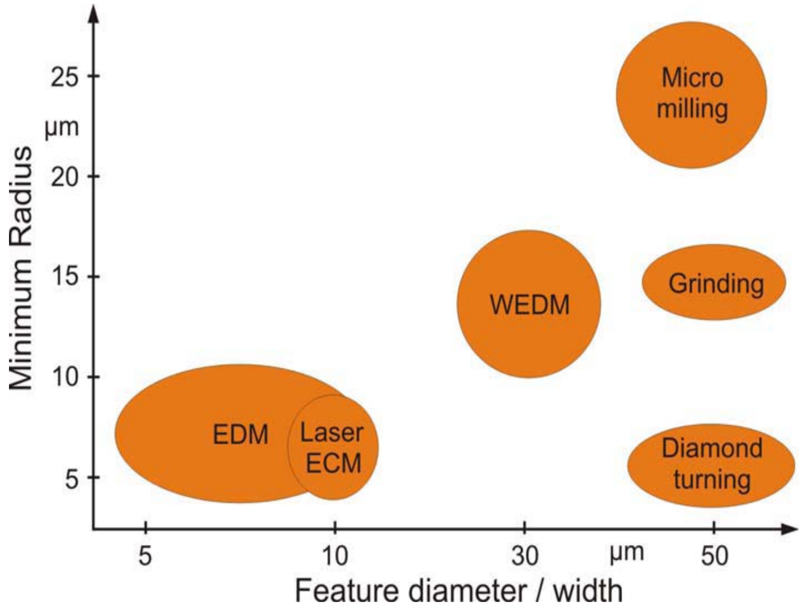


Fig. 46 Dimensions of micromanufacturing technologies (Source: 4M NoE)

Technological bottlenecks in "micro manufacturing" are mainly seen in the areas of "coating", "replication", and "assembling", while EDM, "micro cutting", "beam based processes", and "plasma etching" can be seen as bottlenecks but not by the majority of respondents.

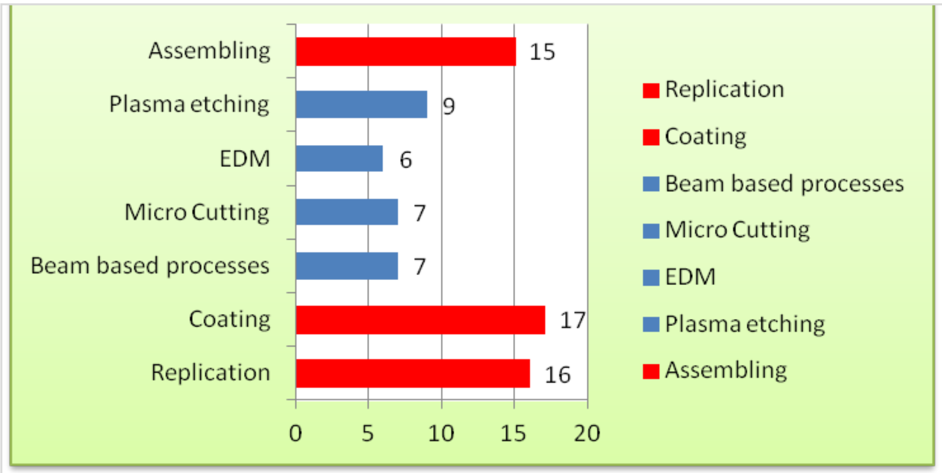


Fig. 47 Technological bottlenecks in "micro manufacturing"

Compared to the results of the 2009 Survey "Replication" remains the most important technological section. Coating technologies seem to gain of importance followed by "assembly" which was ranked very high in 2009 as well, but was treated as a production technology at that time.

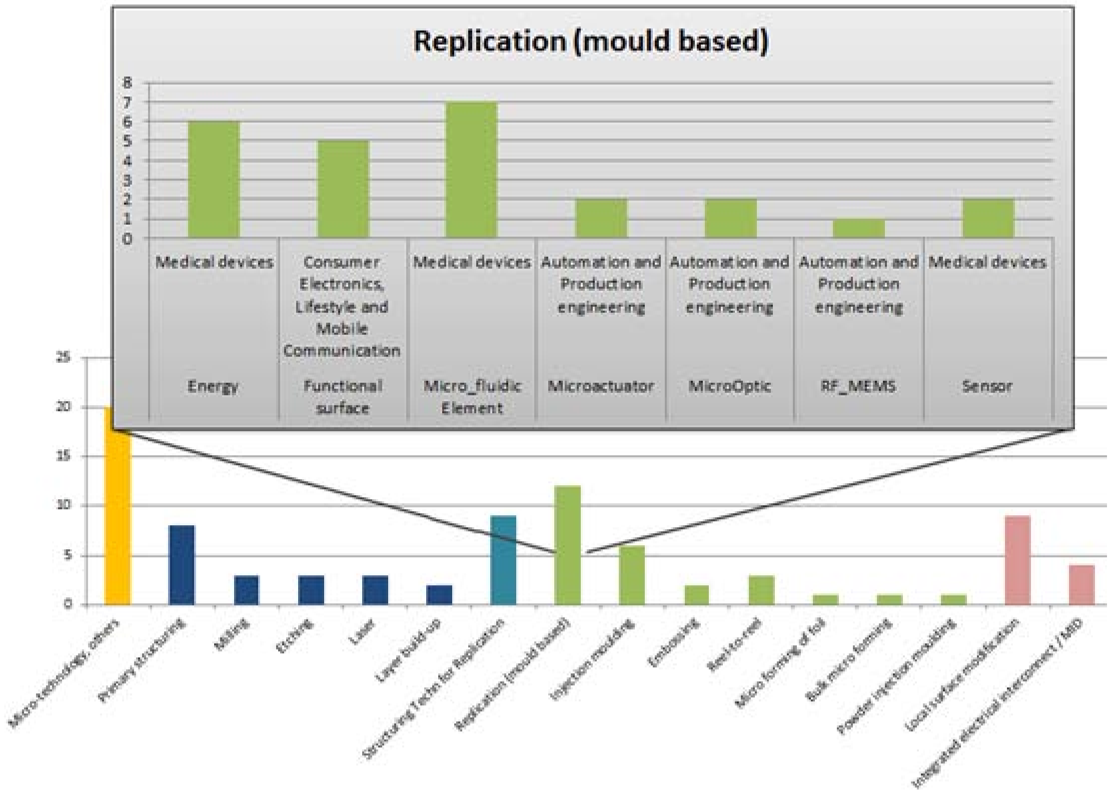


Fig. 48 Detailed analysis of MNMT (2009 survey)

When looking closer at the details of MNMT, **the development of "new processes/technologies"** receives highest scores in terms of being "very critical" or "critical" for the success of MNMT by the participants of the survey.

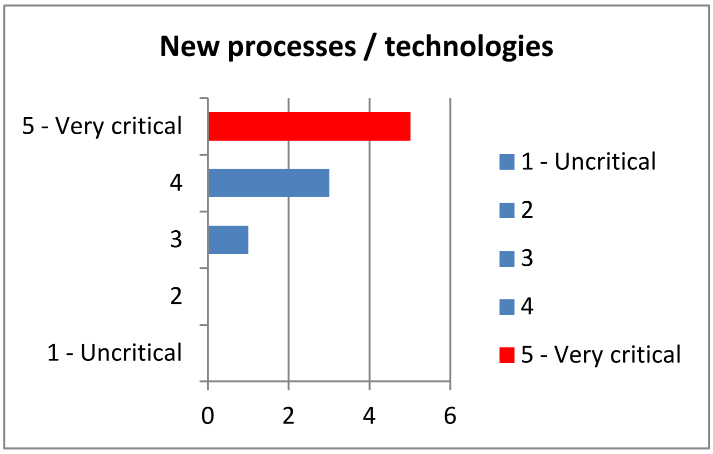


Fig. 49 New processes / technologies

➔ MNMT Processes are still one of the most important topics for the MINAM community!

4.3.1 Micro coating bottlenecks

For "micro coating", the major bottlenecks mentioned are "chemical vapour deposition (CVD)" and "physical vapour deposition (PVD)", while "sol-gel", "thermal spraying" and "epitaxy" seem to be the less critical coating technologies.

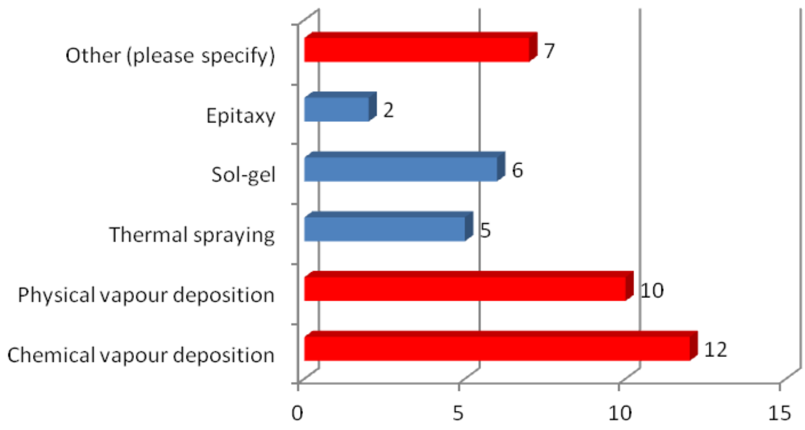


Fig. 50 Coating bottlenecks

Remark: Unfortunately MINAM did not explicitly ask for bio-coatings. With the growing relevance of all kinds of health and food applications the precise coatings of reagents, e.g. for bioassays, becomes more and more important. Limitations often relate from spotting equipment with limited capabilities in microfluidics or accuracy.

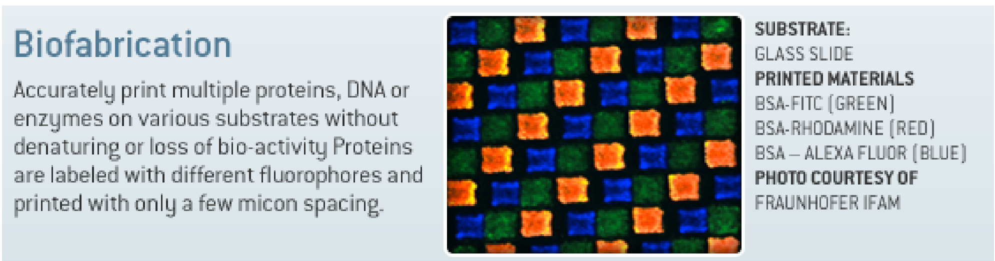


Fig. 51 Biofabrication example (Source: Optomec)

4.3.2 Micro replication

From all micro replication technologies used in MNMT industry so far, "micro-injection moulding" and "embossing" have been identified as major bottlenecks, while "micro-forming" and "micro casting" were not considered so critical.

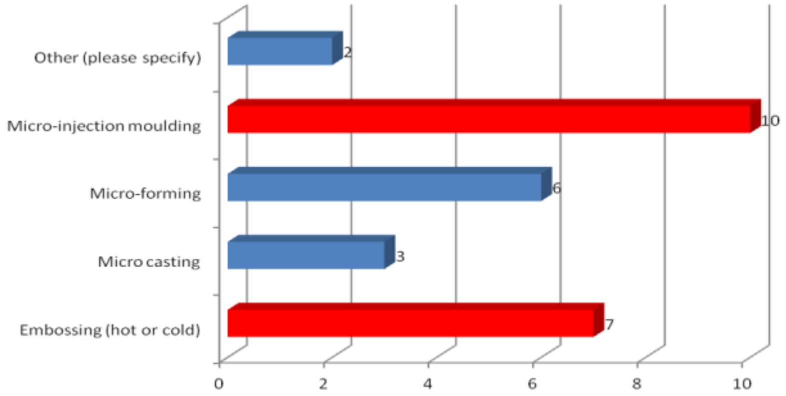


Fig. 52 Replication bottlenecks

The further improvement of conventional replication technologies towards more accurate and integrated solutions in different areas can help to identify relevant thematic areas over the next few years. New polymer and metal devices for application in Medicine, large scale surface structuring for application in energy, as well as precision parts for production, are expected to be seen by the community.

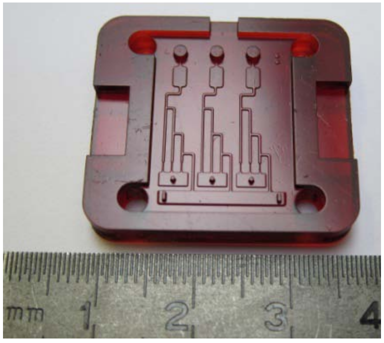


Fig. 53 Micro-embossed free standing structure with aspect ratio of 7 (Source: Cardiff University)

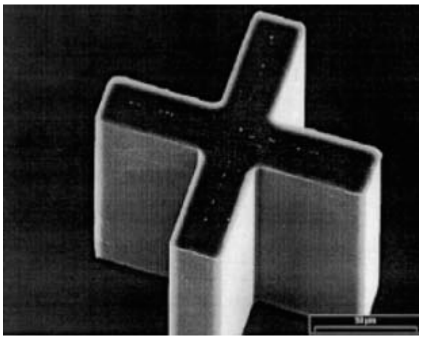


Fig. 54 Micro-embossed free standing structure with aspect ratio of 7 (Source: Becker H.)

Trends in micro injection moulding

In recent years injection moulding for micro parts, polymer parts with micro features or parts with a micro or nano structured surface topography has become a decent process for high throughput production of polymer. Micro injection moulding has proven to be a cost effective and reliable process to replicate polymer micro components for large to medium size batches. Nevertheless for future development a few recent trends can be identified.

For the *production of very small numbers of components in the final material* with the final process (proof of concept studies), the manufacture of injection moulding tools in mould steel can't be justified because of high costs. Recently this has been addressed by producing mould inserts utilising micro rapid prototyping processes such as micro stereo lithography – at least on an R&D level and for very small batches. With that this process chain has shown its potential to replicate small numbers of polymer parts in a very cost effective way.

The trend towards the replication of nano size components in particular with high aspect ratio can be reported as well, e.g. for the replication of components with optical properties.

Advanced process monitoring and process control which has demonstrated the potential in macroscopic injection moulding contributes to a more reliable and optimised quality control and management in micro injection moulding these days. The development of new (smaller) sensors for cavity pressure allows a closer monitoring of the process.

New materials such as amorphous metals e.g. bulk metallic glasses are ideal to overcome the bottle neck between mould manufacture and the replication process. BMG's properties and are ideal for miniature application; the amorphous structure provides a perfectly homogeneous and isotropic material with superior mechanical properties over conventional MEMS materials.

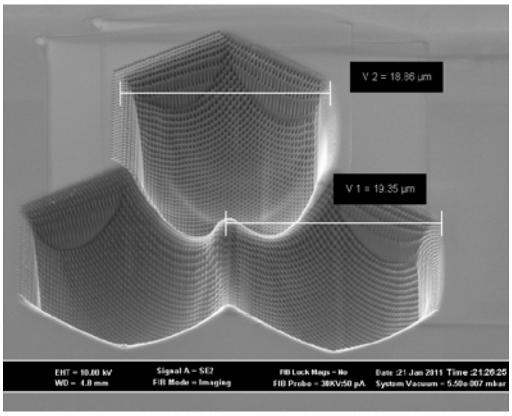


Fig. 55 Bulk metallic glasses as promissing mold material for mass production of bio inspired micro- and nano polymer parts (Source: Cardiff Univ.)

