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Introduction

One of the deliverables of the Diginova project is the identification and description of the most promising opportunities for Digital Fabrication. After careful evaluation of more than 50 market opportunities, the Diginova project partners identified the 10 most promising applications. These were grouped/categorised into 5 application 'domains':

A. **Digital Graphical Printing**
   1. Digitisation of traditional printing industry
   2. Display Graphics

B. **Digital Textiles**

C. **Additive Manufacturing**
   1. Functional end-use parts and products
   2. Additively manufactured objects with embedded printed intelligence

D. **Printed Electronics**
   1. OLED lighting and displays
   2. Smart Windows
   3. Printed Sensors

E. **Human applications**
   1. Personalised Diagnostics & Drug Delivery
   2. Medical Microfactories

In this report we publish the key challenges determined for the identified applications, domains and related industry sectors. These challenges are mostly subdivided into the categories "materials" and "processes".

Although the key challenges for Digital Fabrication will also be incorporated and published in the roadmap for Digital Fabrication at the end of the Diginova project, we also wanted to summarise and highlight these in this separate report. The report will be published on the Diginova website which is open to the Diginova network of stakeholders and the public in general. As stated above, the challenges described in this report will also be incorporated into the final Diginova roadmap for Digital Fabrication.

A. Digital Printing (graphical applications)

A.1 Digitisation of traditional printing industry

Materials

Material demands and developments for (inkjet) inks in digital printing are related to the following drivers and expected trends:

- Low cost materials (to compete with traditional analogue printing)
- Light fastness of colour pigments (no colour fading caused by light or ozone)
- Reducing the size of colour pigment particles. Colour pigment nano particles in the range between 10-50nm are predicted to significantly increase colour strength and print quality
- Reduction or elimination of chemical emissions from (co-)solvents from the ink
- Formulation and production of inks using bio degradable components optimised for re-use, re-cycling and zero impact of prints that ultimately end up in landfill

Processes

- Cost
  - Formation of ultra thin layers, matching the layer thickness of ink in offset printing (<1 micrometer)
  - Reduction of ink cost
- Speed
  - High speed inkjet printheads
  - High frequency jetting
- Print quality
  - High speed in-line image quality inspection systems for closed-loop measurement & control
  - Compatibility of inks with very wide range of substrates
  - Inkjet printheads that can jet ultra-small droplets (1 pL)
- High speed fixation and drying of inks

A.2 Display Graphics

Materials

Currently, inkjet inks based on UV curable polymers (mainly acrylates) or solvent inks (mainly for printing on vinyls) are used in the digital display graphics industry. The challenge will be to develop new ink sets that are compatible with next generation inkjet printheads and that will be compatible with a very wide range of substrates as used in the traditional display graphics industry. The challenges will be in the further development of current ink designs or directed towards development of new ink designs, such as latex inks or water-based UV curable inks.

New inks would have to combine the following properties (combined)):

- Excellent colour light fastness (no colour fading due to sunlight or ozone)
- Eco-friendliness, reduction of solvents, chemical emissions
- High adhesion to a wide variety of substrates
- Flexibility of the ink layers in the printed end products

Processes

- Achieving very thin ink layers
- Increasing the printing speed
- Improvement of speed and quality of ink curing
- High speed in-line measurement and control systems for high reliability and stable print quality

B. Digital Textiles

Materials

Five important ink chemistries need to be (further) developed for digital textile printing to match different types of textile:

- Reactive inks – to print on all natural fibres
- Acid inks – to print on polyamide lycra, wool, silk
- Disperse inks – to print directly onto polyester and blends
- Sublimation inks – to print on sublimation paper to be transferred to textiles
- Pigment inks

The costs of digital printing inks need to be reduced to offer competitive pricing models that will accelerate the growth of digitally printed textiles and to ultimately reach market penetration levels of around 50% of all printed textiles produced worldwide. Other challenges for materials for use in inks in textile printing relate to eco-friendliness and light-fastness.