For example processes like focus ion beam machining which are ideal for nano structuring mould inserts require amorphous material. On the other hand these amorphous materials (typically silicon) can't be used for the injection moulding process because of the brittleness of the material. Bulk metallic glasses have shown their potential for structuring and micro injection moulding as being amorphous and hard, tough and ductile enough for the replication. In addition the extreme hardness of these new materials offers high durability tool inserts and therefore a high number of replicas without any wear.

Another field of interest where recent research is going on is in *length scale integration*. The aim is to directly functionalise a polymer part without any post processing by integrating MN features directly into a macroscopic part.

<u>Advanced replication technologies – key enabler for smart systems integration</u>

In micro replication, especially when it comes to high volumes, there is a clear trend towards function integration. Technologies such as3D MID are in the focus of ongoing development. Laser direct structuring, multi component injection moulding and printing technologies are gaining more and more importance.

<u>Next generation MID</u>

Moulded Interconnect Devices (MID) are electronic components, based on injection moulded polymer carriers with applied electrically conductive circuits. Typical areas of application are telecommunication technology (cell phone antennas) and parts for the automobile industry.

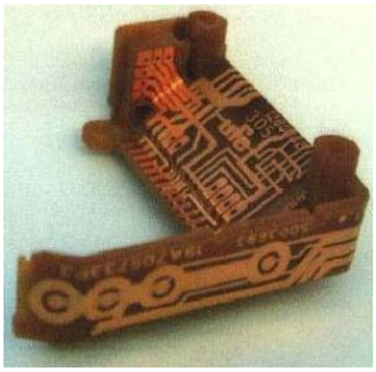


Fig. 56 Component with 3D MID electrical interconnects on the surface

A major advantage compared to classic SMD technology is the possibility of three-dimensional assemblies, which can be adapted to a limited working space or to complex shapes. However, the technology is still limited by the accuracies of the moulded components and particularly the shapes of the conductive circuits. A development towards more accurate MID assemblies is ongoing.

The market volume of MID technology grows continuously (2004: 10.7M€, 2005: 14.1M€, expected volume 2008: 56.2M€, source: Wikipedia, 2012-06-11) and with new emerging innovations and improvements around MID, the technology is expected to further develop and expand to further markets.

Challenges in scale up - Automation of MID processes

The preparation of MID prototypes is still quite expensive, as elaborate forms for injection moulding are required. Research activities for the simpler realization of MID prototypes are ongoing. Approaches include prototyping with 3D printing technologies. Furthermore optimization of the throughput and degree of automation are required.

Fig. 57 R2R MID production integration
Source: Microtec Südwest (Pronto R2R MID project)

What we will see next

There is a trend towards flip-chip assembly onto MID components, which is currently not state-of-the-art, but is part of current research activities. While the moulded component is often free-formed and complex shaped, the surface mount assembly is mostly performed on even surfaces.

<u>Polymer film based technologies – another emerging key technology for smart systems integration</u>

An alternative for the production of thin components are foil-based technologies. These are typically reel-to-reel based, apply printing as well as laminating technologies and allow for high throughputs. Typical areas of application are the production of RFID cards, display foils or touch-sensitive foils.

A promising new technological area can be observed in the printed electronics. New equipment developments have already started to lower the limits in accuracy and thickness of the film.

Even if printing technologies have been introduced years ago, significant R&D challenges remain to be tackled during the next years in terms of precision, characterisation of high throughput and system integration.

Fig. 58 Flexible and conformable 3D sensors with plastic substrates allowing any form factor (Source: ISORG).

Challenges in Polymer film processing: Positioning Accuracy

For the assembly of microsystems, the relative positioning accuracies of conventional reel-to-reel technologies are not sufficient. Currently about one third of state-of-the-art microsystems require positioning accuracies of less than 5µm. With the ongoing trend to miniaturization, the demands in positioning accuracy will further increase.

R&D activities are required to support the development of novel reel-to-reel positioning technologies within the next 5-7 years.

Challenges: Hybrid Integration of components in roll to roll processes

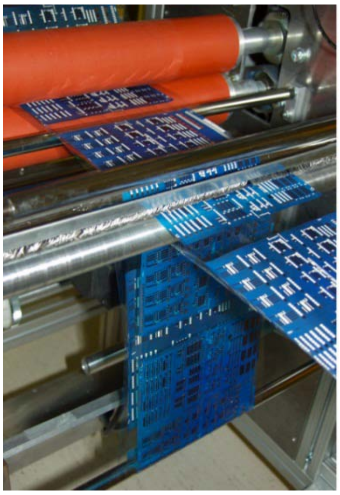


Fig. 59 Roll-to-roll processes

The hybrid integration of micro components is a key element for the production of most microsystem assemblies. Automated hybrid integration of components into roll-to-roll-processes is not possible in many cases. New technologies for positioning, joining and testing are required. Research activities, e.g. in the EU-project “Lightrolls”, show that new ways, e.g. based on self-alignment, are possible ways to realize the combination of ultra-high precision and high throughput.

The availability of these novel technologies is expected to allow the production of microsystems in further fields of application. Point-of-care diagnostic systems, ultra thin and flexible sensors or flexible displays could be just some of the many possible applications.

Similar demands were identified in other areas, where printing technologies can support an optimisation of today’s technologies. As an example, the use of new printing technologies in PV industries to lower the problems resulting out of shadowing or damage of cells.

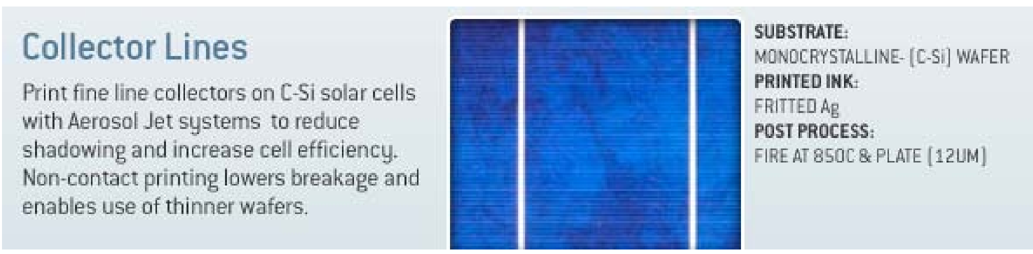


Fig. 60 Collector Lines produced through printing (Source: Optomec)

Challenge: Production of large scale nano structured films for reduction of energy consumption

Several efforts have been invested over the last years to developed large scale nano structured surfaces for application in building and mobility. Nevertheless accuracy is still a relevant issue for the production of the required tools.

Fig. 61 Application of Nano-structured Films to reduce air drag

For example the application of transparent sheets with a ribbed structure in the longitudinal direction, used on the commercial Airbus 340 aircraft.
It is expected that riblet film on the body of the aircraft can reduce drag of the order of 10 per cent. Similar approaches are utilising the shark skin effect to achieve similar results

Besides the further development of this specific structure the application of bio-inspried effects and their extension towards more integrated functionality (e.g. Organic Photovoltaics) still need to be developed to industrial readiness over the next years.

<u>Outlook: Integrated approaches, building on advanced printing and replication technologies for the economic production of small series</u>

In contrary to the demand for high volume low cost, the customization of products is an ongoing trend in the last decade. Customers demand increasingly individualised products, which is a permanent challenge to the production companies.

Furthermore, many microsystems are produced in smaller lots, of the order of a few thousand pieces per year, which makes economical realization of such a production run often impossible. Thus, novel and innovative ways for the production of microsystems are required, which allow for economical production in small to medium lots whilst permitting a maximum degree of individuality. 3D-printing has the potential to meet these requirements. State-of-the-art rapid prototyping technologies are either very precise but slow, or fast but coarse. A combined precise and fast technology would enable the production of parts, or components, in many fields of application. Examples have been shown for biomedical microsystems, sensors, miniaturized actors and many more.

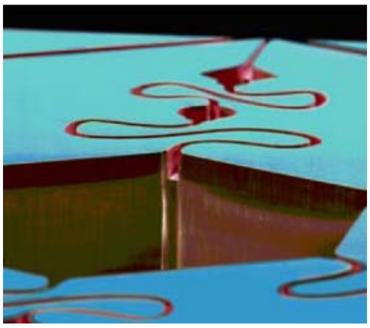


Fig. 62 Microfluidic device (source microTEC)

4.3.3 Micro structuring

Mechanical, e.g. diamond machining and micro milling, and energy assisted processes, e.g. EDM, ECM, e-beam and ion beam machining, and ultra-short pulse laser ablation and excitation are technologies that could provide the necessary 3D structuring capabilities on a wider range of materials. Typically, the materials machined by these processes are the same as those used in macro-manufacturing [20], and include an extensive choice of metals, polymers and ceramics/glasses.

Micro structuring technologies has been categorized into four main areas, with the bottlenecks being analyzed for each of them. For “beam-based processes”, major bottlenecks are “photo-lithography” and “laser cutting”; in the area of “plasma etching”, “reactive ion etching (RIE)” and “deep reactive ion etching (DRIE)” are the critical technologies; in “electro discharge machining (EDM)”, wire “EDM” is key; and for the “micro cutting” area, “micro milling” is the major issue to be solved.

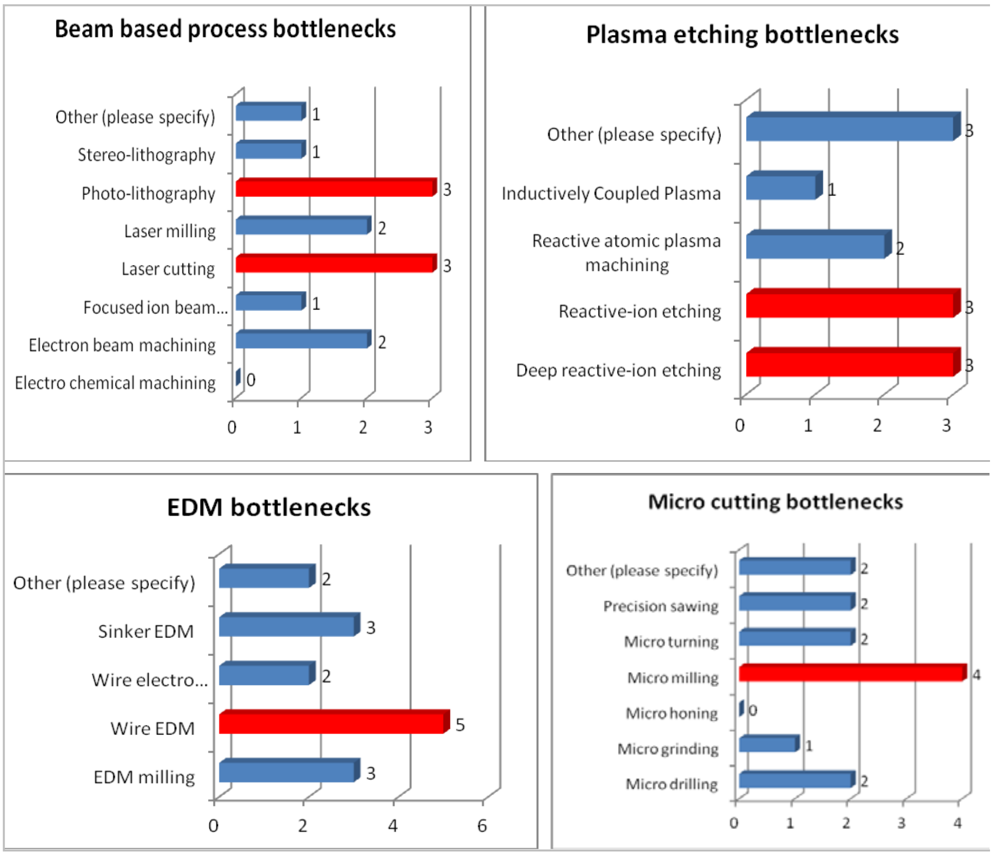


Fig. 63 Microstructuring technologies

Micro cutting

Micro milling has proven to be a reliable and mature process for micro structuring. In order to address the challenges in ultra high speed micro milling recent research is developing precise models and strategies to compensate for the heat expansion of micro milling tools. Furthermore algorithms and techniques for accurate detection of micro tool breakage are under development. This is crucial in order to restart the milling process with a new tool at the position where tool breakage has happened and the machine path can be re calculated accordingly. Another relevant field of interest in current research is the wear behaviour of ultra small micro cutting tools, in particular in combination with harder work piece material such as mould steel. These are only a few examples of current research in the area of micro milling.

Trends in beam based processes - laser

Laser technologies: In laser material processing the application fields of the green energy technologies is a strong growing issue. In the last years especially the solar industry was pushing different laser technologies such as laser micro scribing, micro drilling and thin film patterning/structuring including a successful scale-up of those technologies for economical fabrication processes.

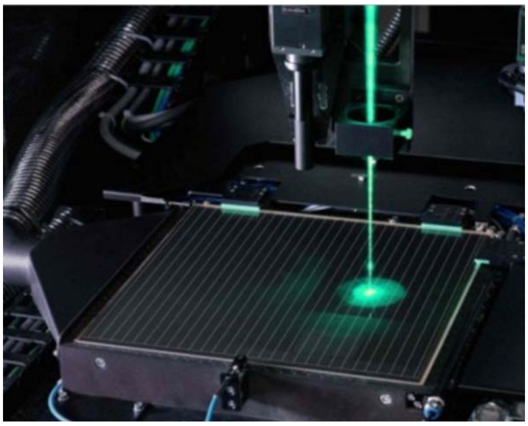


Fig. 65 Structuring and through-contacting of SI-Wafers (Source FZ-Jülich)

New trends in application-oriented laser processing are to use ultrafast laser systems instead of nanosecond laser pulses. This is also a current research topic in laser structuring and micro drilling of solar cells. Ultrafast laser systems (picosecond or femtosecond laser systems) enable a significantly reduced thermal impact which is extremely important for the treatment of functional and electronic doped materials such as solar cells and thin films. Today, picosecond laser systems seem to be more appropriate than femtosecond laser systems because of available laser power, scale-up properties (i.e. high repetition rates) and laser system costs. Nevertheless, new and advanced “ultrafast” fibre-based laser systems have the potential to overcome these limitations.