Digital textile inks need to give excellent colour and fastness performance that match, or better, the end results achieved with analogue printing. The table below outlines the potential barriers to adoption and the likely future developments.

Table 1 – Limiting factors for quicker growth of digital textile printing

Factor	Limits	Impact	Future developments
Initial investment	Cost – performance ratio	Limits the faster spread of the technology	Prices will further fall
Production speed	10 times slower than rotary screen printing	Limits the application to short run	Speeds will further increase
Colour penetration	Drop size combined with resolution	Multiple scanning reduces process speed	Physical limits are given
Colour range	Quantity of inks in use	Several colours cannot be printed digitally as e.g. fluorescent yellow, metallics	Physical limits are given
Ink cost	High price per kg	Often offered as closed system with predefined ink supplier lead to dependencies and high cost	Increasing low cost competition from Asia will lead to falling prices
Resolution	Process speed	The printheads are the limiting factor, higher resolutions require lower speed	New printheads will offer higher speeds at high resolution
Variable dot size	Process speed with grey scale mode	High resolution with variable dot size are at most possible at reduced speed	Variable dot size will be standard
Machine, printheads, inks from different companies	Common strategy for development of systems	3 parties want to generate margins	Not predictable

The new market opportunities enabled by addressing these materials challenges and adding new functionality to textiles are huge. They range from self-cleaning or water repelling nano-particle coatings to enzymes and biologically active materials. Materials can be envisioned that modify textile fibres on the basis of nano-container microcapsules that either prevent bacterial growth by releasing anti-microbiotics or by absorbing odours.

One of the key factors is the increasing need for improvements in textile materials. The Global Smart Fabrics in Interactive Textiles market has also been adjusting to rapid technological advancements. However, the slow rate of adoption of smart fabrics in certain end-user applications could represent a challenge to the growth of this market. The search for better and smaller electronic components is very important for the future of smart textiles. The continuous development of functional inks, that can be used in digital fabrication for example, will be instrumental in this quest, as it will provide truly flexible and inconspicuous electronic components.

> *"E-textile technology holds out the promise of truly wearable computers as well as inexpensive large-scale computational devices. To achieve these goals, e-textiles combine high-volume, low-cost textile manufacturing capability with discrete electronics and novel fiber technologies. E-textiles are most likely to generate a considerable body of research, which will have far-reaching implications in our everyday life, consumer market, and multiple applications. It requires remote sensing, processing and actuation. E-textile will throw new challenges for hardware and software system developers due to its unique and individualistic requirements." (R. Kholiya, S. Jahan, 2011)*

Materials development for functional clothing poses a challenge. The materials used must perform well in a number of dimensions. As they are worn by individuals they must be non-toxic. Further they must have attractive haptic and visual properties and they must be UV insensitive and wear resistant. However, the critical criterion for the materials is that they must be cheap enough to enable an attractive value proposition to the user/consumer.

Printable materials need further research and development in order to achieve printable materials that are robust and flexible and fabric-like. It is unlikely designers will want to migrate to digital until they can produce something that is as good or even better than what they can produce currently.

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Developments in printable materials need further research and development to print materials that are robust and flexible and capable of producing fabric-like materials. It is unlikely designers will want to migrate to digital until they can produce something that is as good or even better than what they can produce currently.

C. Additive Manufacturing

C.1 Functional end-use parts and products

Materials

In the context of the Diginova project, technology challenges are viewed as activities that need to be carried out to overcome impediments to industrial emergence in the form of technological barriers or value chain roadblocks. In previous deliverable reports in the Diginova project, technology challenges were determined on the basis of the identified technology and business implementation barriers and matching approaches.

Virtually all types of materials can be used for additive manufacturing in the production of end-use goods. Materials which can be used for any sort of organised construction or manufacturing engineering application are known as engineering materials. These materials can be classified into the following broad groups: polymers, metals, ceramics and composites.

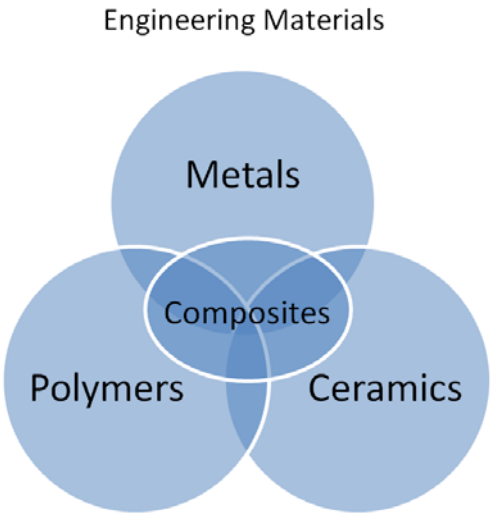

Figure 1: Engineering materials[1]

Polymers form the largest group of materials to be processed by additive processes. These range from photopolymerisation resin that mimics materials for plastic injection moulding to high temperature resistant ultra-polymers. It is important to note that these polymers differ significantly from the ones used for injection moulding. Even if the material is chemically identical, the resulting material and mechanical properties differ significantly. For example, material that is completely molten and injected into a tool under high pressure in a conventional process shows different properties when compared to a material that is locally molten under atmospheric pressure, as in

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[1] Diginova Deliverable 4.2, 2013. Identification of Key Technology Challenges (KTC) for future (additive manufacturing assisted) manufacturing.

some additive processes. Moreover, the addition of fillers such as glass, aluminium and ceramics may alter or improve mechanical properties to a certain extent.

Of particular relevance to this opportunity are the industrial grade thermoplastic polymers used in additive processes of the powder bed fusion and material deposition types, as summarised in Figure 2. Low cost digital fabrication systems aimed at consumers ("home printers") are usually not equipped with heated ovens and therefore not suitable for these engineering plastics.

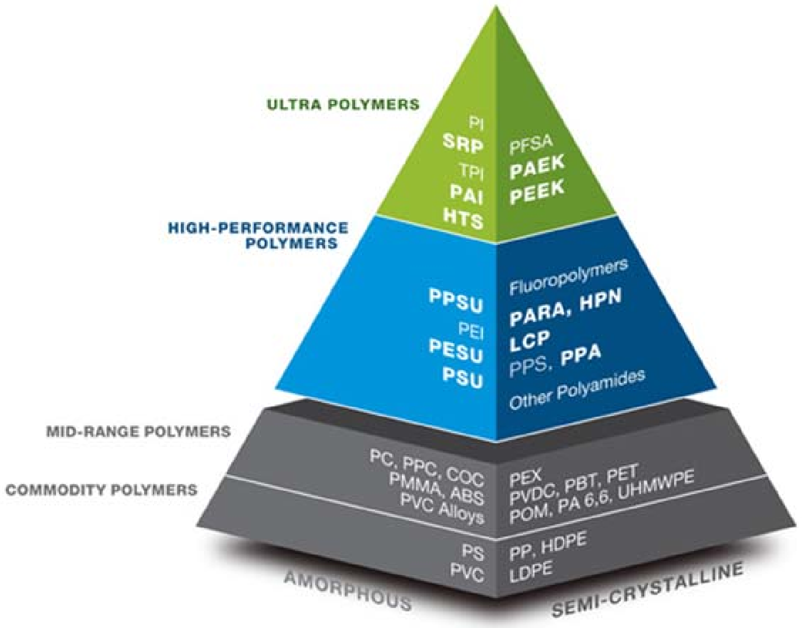

Figure 2: Thermoplastic performance pyramid[2]

More than 100 different photocurable resins are commercially available, simulating various thermoplastic polymers. It is difficult to combine material properties in these resins and generally there is a trade-off such as impact strength versus heat deflection temperature. Stability over time and moisture absorption is also an issue. Using fillers such as ceramic nanoparticles, some limitations can be partly overcome.