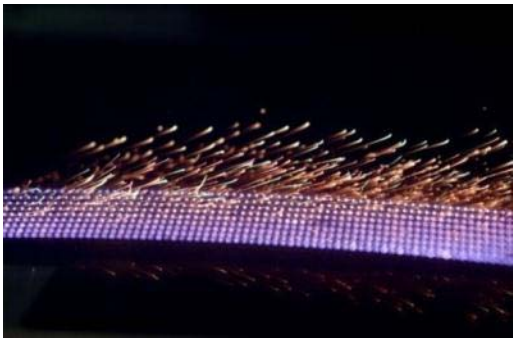


Fig. 64 Parallel drilling of micro holes in a wafer for new contacting strategies in contacting of PV cells (Source Fraunhofer ILT)

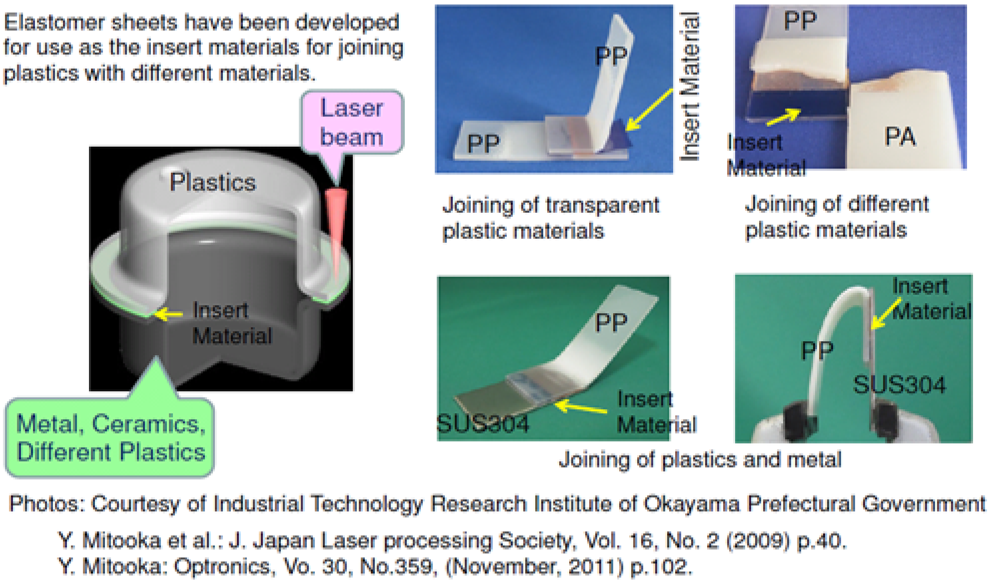


Fig. 66 Example: Joining of different materials, insert materials

Other beam based technologies such as some lithographic processes offer the potential to manufacture specialized applications for ultra high precision or luxury goods in a new dimension of quality. To sustain Europe´s position in these –so far- niche areas significant efforts will be required to not only develop technologies with a potential to take large scale manufacturing a step further, but to also support the improvement of technologies covering the "high-end" level towards more robustness and scalability.

Fig. 67 Beam based production of Ultra precision part for luxury watches (source Microworks)

However, to undergo micro or nano structuring successfully the selected materials have to satisfy specific requirements, e.g. they should be homogeneous and inclusion-free at the considered scales. In particular, to produce nanostructures or surfaces with sub-50 nm roughness, atom cluster and atomic processing is necessary, and hence machining/structuring with processing units in the range of from 0.1 to 10 µm, 1-100 nm and 0.01-1 nm, respectively for the considered scales, and specific processing energies are required.

4.4 Production integration & smart system integration

Over the last years a clear trend towards robust, low cost systems with enhanced functionality can be observed. Organisations such as EPoSS provide roadmaps showing how these integrated systems will change our daily life over the next decade[14]. It is apparent that this next iteration in system development will again require a dramatic change in today's production paradigm.

[14] http://www.smart-systems-integration.org/public/documents/presentations/presentations-at-ssi-2012-in-zurich-21-22-march-2012/2012-03-21_SSI%202012_EPoSS%20Session%202_01_Guenter%20 Lugert_Siemens_Sessions%20Programme_Introduction.pdf

This will be at least a significant improvement of the existing production technologies or –much more likely- a disruptive change in manufacturing technologies as well as philosophy.

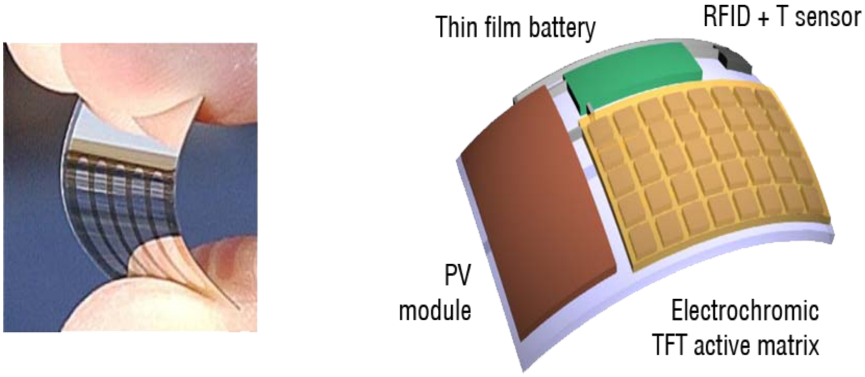


Fig. 68 smart devices and films based on an electro-chromic (EC) thin film transistor matrix (Source: EC Project SMART-EC)

The key aspects for success in MicroNano Production within the next years" were initially extracted from the MINAM 2009 survey (based on 1278 mentions for 13 topics): "desktop factories", "new business models", and "self learning production environments" were identified as key factors with "sector-specific compatibility demands" and "manufacturing system design modelling simulation" next. Even the detailed feedback from the community this

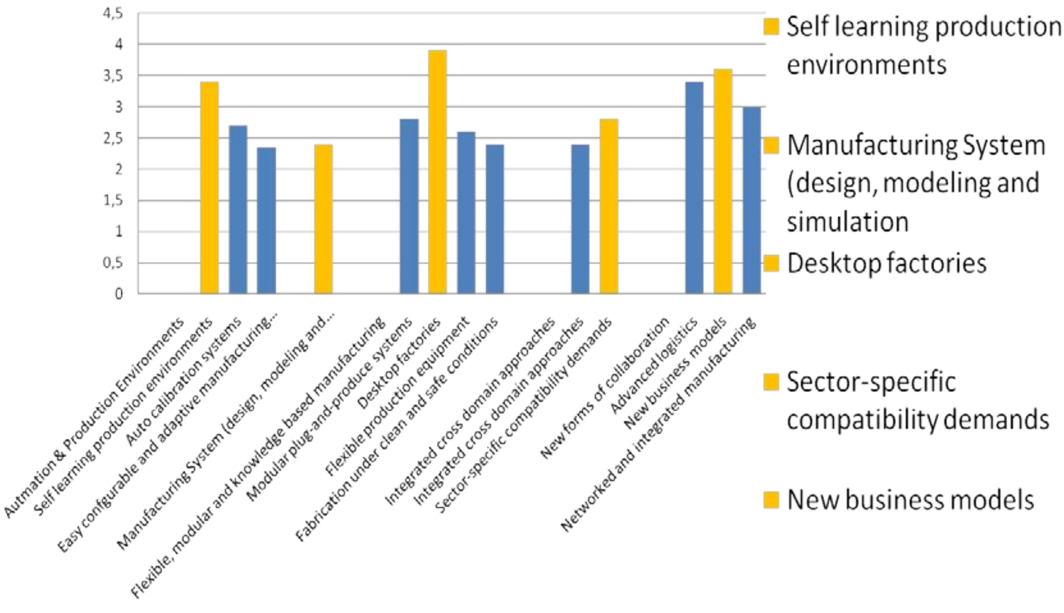


Fig. 69 Major challenges in production (Status 2009)

The following subchapters give an overview of what the MINAM community expects to see next in this area.

4.4.1 Equipment integration

System integration leads to more independency, interoperability and an efficient information flow with a simultaneous reduction in effort of maintenance and complexity. Different disciplines/modules are supposed to work together and communicate in a consistent and effective way. This will be approached by a new generation of modular, knowledge intensive, scalable and rapidly deployable systems. The manufacturing system has to fulfil the typical requirements for MN production.

MN production demands specific approaches, in particular, incorporating novel manufacturing technologies into intelligent, adaptive and scalable systems. Adaptive manufacturing focuses on agility and capability to permit flexible, small-scale or even single-batch-oriented production through the integration of affordable intelligent technologies (e.g. integrated sensors) and process controls for optimal efficiency.

Moreover, the ever increasing demand for accuracy and precision in manufacturing processes constitutes a specific challenge with regard to aspects such as calibration, reproducibility, etc. In this way it should be possible to combine MN manufacturing equipment and process aspects with specific know-how including robotics, cognitive information, optical sensor and production control with real-time capable information and communication systems.

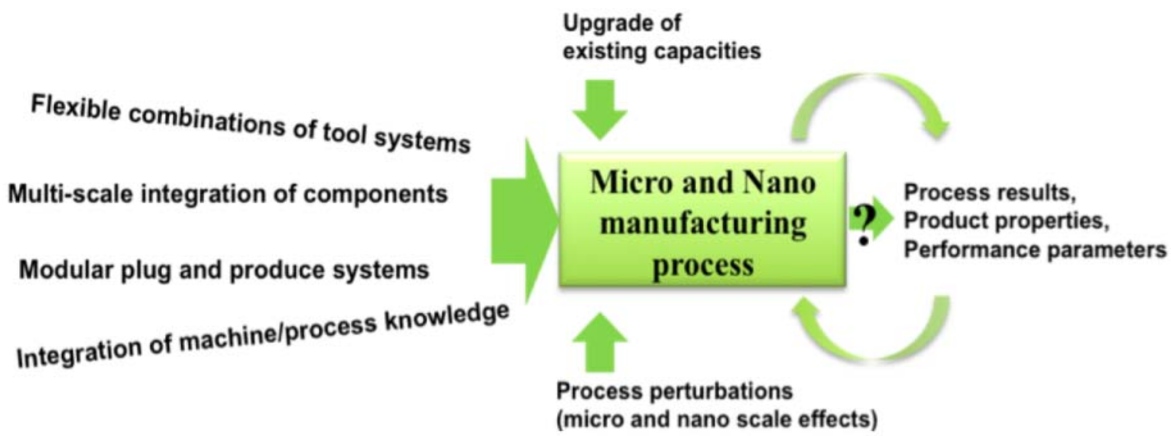


Fig. 70 Challenges to face along the development of MN equipment (source: University of Nottingham)

This requires not only a new generation of systems integrating high precision actuating and tooling solutions, but also intelligent auto-calibration (reacting autonomously to changes in material and environmental properties, tool wear, failures, etc.). The adaptability of the MN manufacturing systems and platforms should also include scalability in order to be able to match changes in the requested production volumes. Ideally, the same manufacturing system should be capable, by means of small configuration changes or by the integration of new modules, to optimise the process parameters under different production schemas, ranging from single products or small series production to large-scale mass manufacturing, and to swiftly adapt to processing new types of components or raw materials.

Fig. 71 Desktop Assembly System (Source: Bosch)

Furthermore, new platforms integrating multiple manufacturing technologies are currently being developed. These platforms combine the advantages of different technologies (e.g. subtractive laser milling with additive 3D-MID). Such approaches significantly increase manufacturing process flexibility and the ability to manufacture multi-material and multi-functional products in a simple and fast manner. These approaches also minimize the need for product handling between different production stages. Therefore, it is expected to see rapid development of such multi-technology platforms in the future.

4.4.2 Assembly

Assembly of MN systems: The ongoing development of intelligent and highly integrated products (e.g. lighting, optical or identification systems) requires the assembly of devices smaller than 500µm (e.g. LEDs, RFID chips and lenses). It is not possible to handle the required components with conventional handling- and assembly-hybrid techniques anymore, as conventional handling- and assembly techniques are limited in the case of the increasing degree of miniaturization.

Further development of "conventional" assembly technologies

The 2009 survey had addressed the importance, combined with a timeline, for a set of assembling technologies. Here the results showed that "joining processes" and "positioning and feeding", and to a lesser extend also "grippers and end effectors", were important issues for the years 2009 to 2016 but seem to be solved for the further future, while integration issues and other (new) assembly technologies still have a requirement for new research beyond 2016.

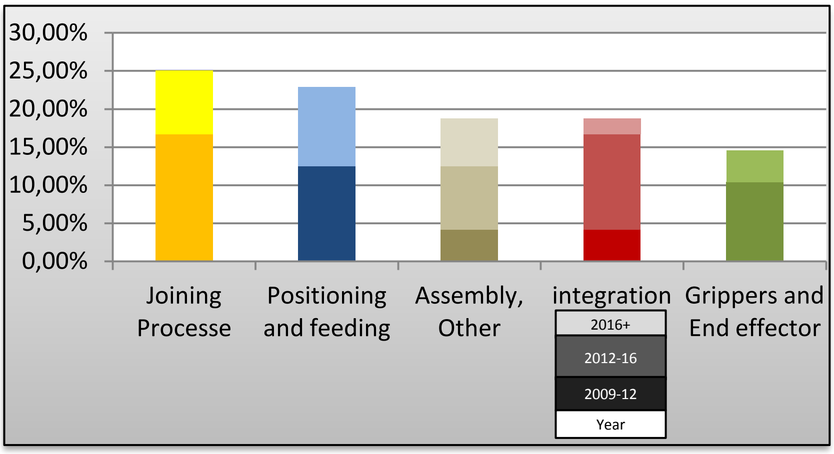


Fig. 72 Priorities in "Assembly" identified by the MINAM community (2009)

The EUPASS Outlook Report15 on the Future of European Assembly Automation highlighted that European R&D needs to focus on the following key factors behind rapid deployment of modular systems: a) referential architectures, b) advanced interfaces, and c) distributed control solutions. European R&D needs to seriously re-assert the validity of scientific innovations that may support adaptability, evolvability and fault-tolerance. Emergent behaviour, multi-agent architectures, and self-diagnosing systems should be highlighted.

Looking at MNMT production technologies and more specifically at the assembly, the precise positioning of the MN component in the assembly line is by far the major bottleneck. Gluing, packaging and releasing are next on the scale of critical steps, while other steps have been mentioned only by a few manufacturers.

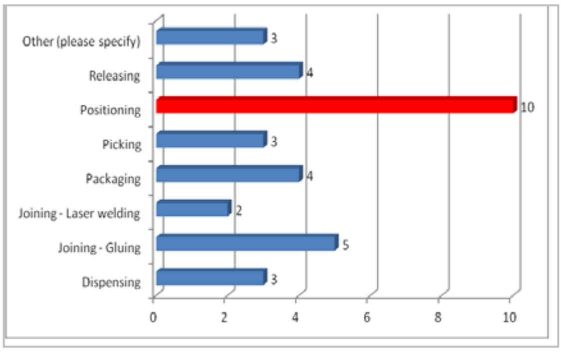


Fig. 73 Assembly related bottlenecks (2012)

Upcoming: Self Assembly and self organisation

New methods, based on the self-assembly effect are required and need to be made available for industrial applications. Nano-scaled structures on the substrate surfaces provide the basis technology and cause a reliable positioning, interconnection and electrical contacting of the devices. In particular research is required on the handling and feeding of micro-parts using self organization. New methods to generate localized nano-scaled surface structures on free-form surfaces of geometrically complex or flexible substrates, and methods for self-alignment of micro-parts on pre-structured free-form surfaces of geometric complex or flexible substrates are required. Additionally methods for self-organized interconnection and contacting of mounted micro-parts with very small pitches are a missing part. Novel assembly processes for the integration of micro-parts into geometrically complex or flexible substrates will give an enormous push to realise highly integrated products in a small- and medium scale production.

[15] Outlook Report on the Future of European Assembly Automation, EC Project EUPASS , 2009 EUPASS

Surprisingly, the development of "new hybrid production systems" is either considered (very) critical or completely uncritical, while no-one considers it medium critical. The reason for this seems to be the very diverse focus of manufacturers in terms of application areas and/or components/technologies used.

The contrary result was given when asked for "new methods for handling and processing" – there respondents agreed that this issue is of medium importance; no-one considered it either very critical or uncritical.

European R&D in adaptable/sustainable assembly systems needs to re-establish a common vision and develop its main deliverable: A methodology that describes how one may achieve an evolvable system solution. Underline that adaptability stretches from autonomous setups to self-modifying system components: the modules/components need to be rapidly & extremely adaptable (evolvable) in order for the assembly system itself to become adaptable.