Metals form the second important group of materials for use in additive manufacturing processes. Unlike the polymers employed in other additive processes, the metals employed by digital fabrication approaches are very similar to metal materials used in conventional manufacturing processes, such as laser cladding or welding filler material.

Powder bed fusion of metals is comparable with the polymer based variant. The main difference is the necessity for support structures. These structures are required for most metals. The high residual stresses experienced when processing metals means that support structures are used to keep the part from deforming. Post processing steps such as stress relief heat treatment and support removal can therefore be time consuming.

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[2] Diginova Deliverable 4.2, 2013. Identification of Key Technology Challenges (KTC) for future (additive manufacturing assisted) manufacturing.

Various metals are available for additive processes, including stainless steel, tool steel, CoCr alloys, titanium, magnesium, aluminium and precious metals such as gold, platinum and silver. Research activity is ongoing to process copper. Process parameters such as applied energy power, scan strategy, process control and powder dispensing have to match the material used.

The particle size will influence accuracy and surface finish in powder based processes. Finer particles will result in smoother surfaces, but are difficult to handle. Materials with low thermal conductivity result in better accuracy, as the melt pool and solidification area can be better controlled. The materials used display shrinkage of 3-4% when processed. This may lead to part distortion. Elevated powder bed temperatures will reduce distortion.

The remaining two material groups shown in Figure 1, ceramics and composites, are believed to be of lower relevance for additive manufacturing processes. Ceramic materials are limited in their processability using additive manufacturing due to their high heat resistance. Composite materials are macro-physical combinations of different phases with the aim of combining beneficial properties of the basic materials. This makes the deposition of composites using additive means very challenging.

Processes

Major technology challenges standing in the way of the adoption of additive manufacturing in the production of functional end-use products range from process fundamentals, process economics, industrial implementation, consistent quality and control as well as product data handling and specialised training. These aspects are especially relevant as the technology will need to outperform established conventional manufacturing processes in many cases. The deliverable report D4.2 generated earlier by the Diginova partners in work package 4 identifies the resolution of these technology challenges as the highest priority.

Overall mid-term priority is given to technology challenges relating to durability and the closed-system approach as well as to supply chain development and collaboration within the supply chain. Other aspects of medium importance are the development of matching design systems, in-line quality control, standards and certification.

A further persistent challenge to address for the application of additive manufacturing in the production of end-use products is the development and integration of complementary technologies and peripherals like electronics, motion control and software. High productivity future additive systems will require specialised datapaths and control systems. Moreover, the development of specialised design software for multi-material and integrated 3D products is currently lagging behind the advances in the mechanical capability of inkjet printheads.

A fundamental limitation of current technology is the size restriction to additively manufacturing products imposed by the internal build volume. The effect of this limitation is that additive processes are able to produce small parts, consumer products and medical components, but not large products.

When attempting to enter new markets, new design rules may need to be established before industry consensus can be achieved. Design rules for additive manufacturing are being developed. The design of integrated and multi-material parts is still very immature. In established industries where technical change is slow and investments are long-lasting, customers prefer to work with technology and suppliers with whom they have existing relations. Also the lack of customer belief in new emerging markets is a barrier. To take on a disruptive technology the customer needs to see that it functions and that the technology is robust and reliable. It is necessary to convince the industry. Multiple demonstrations are needed to reassure the customer that the technology is reliable and to let them see the capabilities.

The structure of the value chain also presents a barrier to the customer since they do not always experience direct financial benefits. For example, the savings that are made from a reduced inventory arising from flexible short runs could be made elsewhere in the value chain.

To resolve the technological challenges present in the manufacture of functional end-use products, research and development funding is required. The provision of such funding affects the pace of technical development. Income from consultancy work and business to business (B2B) agreements can help fund projects but specifications are subject to the requirements of the customer. Therefore, this can lead to a bias towards the requirements of the funder and slow down the speed of development. Sales revenues can provide the financial resources for technical development. Using licensing of IP and technology as a revenue generating strategy can prove successful but is less effective during the development of a new technology. Few end-users are involved in the upcoming market resulting in quick saturation of the licensee market.

C.2 Additively manufactured objects with embedded printed intelligence

Materials

On the materials side, major technology challenges will involve combining several materials successfully for the purpose of printing an integrated product. This implies that the materials used must be compatible on multiple levels. Moreover, the materials and the deposition technology need to be matched for each particular application and substrate.

The scope of potential applications is limited because particular deposition processes are limited to certain types of materials. Each material requires a specific formulation and it is expensive to match the material to a deposition system, such as a printhead. Further complicating this matter, the materials are likely to be proprietary formulations developed to have specific characteristics, e.g. to allow shrinkage and thermal expansion. Examples for such materials are engineered mixtures of monomers, photo initiators, dispersants, colorants, viscosity modifiers and inorganic powders.

To achieve the required physical and mechanical material properties, such as conductivity, strength and stiffness, the inorganic portion of the printed material must be composed of a precise distribution of functional fillers like fine ceramics, metals and/or modifiers.

The development of materials suitable for the digital fabrication of printed functional structures has attracted a considerable amount of research in the last two decades. However, this application domain is a very competitive space, which is why progress must be achieved in applications like printed electronic displays within the next 5-10 years if commercialisation of digitally fabricated displays is to be realised. From a business standpoint, it must also be noted that emerging applications require materials in low volumes. Therefore material suppliers may see only a limited incentive to develop specific materials and prefer to sell into markets that are already established, which may obstruct the innovation process in this application.

Particularly for the fabrication of printed electronics the development of suitable materials forms a considerable challenge. The material spectrum required includes dielectrics, conductors, optical carriers, and structural materials with tuned mechanical, thermal and physical properties. The key aspect in these considerations is the interaction of the materials within the digital fabrication process. Parameters such as temperature resistance, viscosity, curing/solidification methods and deposition accuracy are expected to play a significant role.

In sensing applications, both the design and build material of the sensor will be determined by the specific sensing purpose, therefore the required materials need to have the appropriate properties for applications. For successful deposition of materials in digital fabrication processes, aspects such as viscosity, adhesion characteristics, and wettability are of importance.

Regarding printed power storage devices, much of the developmental effort towards digitally fabricated components has been expended on small batteries. This has resulted in the manufacture of alkaline, lithium ion and other types of micro batteries. Printed zinc-air batteries have been integrated into electromechanical devices. Further, it is expected that the material requirements will depend on progress in Micro-Electro-Mechanical Systems (MEMS) and nano-scale applications for which power sources of a matching scale are needed.

Processes

The most important process-related technical barriers to the realisation of digitally fabricated products with integrated intelligence are reliability, maintenance and uniformity. For the deposition of such structures, the focus within the Diginova project lies on digital fabrication technologies depositing build materials via jetting heads.

Operating the existing materials jetting platforms in a reliable round-the-clock configuration poses a challenge at the current state of the technology, not only because of the clogging issue of the inkjet nozzles, which causes line defects, but also the heat generation of the printhead. Also, industrial printing requires a high throughput; however, there is a trade-off between printing times and accuracy.

A further process-related challenge faced in the multi-layer, multi-material deposition of functionally integrated devices is the linkage with other manufacturing technologies with different process parameters, such as speed and process environment requirements. This is due to the fact that digitally fabricated embedded functional structures are mostly manufactured in hybrid manner, combining various additive and conventional technologies. Modular production configurations featuring elements of digital fabrication and conventional processes have been introduced to meet this challenge.