4.4.3 Clean production

The requirements regarding production cleanness – e.g. ABS, Common Rail – have been constantly increasing in the past few years. As a consequence of that, a big effort is put into the cleaning of each component and the quality of cleanness has to be controlled before delivery / subsequent processing.

Fig. 74 Planning ultraclean systems and equipment design (Source: Fraunhofer IPA)

The challenge in this area is, that the production parts are permanently exposed to particle source during the subsequent processing, e.g. to assembly facilities and the working environment, to joining technology, to assembly tools or to logistics. Thus, despite clean individual components, it often fails to manufacture clean systems and units. Therefore, one of the main goals is the planning / optimization of the assembling manufacture to meet the cleanness requirements. Another aim regarding ultraclean manufacturing is to find an efficient solution that leads to an amelioration of product cleanness and which prevents bad investment.

4.5 Production planning, monitoring and characterization

With an increase in the costs for the MN enabled systems, any kind of technologies that will help to decrease the risk of failure in the planning and production of parts will be very welcome. MINAM asked the community to provide an estimation on relevance of the different related thematic areas:

4.5.1 Design and Simulation

Design & simulation are considered of medium importance by most but overall, replies are scattered rather equally between extreme views, "uncritical" and "very critical".

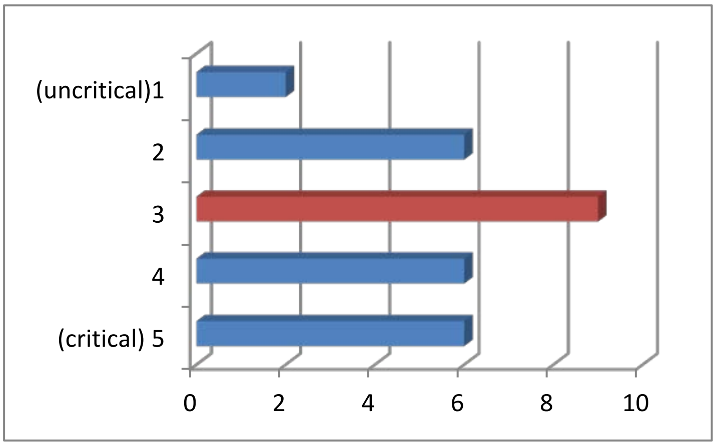


Fig. 75 Design & Simulation

As the major bottleneck in the area of design & simulation, “process design/simulation” is identified, which is closely followed by “cost”, “product” and “application” design/simulation.

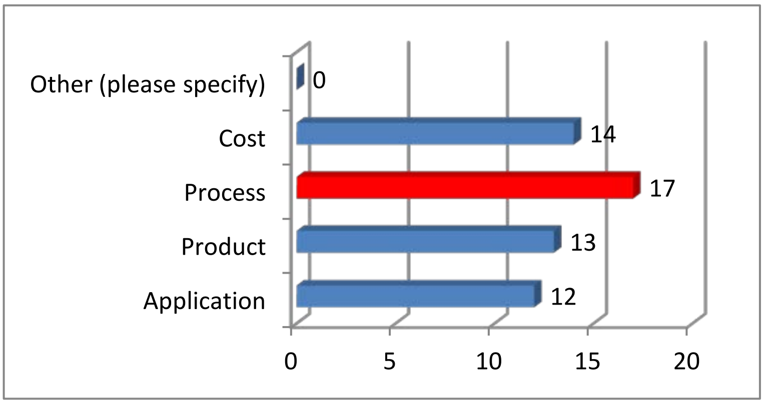


Fig. 76 Design & Simulation bottlenecks

- ➔ Medium relevance
- ➔ Focus on Process simulation

4.5.2 Characterisation of microsystems

Characterisation is seen as “critical” by most, with variations in responses ranging from “uncritical” to “very critical”. Remarkably, this is one of the questions that was answered by more respondents than most other questions; this underlines its high relevance.

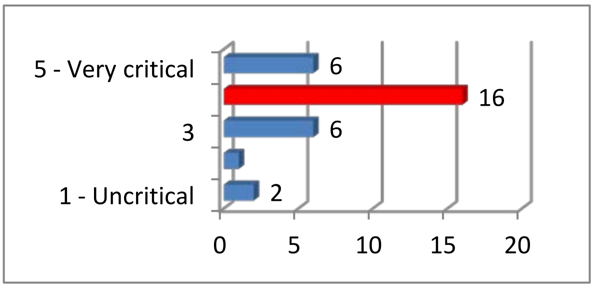


Fig. 77 Characterisation

Characterisation bottlenecks are mainly seen in the areas of “process control” and “(online) product control” but also in “(offline) product control”.

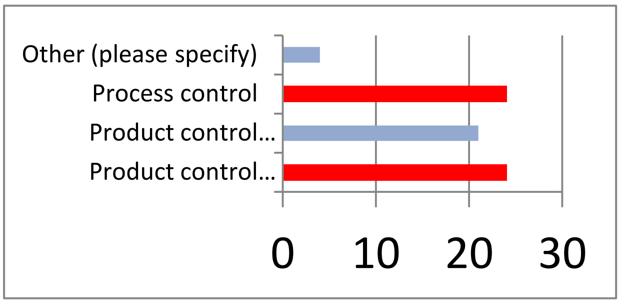


Fig. 78 Characterisation bottleneck

The measurement infrastructure must be extended into the nanoscale, to bring nanotechnology based products or manufacturing processes successfully and safely into the market place. It should provide the ability to measure surface nanostructures and the nanomorphology of nanocomposites and coatings. In order to fully assess the 3D sample structures with high resolution and contrast, FIB/SEM technologies will be further optimized. In addition, the characterization should include a high resolution 3D chemical mapping using analytical methods such as, e.g., EDX, XRF, SIMS, XPS, EELS, etc., which need to be correlated with the structural information. Advanced X-ray metrologies, non-destructive tomography and analytics, will address new applications with increasing resolution.

Manipulation of nanoscale structures and objects will gain importance as well as SEM/TEM sample preparation techniques. Fast and reliable techniques for nanoparticle characterisation down to 10 nm or less will need to be developed.

Standards for the metrology and analytics should be established and be traceable back to internationally accepted units of measurement (e.g. of length, angle, quantity of matter, and force). This requires common, validated measurement methods, calibrated scientific instrumentation as well as qualified reference samples. In some areas, even a common vocabulary needs to be defined. A traceability chain for the required measurements in the nm range has been established in only a few special cases.

Workflow optimization is another constraint for future developments due to the large variety of application requirements and the combination of different techniques to characterize nanomaterials.

The challenge is to transfer novel processes from the lab to an industrial manufacturing processes.

For industrial applications and process control in a production environment, techniques to characterize large-area nanoengineered surfaces and coatings need to be developed along the whole process and product chain and to integrate these characterization techniques inline into the rough production environment. To achieve this, model-based technologies, e.g. scattering techniques or spectral ellipsometry, need to be adapted to large-area and high-throughput applications. Thereby data analysis and data fusion of different sensors will play a dominant role.

Challenges in in-Situ Characterisation- Example: Inverse Scatterometry

Inverse Scatterometry is the technique of choice that can be employed for the fast analysis of functional thin films and nano-structures for dimensions below the optical resolution. Inverse Scatterometry is based on physical modelling of light scattering from the nanostructured surface. The simulated data are employed to retrieve characteristic parameters of the measured sample from the interaction of light with the nanostructured surface.

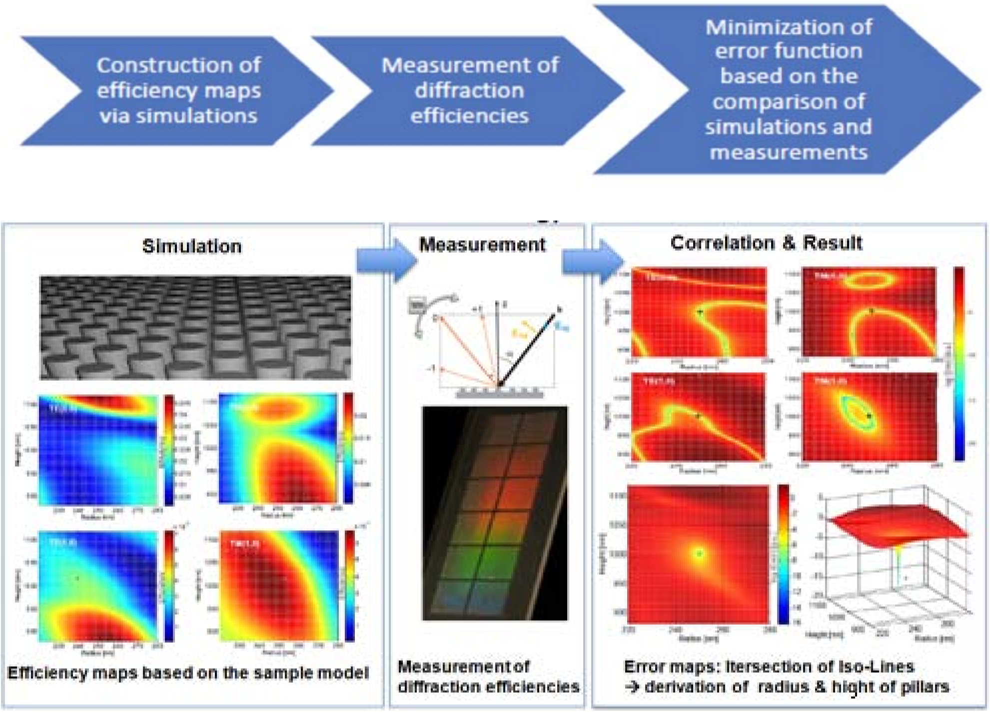


Fig. 79 Model based nanometrology; (Source: ZEISS)

5. Non-technological bottlenecks in MicroNanoManufacturing

Besides those aspects, which can be directly related to the development of manufacturing technologies, other drivers for success have been identified. The following chapter distinguishes between aspects which directly belong to the fact that Micro Nanomanufacturing is still a developing technology with sector specific constraints and between aspects being of a quite generic nature and of relevance for the manufacturing community in a wider sense.

5.1 MicroNanoManufacturing specific bottlenecks

In the following chapter MINAM investigated the influence of aspects, being "indirectly" connected to the advances in the technological development. Nevertheless these aspects have a significant influence on the successful introduction of MN enabled products into the market.

- Technology maturity
- Lacks in standardisation
- Immature and unsubstantial market

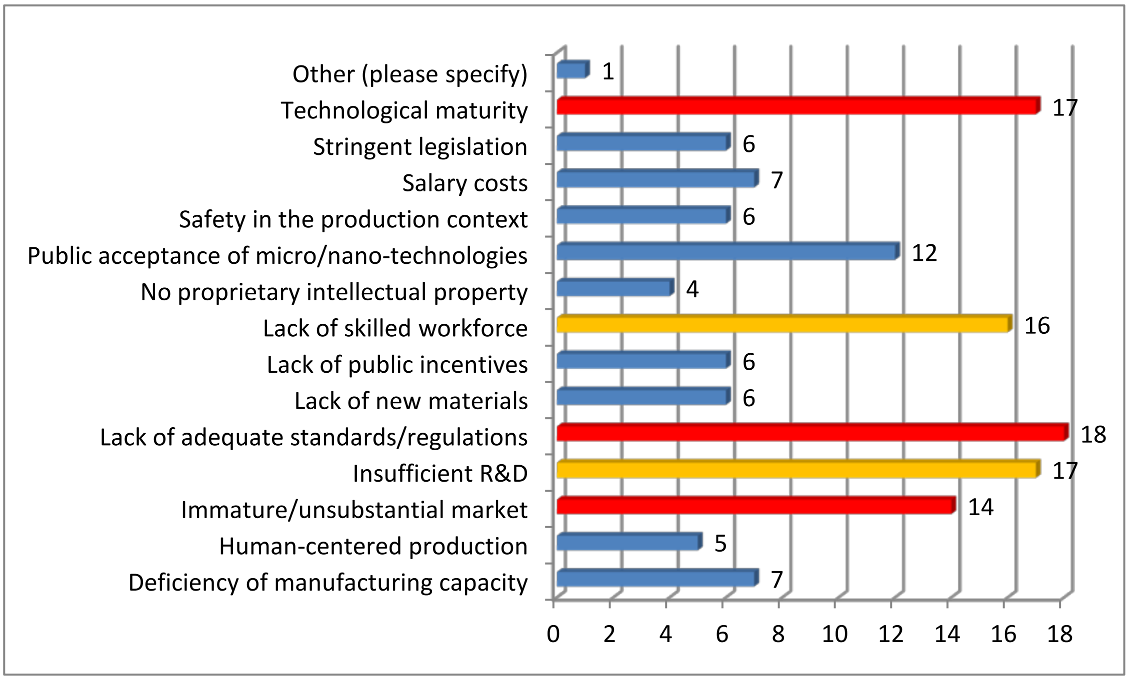


Fig. 80 Non technological bottlenecks MicroNanomanufacturing-specific aspects

5.1.1 Technology maturity

From the MINAM community in the 2011/2012 survey, it is a clear response that it is important to develop an approach for evaluating the "maturity" of the existing process chains as potential manufacturing platforms for producing miniaturised products. Both types of analysis will also lead to the design of new process chains, and will represent an objective means for assessing the risks associated with the adoption and implementation of these technologies on their path to commercial exploitation. Finally, the ability to assess the technology readiness or "maturity" of the technologies in process chains will also provide a means for benchmarking them. Such benchmarking could be used for ranking purposes, and therefore could eventually be applied for process chain selection when there are alternative competing solutions for the fabrication of a given micro component.

In 2009 MINAM was investigating, in great detail, the technology maturity of more than 70 technologies. Surprisingly the community identified technologies as “not mature” which had already been introduced to the market for a long time. Looking at these findings in more detail it quickly becomes clear that the reason for this is that it is the potential for improvement of these technologies that led to these results. Good examples of this are the replication technologies.