Another area that requires significant attention in the digital fabrication of complex embedded multifunctional structures is related to the avoidance of process and deposition errors. To realize a viable production setup based on digital fabrication, aspects such as error prevention, prediction, detection and correction form a top priority. For the commercial implementation of digital fabrication techniques in the production of embedded structures, reliability of print head architecture and operation system is critical.

Figure 3 provides a summary of the process and materials-related technology challenges faced in the deposition of intelligent embedded structures, as identified by the Diginova partners.

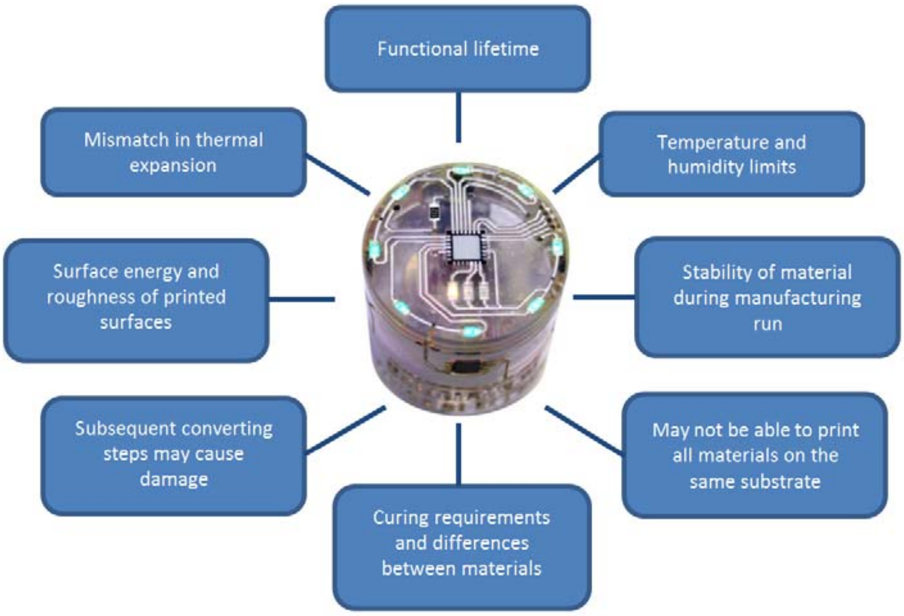

Figure 3: Major technology challenges for embedding functional structures[3]

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[3] Diginova Deliverable 4.2, 2013. Identification of Key Technology Challenges (KTC) for future (additive manufacturing assisted) manufacturing.

D. Printed Electronics

D.1 OLED lighting and displays

Nowadays OLEDs and their materials are on the cutting edge of technology development. To enable OLED expansion in the big markets and industries there are still many challenges to be overcome.

Materials

Organic conductive materials are applied in many industries and research programs already. There is a lot of knowledge on a large number of organic materials being applied in many ways, meaning that many companies are investing their knowledge and energy to harvest the enormous opportunities. However, most of these organic conductive materials deteriorate under ambient conditions (oxygen, water vapour). In order to overcome this limitation many R&D projects in research centres and big industries, invest heavily in resolving this specific issue. In particular, there is a big technology challenge for OLED technology in the field of flexible electronics, especially in organic device encapsulation.

Organic device encapsulation has many different processing techniques, for which several patents are filed, and several disputes between the corporations and R&D institutions involved have taken place. The encapsulation process is a big challenge for flexible organic electronic devices. The use of glass as barrier material is the best option for non-flexible and rigid organic electronic devices. There are already OLED products in the market with glass encapsulation such as smart-phone devices, AMOLED TVs and products from the lighting industry such as Lumiblade from Philips and Orbeos from OSRAM.