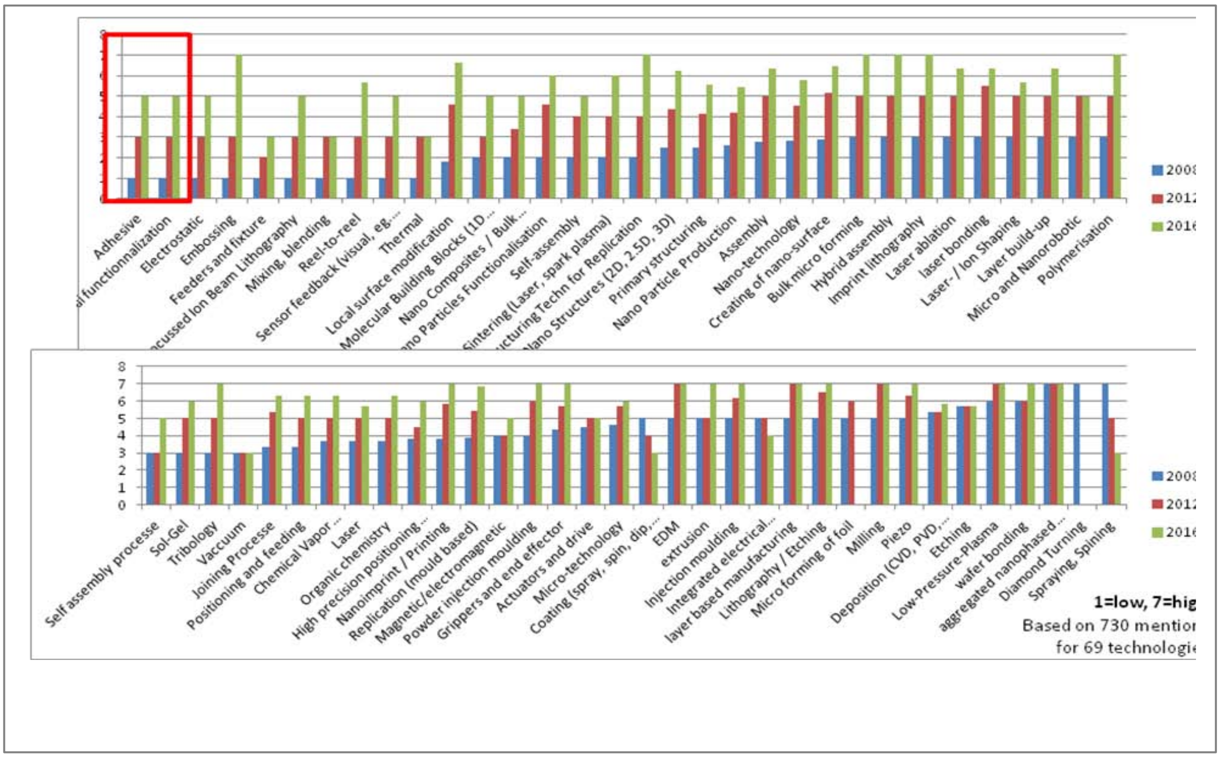


Fig. 81 Assessment of technology maturity and potential for further development (MINAM 2009)

5.1.2 Standardisation of micro components and-processes – A key to Europe’s Competitiveness

Lack of standards was mentioned by most of the participants. In contrary to skilled workforce the community has a clear picture of what needs to be done in this area. The interviews with MINAM stakeholders and European experts showed a significant demand for the coordination of standardisation activities in the different areas. Europe seems to be fragmented and standardisation is, besides a few NM related activities in CEN/CENELEC and ISO, often restricted to national activities.

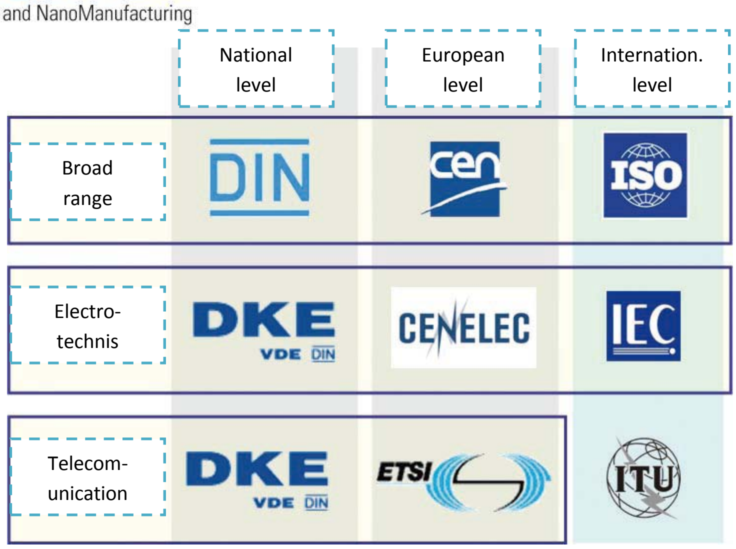


Fig. 82 Standardisation hierarchies (from the German viewpoint ; Source: IVAM)

Despite of these activities Standardisation had been identified to be one of the major hurdles for Europe's competitiveness. This is not a new issue[16] but an aspect which has been widely ignored in Europe's MN industry so far.

<u>Standards in micro production</u>

The variety of technologies, processes, materials and applications of microsystems technology makes standardization difficult.

- Standardisation is often based on a wide range of options and opinions and leads to compromises that are not necessarily the best available technical capabilities.
- Many technologies have not yet reached the necessary market for standardization or are not yet necessary to standardize.
- The standardization process is lengthy: Until a standard is formulated and published, can take many years.
- Small and medium-sized companies often lack the human and financial Resources to participate in standards committees.

MINAM was asked to provide support (not to conduct!) the coordination of the different bodies involved in the development of standards. The following areas show where certain weaknesses were reported

[16] Economic benefits of standardization, published by the DIN eV, Berlin, Vienna, Zurich: Beuth, 2000.

Standardisation of micro component formats

Standardisation of micro (enabled) components is probably one of the biggest challenges for the next 10 years. Experts from PV industry reported that -in their opinion- one of the reasons for the problems of European PV industry resulted out of a lack in standardisation of PV modules causing additional cost for adjustment of PV production equipment to each distributor’s needs.

Another example was observed in the Health sector, where the introduction of microfluidic chips for bioanalytics is still lacking behind expectations. One of the reasons might result from a lack in standardisation of interfaces, e.g. between instrument and disposable

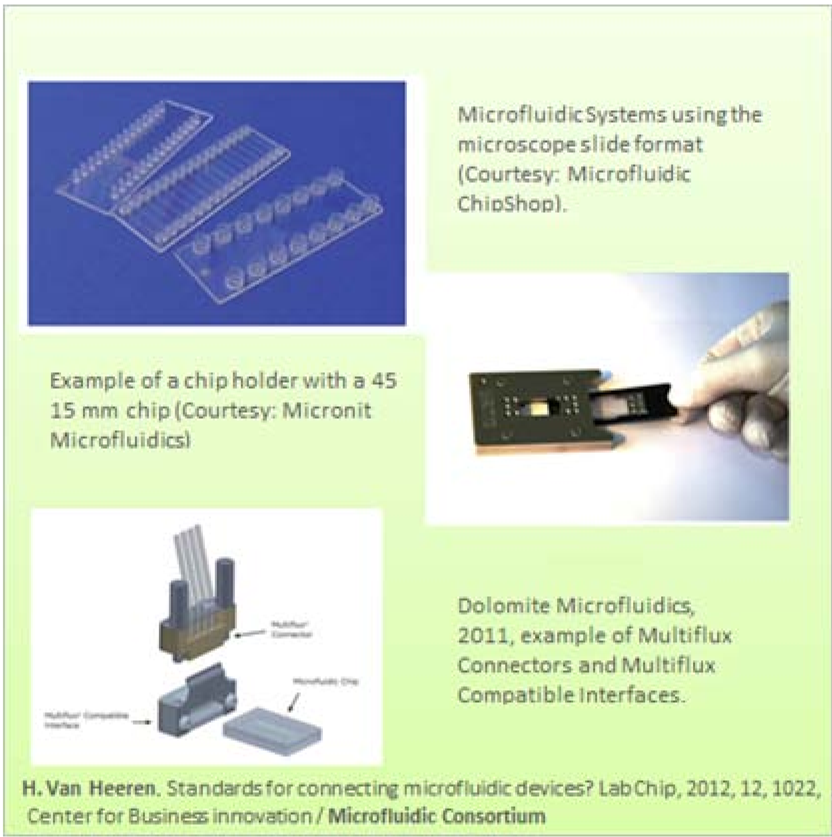


Fig. 83 Standardisation activities in microfluidics

- Health care: to enable diversity in testing (there are hundreds of specific tests needed) with a limited number of instruments
- Analytical instruments / processing equipment: to enable the selection of the best components and the ability to compare / qualify those components and the systems.
- Successful introduction of key enabling technologies often lacks of a holistic approach for process standardisation, allowing for faster scalability and compatibility
- (At least) Synchronisation /Set up of European standardisation activities should be considered as a key success factor for European industry

Standards in metrology

Standards for the metrology and analytics should be established and be traceable back to internationally accepted units of measurement (e.g. of length, angle, quantity of matter, and force). This requires common, validated measurement methods, calibrated scientific instrumentation as well as qualified reference samples. In some areas, even a common vocabulary needs to be defined. A traceability chain for the required measurements in the nm range has been established in only a few special cases.[17]

5.2 Nontechnolocial bottlenecks of relevance for Micro and Macro manufacturing

In its 2011 and 2012 survey MINAM asked the clusters and ETP to give us their estimation on non technological bottlenecks. Besides the MN manufacturing specific bottlenecks the following aspects:

- Lack of skilled workforce
- Insufficient R&D
- Immature unsubstantial market

were identified as major bottlenecks in this context.

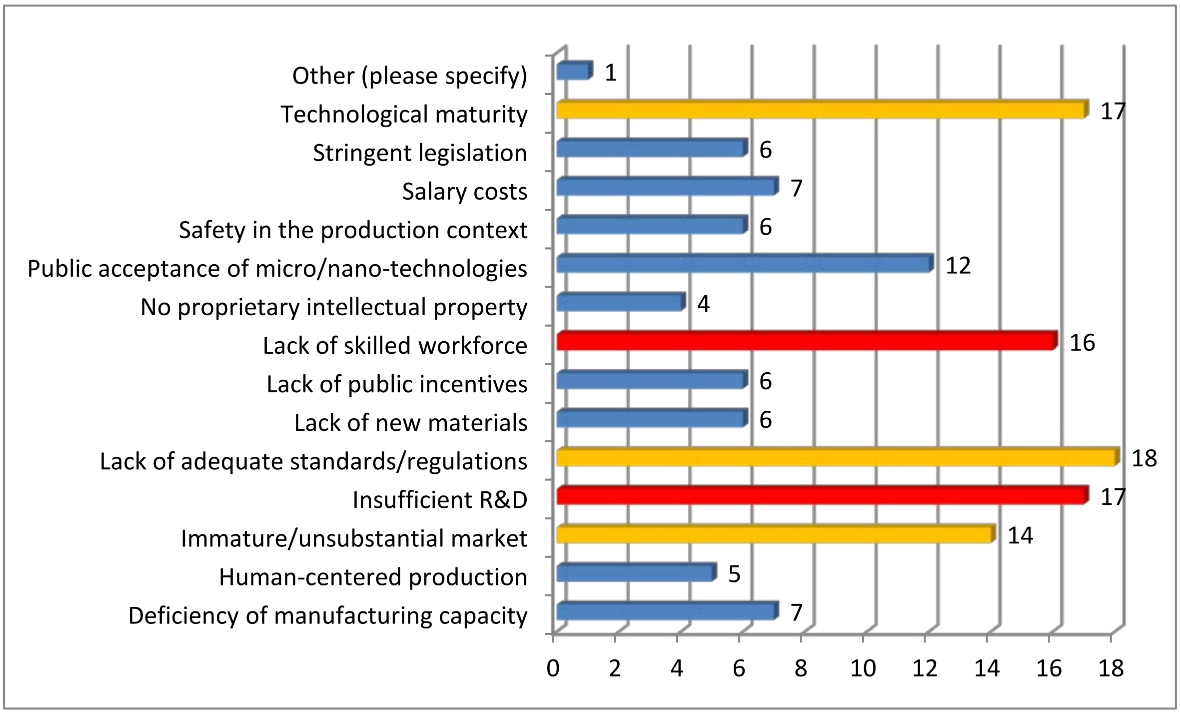


Fig. 84 Production related (non micro nano specific) bottlenecks resulting out of non technological barriers

In the discussion with representatives from other communities it turned out that several non-technological aspects identified by the MINAM community had been identified as of relevance for the production community in a wider sense by other manufacturing communities as well. Due to this overlap MINAM decided to collect the information related to these overall production oriented topics and present them as a kind of input for activities to be discussed in ManuFuture and with the other Sub-ETP´s.

[17] Microsystems Technology Standardization Roadmap, National Physical Laboratory, Teddington, UK, 2003, pp. 9 f

5.2.1 Knowledge management and education

In terms of “knowledge management and education”, the MINAM 2012 survey identifies “education” as most significant with ratings between “very critical” and “critical” and “production strategies” as “critical” with diverse views between “rather uncritical” to “very critical”. “Tools for process planning” were ranged between “critical” and “rather uncritical”, while “decision support methodologies” were regarded as “uncritical” by most and “critical” by a few respondents.

Nevertheless, looking at the overall response the feedback on what explicitly needs to be done was extremely low, too low to build a dedicated strategy on it!

MINAM discussed this problem and suggests investigating this topic in a separate activity in more detail. Coordinated actions including specialists from more labour oriented research as well as from production planning research would be useful.

The following graphs provide ideas where support of planners and workers was expected:

Samples for (non-representative) answers in this area (Status 2012):

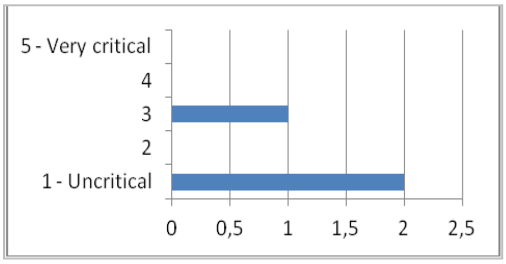


Fig. 86 Decision support tools

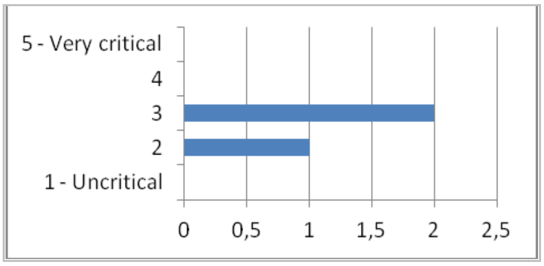


Fig. 85 Use of process planning tools

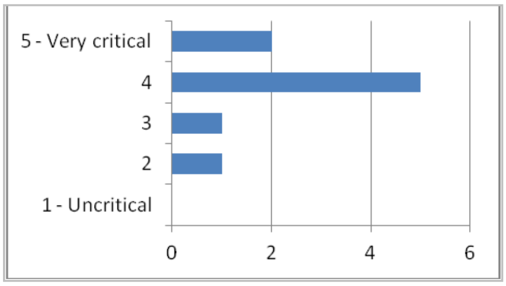


Fig. 88 (education of) new production strategies

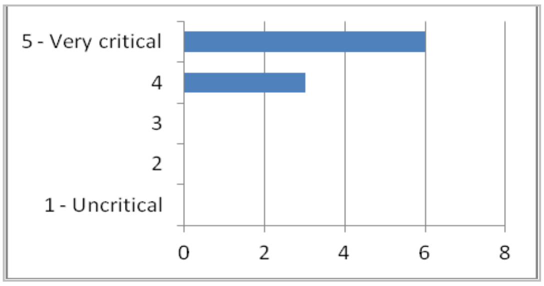


Fig. 87 Education of workers

5.2.2 Bottlenecks in R&D

Immature/unsubstantial market was mentioned especially in the context of nano technology. People differentiated between the role of MN manufacturing being a lever for success of other (multi trillion Euro) sector and the turnover resulting out of the business itself (see Market forecasts at the introduction to this document) MINAM asked the community on what they see as the major driving forces for their innovation. While “market demand” is, as expected, the main driving force for investing, “public funding for projects” are also key to innovation. Own RTD and “collaborative projects without direct funding” are also important, as well as open innovation.

However, "open innovation" is seen quite critical by the SME driven MN community since IPR and partnership between large companies and their suppliers is often quite unclear. Publicly funded projects are still a major source for SME´s to harvest RTD results from research institutions and to have an exchange with other SMEs – even if the projects do not lead to commercial results directly.

These aspects have very clear implication on what SMEs expect from an effective R&D funding in Europe – and this is often in contrast with the intentions/expectations of large enterprises and research institutes.

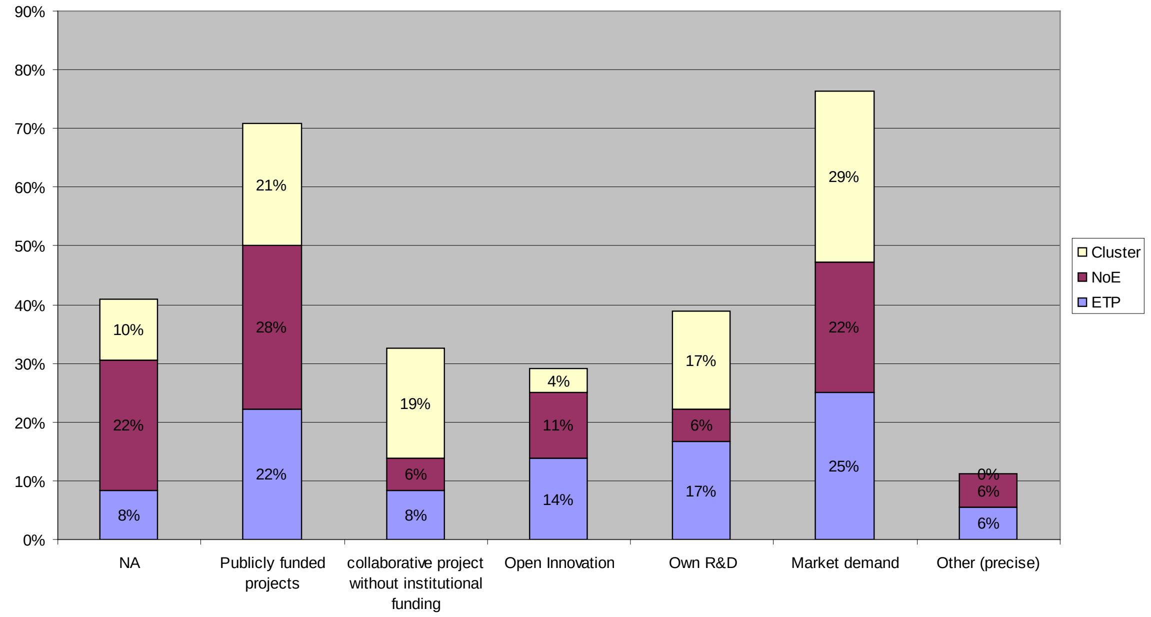


Fig. 89 Driver of Innovation in Europe (Survey 2011 result)

5.3 Economical bottlenecks and cost issues

As major "economical bottleneck", "cost issues" were identified, while also "high investments" and "market barriers" were identified as key hurdles. "Manufacturing" is not a major economical bottleneck but still relevant to some players.

Subdividing "critical cost" into more details shows that "application development" and "process development" are the main cost drivers and also "scale up cost" and "product qualification" are significant. "Salaries" are next on the scale, while "safety issues", "lack of public incentives", and "energy cost" seem to be the minor issue in terms of cost bottlenecks.

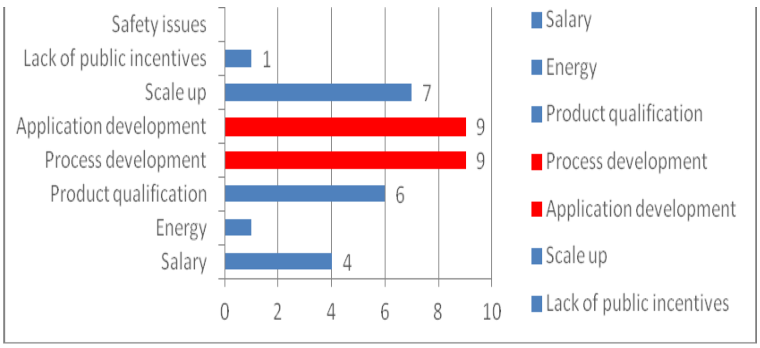


Fig. 90 Economical bottlenecks

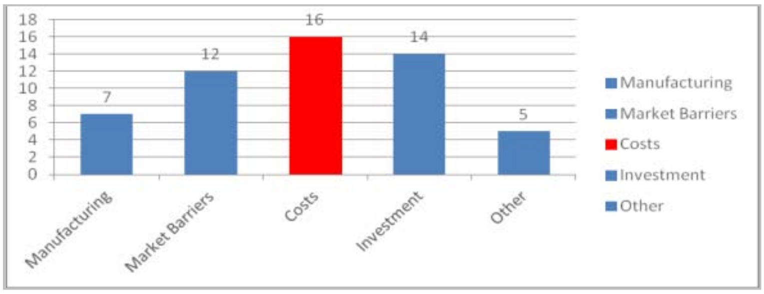


Fig. 91 Critical costs

Costs for the development of new products and related production lines was highlighted to be the most critical bottleneck. For MN manufacturing this underpins the afore-mentioned necessity to reduce the setup costs for MN components, especially where small medium series are targeted.

5.4 How to push innovation in MN manufacturing

When Clusters, NoEs and ETPs were asked how they propose to "push for innovation", the clear priority was for following "market demand" and for supporting "publicly funded projects", with about equal answers from the three groups addressed with the question. "Own R&D", "collaborative projects without institutional funding", and "open innovation" were considered relevant but not as main drivers with "collaborative projects without institutional funding" favoured by clusters, while "open innovation" was more a key interest of ETPs and NoEs.

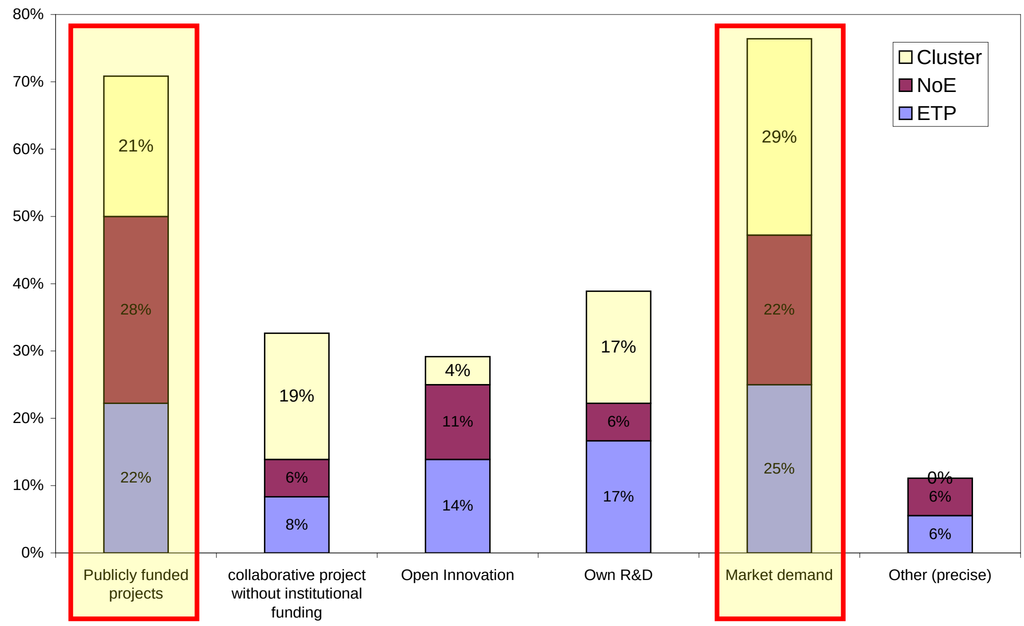


Fig. 92 How to push innovation (MINAM surveys 2011/2012)

5.5 Access to Research Infrastructures

Besides the "high level" topic MINAM asked for, some first ideas were tested in conjunction with the setup of the MINAM 2.0 services:

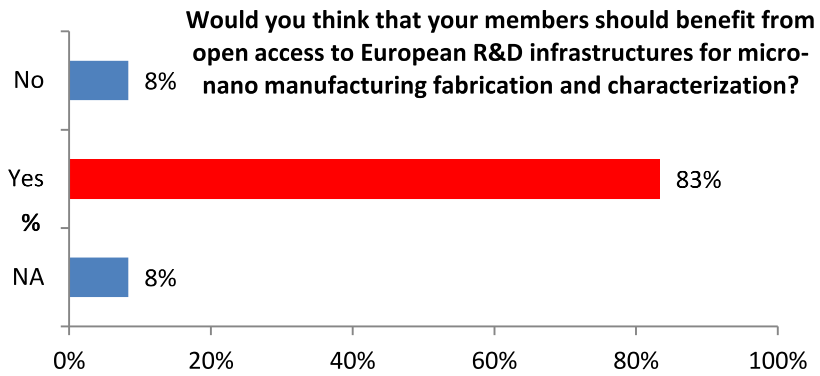


Fig. 93 Relevance of Research Infrastructures

Access to "research infrastructures" was deemed useful to the MINAM community with 83% of answers confirming the benefits. Considering the more detailed replies, "research infrastructures" shall offer the following (sorted by relevance):

1. High end technologies and technological expertise
2. IPR shall belong to the user
3. Confidentiality
3. Function/application related consultancy
4. Low cost
4. Offering system design and modelling

Fig. 94 Most beneficial characteristics of research infrastructures

The most significant barrier for SMEs from using "research infrastructures" is the "slow response to requests", followed by "infrastructure is at a different country" and "access cost > 30k€", while, for instance, "all communication in English" doesn't seem to be a hurdle. Also, a "lack of design consultancy" or the "need to publish results" don't seem to be significant issues.

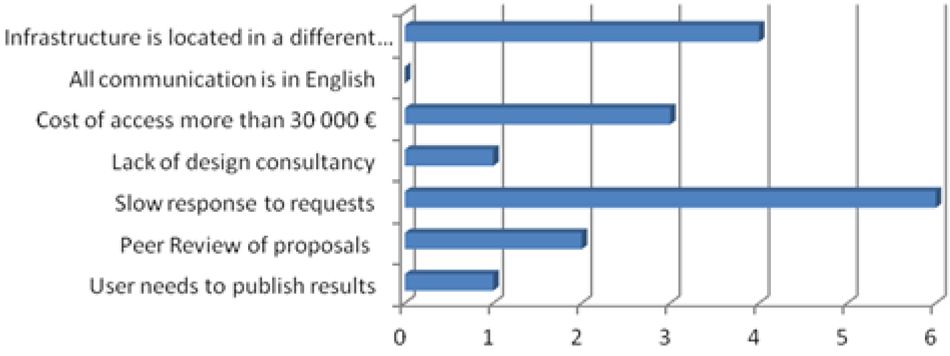


Fig. 95 Barriers which would deter most SMEs from using R&D infrastructures

As a conclusion, it can be stated that there exists a clear demand for access to Research Infrastructures. Such infrastructures are provided by the EUMINAfab project and in the past, EUROPRACTICE had provided similar structures in terms of design and manufacturing services in the MN manufacturing area. Currently Europractice only provides services in the semiconductor area.

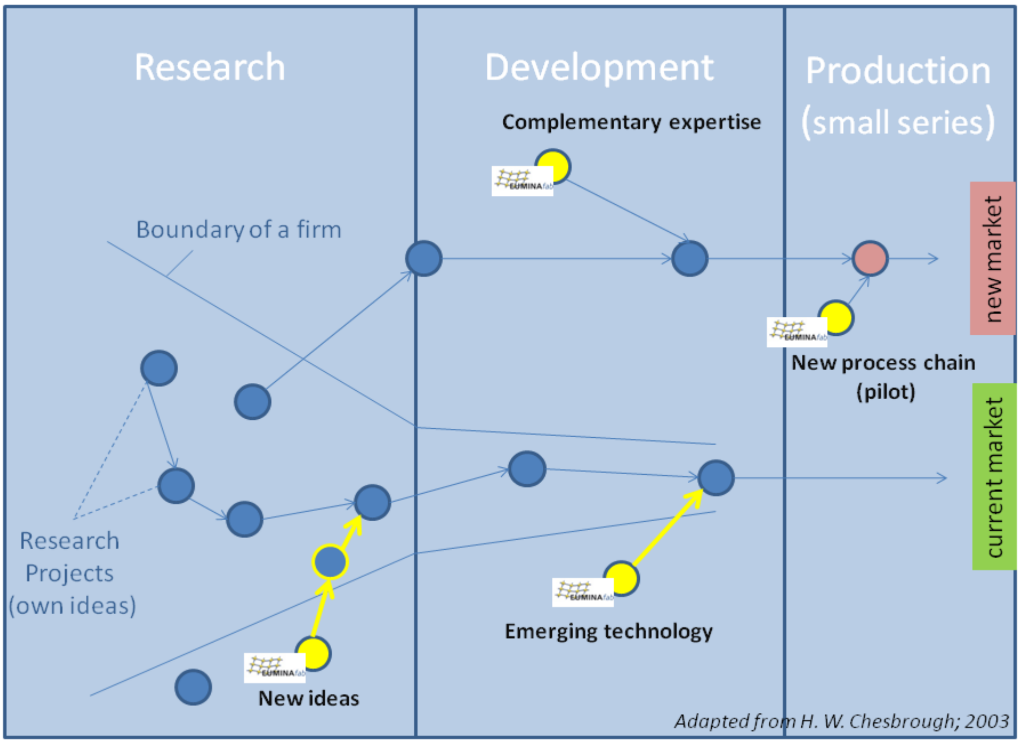


Fig. 96 Access to Research Infrastructures, example: Transnational MN related research infrastructure EUMINAfab

Anyway a lot of work needs to be done on governmental level as well as on research infrastructure to reach the point where the European industry and R&D can benefit from a synchronised distribution of work between local, regional, national and EC institutions being required to allow for an optimum of support.

6. Conclusions and Recommendations

MINAM 2 contributes to ManuFuture / EFFRA aspects through raising the following conclusions:

The results of the MINAM surveys in 2011 and 2012 have shown that MN manufacturing is still an emerging technology which gains more and more in importance as a key enabler for macro world products in all areas of our daily lives. This trend is supported and underlined by the latest reports from leading market research providers and also by product and technology roadmaps from small and large industries and research labs worldwide.

Opportunities were identified for a range of application areas, with a main focus on production, health and energy, where MN has, and is expected to, provide high benefits to European society in a wider sense as well as providing the key to (commercial) success for European industry in a narrower (but very significant) sense.

The MN community has identified key barriers to success and generated ideas/concepts on how these can be addressed. We have categorised these into three main sections:

Barriers relating to the specific requirements of the MN technology as a developing field (technology maturity, introduction of new technologies, smart system integration):

- New processing methods to achieve nano-sized microstructure components
- New nano-compatible “in situ” characterization as key enabler for robust nano enabled production

Barriers relating to the overall developments in the production area. Here MINAM identified a significant overlap with ongoing activities in MINAM, ManuFuture and EFFRA. Nevertheless, a number of MN specific issues need to be addressed in a more detail:

- Mass production of functional 3D systems
- Manufacturing for custom made parts.
- Automated production of composite structures/products
- Joining technologies
- Delivery of new functionalities through (mass production) manufacturing processes
- Product life cycle management for advanced materials
- Multifunctional manufacturing processes
- New approaches for production planning and control
- Novel supply chain approaches for innovative products

Barriers relating to the lack of European-wide coordination action:

- European-wide standardisation of processes and components
- Linking European clusters with specialized competences to provide a strong, SME driven “bottom up” approach for identification and support of European industries’ needs.
- Provision of a European research Infrastructure to support SMEs and large Scale Industry along the innovation chain - the European MN-“One Stop Shop”

6.1 Conclusions for technologies

In many application areas there is a need for the **continuous miniaturisation of novel components and products** and for integrating new application approaches that require the integration of nano, micro, meso and macro scale features into new generations of multifunctional products and systems. Affordability of technology is not a generic question anymore but a strong request from the customer, thus, (new) technology has to be made affordable by making it manufacturable (at a reasonable cost).