Processes

In the process area the biggest challenge is in scaling up to large scale production. Nowadays, OLED devices are mainly produced using thermal evaporation of small molecules. This technology has several disadvantages:

- The use of a vacuum system, making it an **expensive** production method
- Slow processing speed, due to the evaporation process
- **Low scalability**, since large systems are needed to deposit on relatively small areas

In order for OLED technology to become a mainstream technology, it is commonly accepted that the vacuum evaporation process should be abandoned. The idea is to produce OLED devices in a fast and continuous process. But once more, the feasibility and manipulation of organic materials remains a big challenge. Some of the technologies that might be used as an alternative for vacuum evaporation include rotary screen-printing, slot-die and inkjet printing.

In order to allow digital fabrication the most promising process is inkjet printing. For the transparent conductive layer, digital fabrication through inkjet printing seems feasible. However, the entire OLED device also requires ceramic and metallic materials to shield the organic material from the environment and to interconnect all the parts of the device. Although it is possible to produce the organic materials by an inkjet printing process, challenges still remain in the field of barrier and electrode fabrication, thereby disabling entirely digitally fabricated OLED devices for the moment.

Although the huge difficulty is the encapsulation process for organic devices, the facts are that, nowadays the growth of the OLED industry still depends on materials that can only be made by expensive and non-digital fabrication processes. One example is the TCOs or any type of structure and conductive thin transparent layers combined with the organic material.

The technology of OLED lighting will be able to enjoy the advantages accrued through the introduction of new materials transferred from other OLED applications as they gradually become introduced in most other OLED application categories. However, the creation of new OLED producible materials is the weakest link in determining the forward progress of this technology and its related applications into the future. New emphasis needs to be placed on developing new materials first before that of designing new OLED applications. In addition, because of the unique requirements surrounding the fabrication of OLED Lighting and Displays, new materials introduced for these lighting and display products may also flow back synergistically into other applications as well.

The OLED path to success depends on market, technical and manufacturing aspects. In the table below some are described:

Table 2: Market, Technical and manufacturing challenges, Eric Mounier from Yole Development.

Market challenges	Technical challenges	Manufacturing challenges
• LED competition • Higher performances while keeping small form factor & potentially low cost • Adequate supply chain • Targets market with production scalability	• development of new cost-effective materials for OLED encapsulation • Adoption of flexible plastic substrates requires lowered substrate and barrier material costs	• Today “standard” technology for organic layer deposition is vacuum • But Roll-to-roll techniques promise high potential for OLED cost reduction due to the high-speed processing.

Future developments must be focused on production of new formulations/inks to print both organic and encapsulation layers with low production costs and commercial viability. Concurrent with these developments, TCOs must also be produced using new technologies that enable reduction of processing costs and allow for higher market implementation, thus forwarding digital fabrication of OLED devices.

D.2 Smart Windows

Materials

The impact of digital fabrication on the set of materials used for smart windows will initially be low, as digital fabrication is particularly useful in patterning materials that are continuously being developed for products produced with analogue technology. The main impact is expected to arise when demand for customised patterned windows or mirror elements arises. It is expected that the main driver for these innovations may initially come from the automotive and aerospace industries.

Electrochromic glass already has a history in commercial transportation markets with the commercialisation of controlled shading windows in aircraft passenger windows and isolation screens for train operators. However, as the market penetration in the transport market increases costs will come down: at the same time, awareness of their features goes up, facilitating the introduction of the technology into new areas such as consumer markets for appliances, household mirrors and toys.

Actually the value for money of smart windows is perceived higher than the straight costs of architectural glass (which itself is considered expensive).

Processes

2D digital fabrication technology (covering all the types of inkjet mentioned in deliverable D 4.2) and laser ablation are high resolution techniques that are useful in the processing of smart windows. As mentioned, employing high throughput technologies may not prove to the most commercially viable option regarding the level of customisation that may be required for smart windows, and also the wide range of different applications/functionalities need different smart windows installed in the same structure (aircraft, vehicle, floor/division of building). Therefore, the opportunity is around developing 2D digital fabrication technologies that will allow for the development of specific designs and specific functionalities integrated into an individual window panel.