MN manufacturing processes, especially replication, coating/printing and assembly technologies, need additional research to improve the technological maturity of processes. Also a faster transfer from RTD into production through Research Infrastructures will help. Additionally, an accelerated Information exchange on capabilities within the community is needed.

New system integration approaches allowing for functional integration of ICT, mechatronic and materials based engineering will enhance product integration at lower cost. However, this also requires the synchronisation of **standardisation activities** for production of micro enabled components and production equipment and new approaches for in situ characterisation of quality and repeatability.

An increased efficiency and flexibility in the production of customised small-to-medium series of micro components needs to be implemented through easily reconfigurable and scalable manufacturing approaches.

A focus on the development of new materials for multi material 3D complex products (Micro and Macro) will enable sustainable products through new material features, re-use and recycling methodologies.

6.2 Conclusion for production / non-technological aspects

Continued funding of precompetitive projects will stimulate collaboration and innovation, which is especially important for SMEs.

For a significant market penetration to the benefit of European industry, the synchronisation of standardisation activities is important. Early and European industry-driven standards (or quasi standards) can be a success factor for the European manufacturing Industry to compete against Asia Pacific in the high tech area.

Specific services to link regions on a management level as well as on member level will help in establishing collaborations (for RTD and manufacturing), identifying opportunities and in exploiting results from research. This includes information exchange & Meta databases, improved cooperation within the community to fasten the innovation cycle, and taking results from EC projects into the regions (where local SMEs will often not screen EC results and/or understand much English). A new quality of cooperation between partners in this area can be achieved through the joint use of infrastructures and new business models (to be further investigated).

7. Annexes:

7.1 Annex 1: Micro Nano related market research

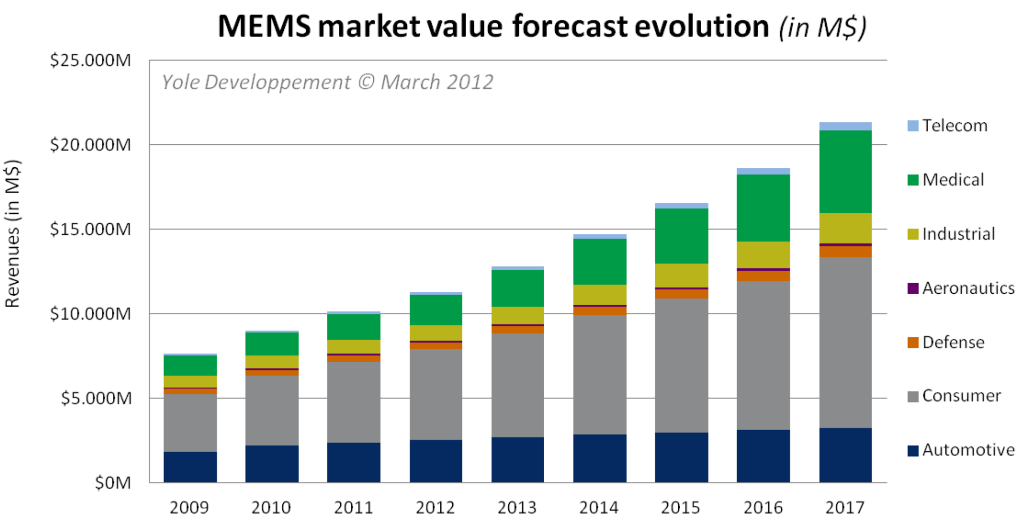
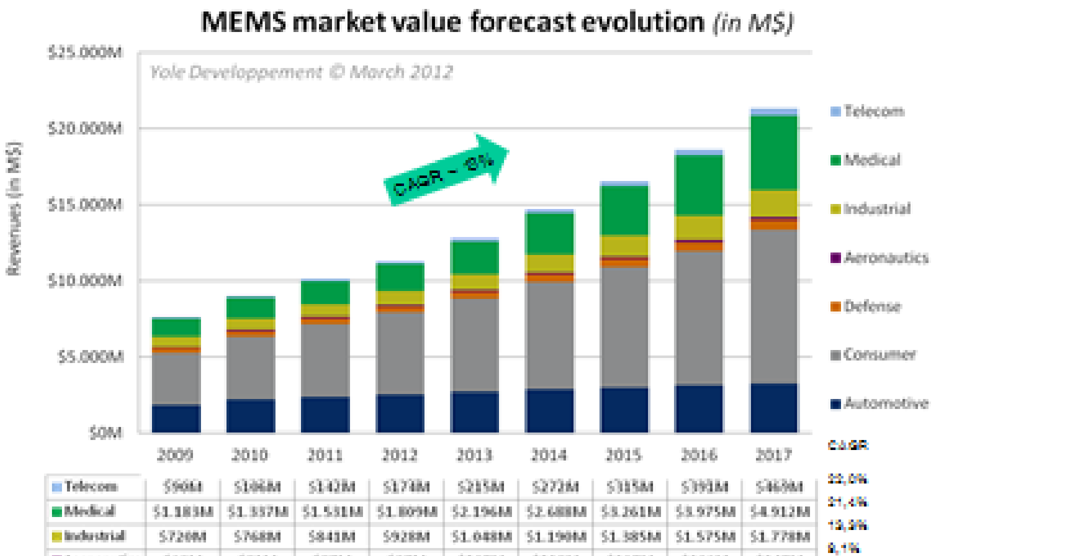


Fig. 97 MEMS market value forecast evolution (Source: Yole 2012)



	2009	2010	2011	2012	2013	2014	2015	2016	2017	CAGR
Telecom	$90M	$106M	$142M	$174M	$215M	$272M	$315M	$391M	$469M	22,0%
Medical	$1.183M	$1.337M	$1.531M	$1.809M	$2.196M	$2.688M	$3.261M	$3.975M	$4.912M	21,4%
Industrial	$720M	$768M	$841M	$928M	$1.048M	$1.190M	$1.385M	$1.575M	$1.778M	12,2%
Aeronautics	$68M	$81M	$87M	$97M	$107M	$118M	$127M	$136M	$147M	8,1%
Defense	$308M	$339M	$366M	$401M	$433M	$504M	$564M	$649M	$685M	11,0%
Consumer	$3.412M	$4.155M	$4.795M	$5.387M	$6.132M	$7.064M	$7.924M	$8.809M	$10.082M	12,2%
Automotive	$1.834M	$2.191M	$2.367M	$2.508M	$2.690M	$2.860M	$2.958M	$3.100M	$3.244M	5,4%
TOTAL	$7,68	$8,68	$10,18	$11,38	$12,88	$14,78	$16,58	$18,68	$21,38	13%

Fig. 98 MEMS Market value forecast evolution (Source: Yole 2012)

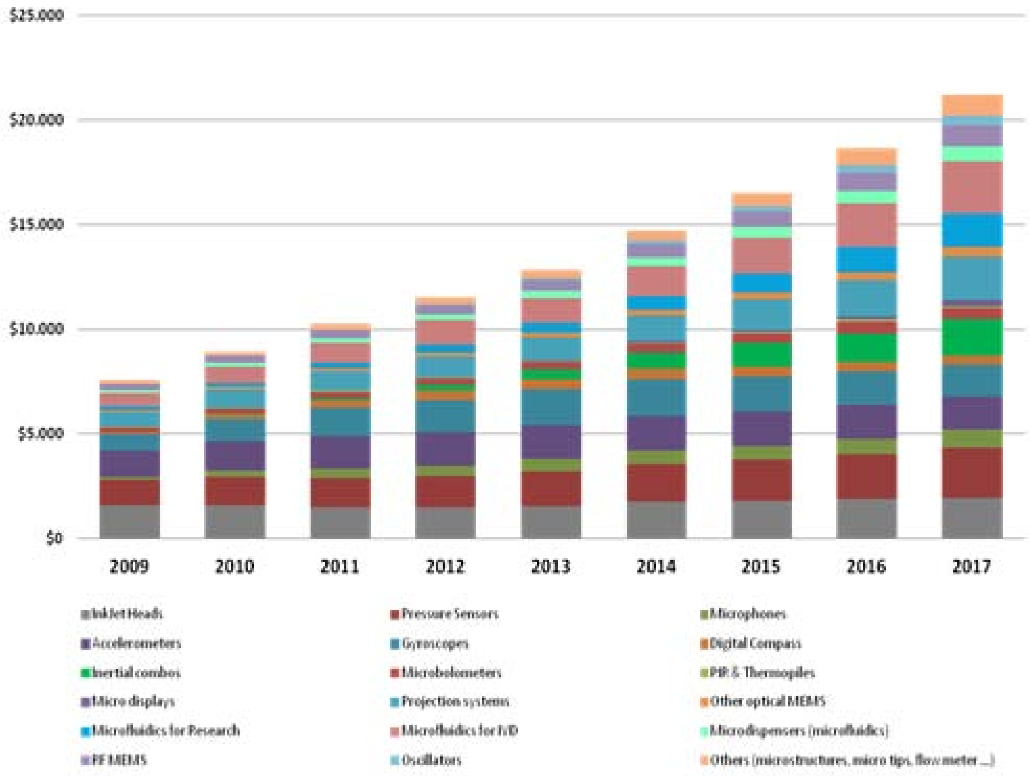


Fig. 99 MEMS Market forecast 2009-2017 (Yole 2012)

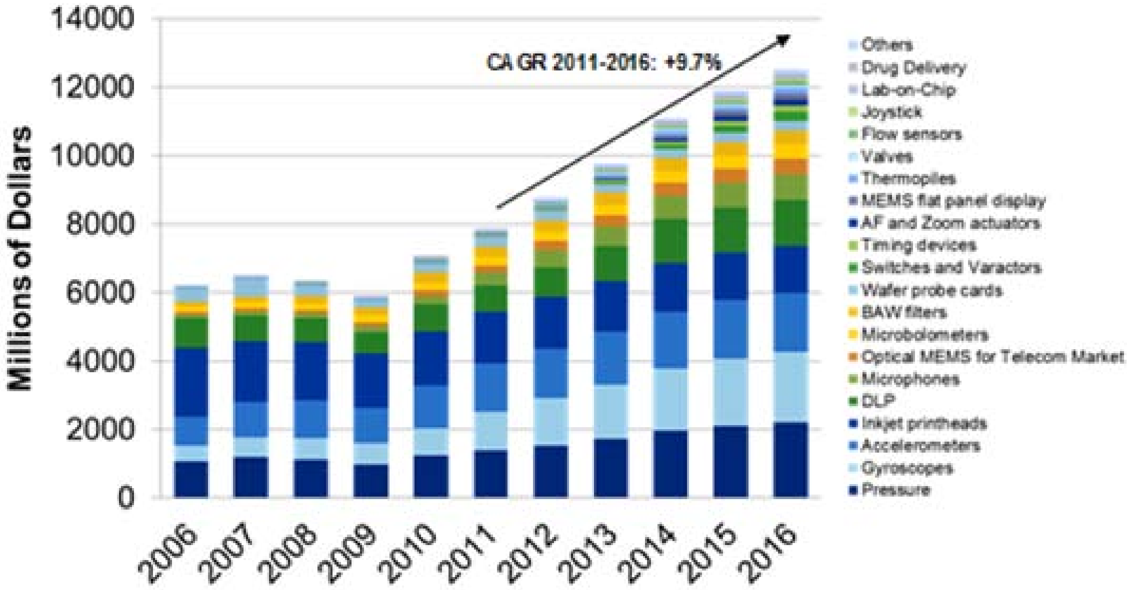


Fig. 100 MEMS Market by Devices, 2006-2016 (Source: iSuppli 2011)

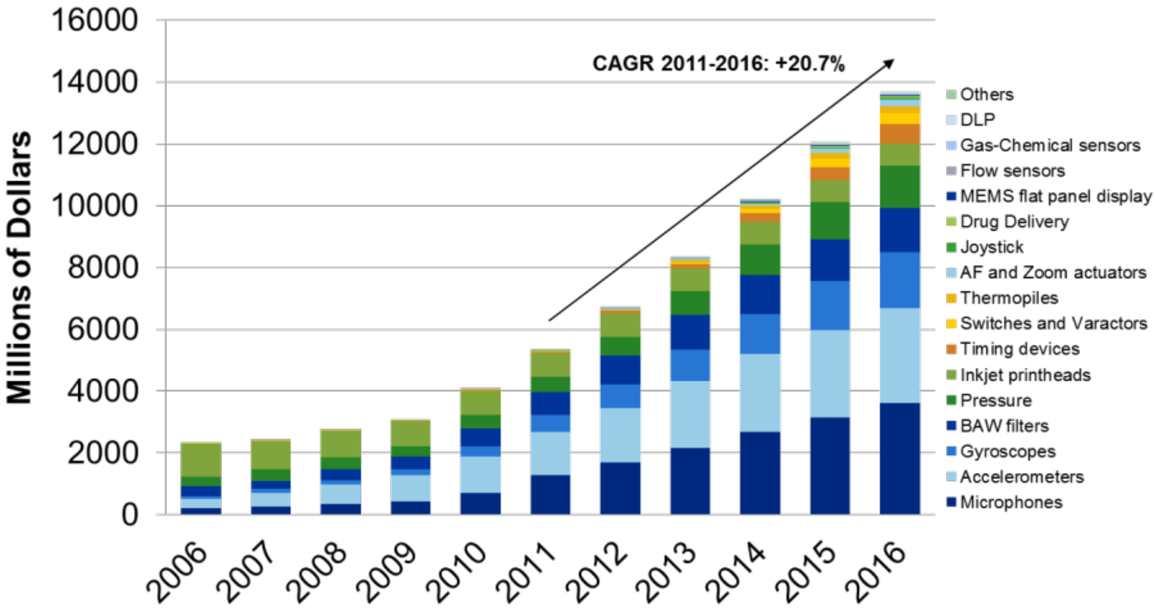


Fig. 101 (Source: iSuppli 2011)

7.2 Annex 2: Examples for recent EC Projects dealing with strategic aspects, identified by the MINAM community

Projects addressing technical trends

New flexible scalable equipment

SMARTLAM - Microsystems, built of functional Polymer Films

Contribution to MINAM - Felixble scalable production

Today's microsystem enabled applications are high volume products and in most cases build on a few mature micro components. Nevertheless there is an enormous demand for small medium series of specialized components for key products which can't be satisfied due to costs for process/production setup.

Short Project Description

Create a new paradigm for process integration, building on a rapid scale up from prototype to medium series in conjunction with cost efficient manufacturing of (small medium series) next generation 3D micro components.

Targets	RTD		Applications
		SMARTLAM Platform modules	
• Capability to rapidly produce complex 3D meachatronic micro systems • Increased flexibility and scalability of processes • Reduced energy consumption • Reduction of development and sale up time • Product quality improvement • Waste reduction and reduced impact on the environment	3D-I Modelling & design approach 3D-I compatible production platform SMARTLAM adaptive control and vision inspection	3D- Aerosol inkjet printing Laminating of polymer films Micro laser cutting, milling, welding, sintering Polymers with advanced properties	Towards Next Generation micro products that are: • Complex in geometry • Multi-Material • Three dimensional • Micro sized with nano features Consumer (sensor, user interfaces) Bio-Medical (e.g.disposables, hearing aids) Energy (e.g. Energy harvester, printed batteries, organic PV)

Project Partner

Project Coordinator:
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KIT PROFACTOR The University of Nottingham neotech designled micrux Fraunhofer IPA DAY4

Use of new materials

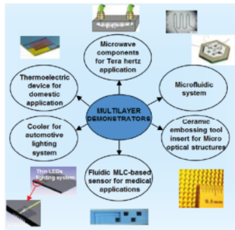
Multilayer - New platform for large-scale production of 3D micro devices

Relation to MINAM

The MULTILAYER consortium was solicited for the MINAM survey. The key technologies & markets associated to the project demonstrations (photonic guiding systems, micro fluidic systems, ink-jet specific inks, screen and rotogravure printing processes, new substrates for printing techniques) were also considered in the MINAM position paper.

multi layer

Short Project Description



MULTILAYER is focused on the mass-production of micro devices by using several different layers which are individually structured and treated and then ultimately assembled.
The main objective of the MULTILAYER project is therefore to develop a set of solutions for the large-scale production of micro devices based on a technology we call "Rolled multi material layered 3D shaping technology" and using the concept of tape casting and advanced printing techniques.

Targets / Goals of the activity

MULTILAYER will increase European competitiveness in:

- Micro- and nano materials and its processing
- Tools for producing micro- and nano structures with advanced materials (ceramic, metalceramic composites, metal, polymer, glass)
- Know how to develop and produce low cost products, parts, semi finished materials in the area of photonic guiding systems from day light guiding to PMC
- Knowledge of the relevant properties of inks, specifically for the ink-jet, screen and rotogravure printing processes, used in the context of micro- nano- technologies
- Know how to use new substrates for printing techniques

MULTILAYER Contact Point
Coordinator:
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Project Manager:
Dr. Stéphane Bredeau
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for further information visit our website http://multilayer.4m-association.org

Adaptive Manufacturing

FRAME - Fast Ramp-Up and Adaptive Manufacturing Environment

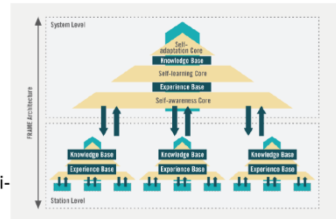
Relation to MINAM

The aim of the FRAME project is a paradigm shift from the conventional human-driven ramp-up and system integration process to fully automated, self learning and self aware production systems.

Short Project Description

The FRAME concept comprises three core themes which provide the core functionality on both individual assembly workstations and system level:

1. Self Awareness: Enhance assembly station and system self-awareness based on synergetic interaction between human operators and machines.
2. Self Learning: Extend functionality of station and system to learn from experience through access to inherent ramp-up and disruptive event knowledge for future decision making.
3. Self Adaptation: Enable proactive participation of assembly stations and systems in solution mining through utilising ramp-up and operational process knowledge.



Targets / Goals of the activity

- FRAME aims to create a new solution for highly adaptive, self-aware assembly systems, which will use automated self learning, dynamic knowledge sharing, highly integrated sensor networks and innovative human-machine interaction mechanisms.
- Next generation assembly systems equipped with FRAME technology will be able to proactively support ramp-up, error recovery and operational performance improvement.
- FRAME is funded by the European Commission under the FP7 NMP Programme and brings together ten partners with expertise from both industry and academia.

Project Coordinator:
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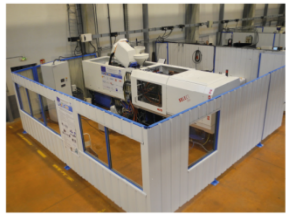
for further information visit our website http://www.frame-eu.org

Advanced manufacturinfg technologies

IMPRESS – Flexible Compression Injection Moulding Platform for Multi-Scale Structures

Relation to MINAM

IMPRESS will accelerate the production and reduce time to market of micro nano-scale functional feature on multi-component devices. By doing this, IMPRESS addresses one of the micro nano manufacturing challenges identified by the MINAM community.



Short Project Description

Objective of the IMPRESS project is to facilitate the development of new manufacturing routes of micro/ nano-scale feature manufacturing by implementing a complete technology platform.

Targets / Goals of the activity

- Tool manufacturing, involving different technologies of micronano direct manufacturing, from top-down to bottom-up such as self-assembling,
- Injection moulding, including equipments fitted with innovative hardware technologies to improve replication quality and capability,
- Intelligence and reliability module, dedicated to advanced-process control and online metrology integration.

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for further information visit our website http://www.impress-fp7.eu

Human centered production

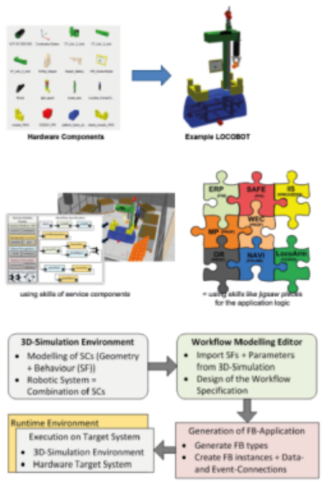
ToolKit for Building Low Cost Robot Co-Workers in Assembly Lines

locobot – low cost robot co-workers

Short Project Description

LOCOBOT addresses strategic objective - Plug-and-Produce components for adaptive control. LOCOBOT is a stn the automotive industry: it incorporates a flexible robotic assistant platform to support and increase manual production processes, as well as the engineering tools required for its setup. Further, this project aims to improve the ergonomics in industrial production processes.

- **Design your LOw-COst-RoBOT**
  The LOCOBOT Toolkit consists of the LOCOBOT Plug&Produce Components (HW-Modules) as well as the LOCOBOT Plug&Produce Robot Configurator Framework in order to configure, plan and set-up a robot application for robot co-workers that assist human workers
- **Design your specific application**
  Modeling application logic (user-friendly work-flow modeling evironment) Supervisory control is generated workflow execution control' (WEC)
- **System Integration using 4DIAC**
  Open Source Tool: 4DIAC (www.fordiac.org)



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PROFACTOR, Audi – Vorsprung durch Technik, FESTO, Hochschule Ingolstadt, Heriot Watt University

for further information visit our website http://www.locobot.eu

Enhanced product integration at lower costs

Manufacturing Felixble Products for Today Needs: Lightrolls

Relation to MINAM

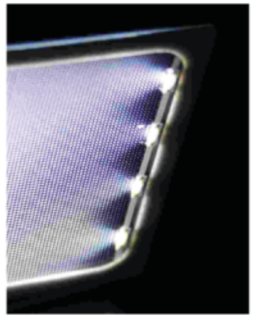
As a new micro-product production platform for high tech products in LED, lab-on-a-chip systems and other micro electromechanical systems fields, Light Rolls will widen business opportunities of European SMEs to new and well known growing markets.

Light-Rolls

Short Project Description

Light-Rolls is a new manufacturing technology platform, integrating different production modules, based on roll-to-roll manufacturing concept for the seamless, high throughput manufacture of micro-structured polymer based components and microsystems. Light Rolls

- integrates different production processes, which are based on a photo-polymerisation process to generate polymer micro-structures,
- self assembly methods and conductive track generation.
- A modular software framework for advance process control and



Targets / Goals of the activity

- High Flexibility: manufacturing modules integrable and exchangeable
- High Yield: by the application of advanced process control and production IT methods
- Pilot Line and User Training: for manufacturing flexible LED-display systems available
- Environmentally Friendly: lines run without dangerous chemicals and use integrated recycling

Project Coordinator:
PRODINTEC
info@prodintec.com

CRF Centro Ricerche Fiat, Norbert Schläfli Maschinen, XAAR, ocp, designled, microTEC, Fraunhofer IPA

for further information visit our website http://www.light-rolls.eu

Projects addressing nontechnological trends, identified by the MINAM community

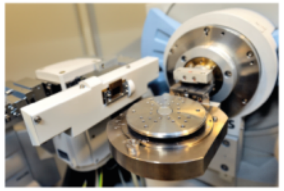
European regions

SMART FRAME - Smart Framework for SMEs focused on Modern Industrial Technologies in central Europe

Relation to MINAM

SMART FRAME is strengthening the transnational cooperation through its platform for exchange of intermediary know-how and thus is linking middle-east manufacturing community to MINAM!

Short Project Description



SMART FRAME is a project that creates a dynamic network by connecting partners from several European countries. The focus is on four high technology areas:

- materials,
- surfaces,
- technology-oriented processes
- sensors/actors

and on the integration of these technologies into products and production.

Gain benefit from the results

The goal of SMART FRAME is to sustainably improve the regional innovative framework in CENTRAL EUROPE by elaborating and distributing know-how in the fields of

- Intermediary support,
- R&D co-operations,
- Settlement and
- Spin-offs.

Project Coordinator:
ecoplus. The Business Agency of Lower Austria
Viktor Kaplan Strasse 2,
2700 Wiener Neustadt, Austria

The project is funded under the Central Europe Framework program

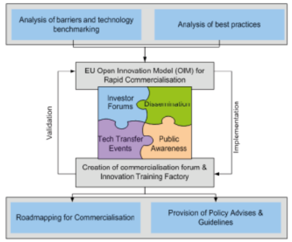
for further information visit our website www.smart-frame.eu

Commercialisation

NanoCom - Lowering the Barriers for Nanotechnology Commercialisation

Relation to MINAM

The NanoCom Coordinated Support Action brings together partners from across Europe. The strong industrial drive ensures that NanoCom meets the challenges of commercialising nanotechnologies and that the results can be directly exploited.



Short Project Description

NanoCom contributes to bridging the gap between lab based and industrial applications in nanotechnology by creating a European wide approach and mechanisms for lowering the barriers and spreading best open innovation practices for rapid commercialisation and investment in innovative nanotechnology driven products.

Targets / Goals of the activity

- Identification of barriers to commercialisation and analysis of best practices and entrepreneurship patterns in commericialising nanotechnology based products.
- Development of an Open Innovation Model for rapid commercialisation using nanotechnology specific examples.
- A programme of networking and dissemination events including an Investor's Forum and scheduled Innovation Training Factories to deliver necessary changes in attitudes, thinking and commercial proficiency of key players in the innovation process.
- Initiation of a web portal with support, brokerage and advisory services and integration of Open Innovation tools.
- Publication of a strategic roadmap and policy guidelines to support the EU and national governments in increasing successful commercialisation of nanotechnology research.

Project Coordinator: Professor Svetan Ratchev, Svetan.Ratchev@nottingham.ac.uk

The project is funded under the FP7 Framework program of the European commission

For further information visit our website http://www.nanocom-eu.org or follow us via twitter EU_NanoCom

Standardisation

CEN - Project liaisons

Relation to MINAM

The MINAM community had identified the lack of standardization in manufacturing and application of Micro Nano Systems as one of the most critical bottlenecks for introduction of MN enabled components.
As a result of this MINAM will start to build up service structures for related projects and interest groups in the Micro Nanomanufacturing Area supporting them to start information exchange on standardization and by establishing contacts to organisations such as CEN

European Committee for Standardization
Comité Européen de Normalisation
Europäisches Komitee für Normung

Approach

Research projects (FP7) can conclude 'Project Liaisons' with CEN Technical Committees allowing a research project representative to participate in Technical Committees and relevant Working Group meetings as observer.
However, the participation from the research project representative is without decision power. Some conditions apply:

- The project requesting the Project Liaison is an approved bona fide European research or similar project (EU Commission or EUREKA);
- The Project Liaison applies for the duration of the research project;
- The project signs an undertaking accepting CEN's exploitation rights policy and agreeing that no information brought to the project's attention will be disseminated or exploited in any form.

MINAM relevant technical comittees in CEN

CEN/TC 114 | CEN/TC 123 | CEN/TC 140 | CEN/TC 143 |CEN/TC 148 | CEN/TC 169 | CEN/TC 170
CEN/TC 184 | CEN/TC 186 | CEN/TC 187 | CEN/TC 198 | CEN/TC 205 | CEN/TC 224 | CEN/TC 240
CEN/TC 243 | CEN/TC 261 | CEN/TC 262 | CEN/TC 271 | CEN/TC 285 | CEN/TC 310 | CEN/TC 352
CEN/WS 067

Coordinator:
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for further information visit our website http://www.cen.eu

Technology readiness

Polytubes - A Process Chain and Equipment for Volume Production of Polymeric Micro-tubular Components for Medical and Non-Medical Device Application

POLYTUBES
Polymer micro-tubes & tubular micro-components

Relation to MINAM

Polytubes is pushing the limits of polymer micro manufacturing technologies into new dimensions and realizes a flexible manufacturing chain producing never seen tubular components. These products enable a wide range of applications like electrophysiological studies on human sperms, heat transfer structural and functional parts for micro-heat exchangers, parts for Capillary Electrochromatography, etc. and target therefore the great social and economic challenges described in MINAM Roadmap.

Short Project Description

The overall objective of the POLYTUBES project is to develop a process chain and corresponding micro-manufacturing platform for the manufacture of polymer-micro-tubes and tubular micro-components for medical and non-medical applications.

Targets / Goals of the activity

- To implement a Design for Manufacturing Methodology for design and manufacture of polymer-micro-tubes and tubular micro-components for volume production (from hundreds microns overall sizes to 2-3 microns inner channels), and to validate the methodology and the prototype-products by the end-users.
- To transfer laboratory processes and equipment (polymer-micro-tube extrusion, micro-tube-shaping and laser processing) to volume production of tubular micro-components.
- To integrate the individual equipments into a process chain and implement it in a manufacturing platform, by adapting a Process Transfer Strategy (Maturity Model), which integrates the business cases into the process chain, together with advanced IT integration and logistics integration.
- To demonstrate the technical and commercial viability of the volume production on a full industrial scale by manufacturing prototype products which meet all functional requirements for applications (both medical and non-medical sectors).

Project Coordinator:
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The project is funded under the FP7 Framework program of the European commission

for further information visit our website http://www.polytubes.net

Characterisation

Co-Nanomet - Coordination of Nanometrology in Europe

Relation to MINAM

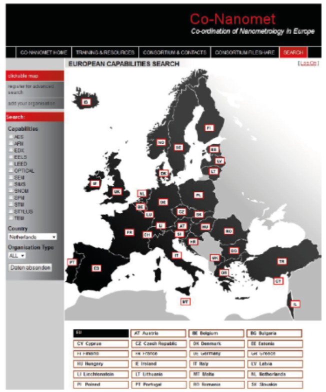
The MINAM community hat identified characterization as one of the most critical topics for the further development of MN manufacturing. Especially in-Situ characterization of Nanosurfaces was mentioned as "very critical".

Co-Nanomet
Co-ordination of Nanometrology in Europe

Short Project Description

Scientifically and economically nano-metrology is an indispensible part of nanotechnology which must develop hand-in-hand with it.

Co-Nanomet is a programme of activities addressing the need within Europe to develop the required measurement frame to successfully support the development and economic exploitation of nanotechnology.



Targets / Goals of the activity

- European Nanometrology strategy definition
- Support to 5 European Nanometrology Action Groups
- Co-ordination of skills and education
- Exploitation and development of infrastructures

Project Coordinator:
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The project is funded under the FP7 Framework program of the European commission

for further information visit our website http://www.co-nanomet.eu/

MINAM2 Coordination and Support Action

MINAM Micro- and NanoManufacturing

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