Currently, these types of Smart Windows are either colourless when transparent or dark blue when opaque. This opens new opportunities for research into material that could switch between colourless transparency and a range of opaque colours.

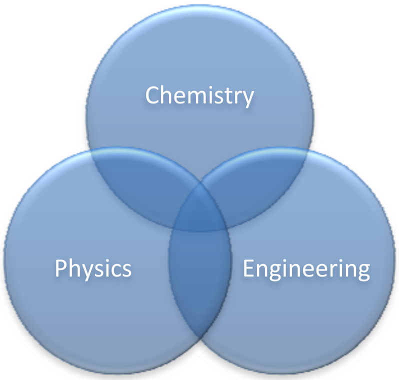
D.3 Printed Sensors

Materials

Future development is related to integration of sensors with other functionalities into an integrated smart system. The key challenges to be faced are related to integration of different components and especially interfacing to printed electronics circuitry.

Currently the market is accepting new products with integrated sensors and improved hardware and software. There is a need for the continuous development of new functional inks, to increase the range of applications for printed sensors, and also the optimisation of existing digital printing systems to maximise output and lower cost.

The production of printed sensors requires a dedicated multidisciplinary collaboration between science and engineering.



Processes

Printed sensor manufacturing needs a number of different materials with completely different properties, but still compatible with each other.

- Conductors, semiconductors, dielectrics, functional polymers

There are several commercially available inks.

Table 3: Features of inks for the manufacturing of sensors.

Property materials	*Specification materials*
Conductive materials	metal particles and conductive polymers
Semiconductor materials	semiconductors polymers and ceramic materials
Dielectric materials	polymers and ceramic materials
Functional materials	materials that have properties that can be easily controlled by external parameters

In order to happen, the value chain has to be closely connected so that materials can be adapted to process technologies and vice-versa. New materials, manufactured by new kinds of process methods, have, as a minimum, to present the same properties as the materials they are replacing.

The term “printing” refers to the most commonly used techniques such as screen printing, inkjet, flexo- or rotogravure processes. Functional inkjet has received a lot of attention because of its ability to create very small features in a very flexible way. This could make inkjet highly suitable for digitally fabricating sensors. Other techniques, like flexo- and rotogravure are very high throughput processes and are therefore highly suited for roll-to-roll products.

Figure 4: Value chain for Printed Electronics.

The printing methods most commonly used for printed sensors are screen printing, gravure printing and inkjet printing. Here are some characteristics of those techniques:

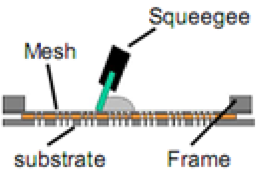
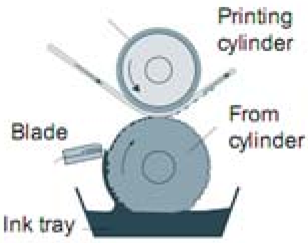
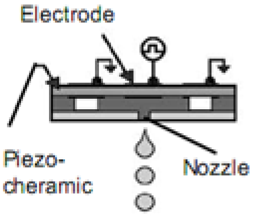
Screen printing	Gravure printing	Inkjet printing
		
(+) Most mature; (+) Rather inexpensive; (+) Roll-to-roll compatible;	(+) Allows thick and thin films; (+) Good scalability; (+) High layer quality; (+) High resolution; (+) Roll-to-roll compatible;	(+) High resolution; (+) Flexibility (digital method); (+) Substrate independent; (+) High resolution; (+) Roll-to-roll compatible;
(-) Requires masks; (-) Waste of ink; (-) Limited resolution;	(-) High cost of cylinders; (-) Highly demanding;	(-) Nozzle clogging;

Figure 5: Most common techniques for Printed sensors.

The roll-to-roll manufacturing method enables reduction of mass production costs for printed electronics. Printed sensors could also be created using the conventional deposition and patterning processes found, e.g., in the semiconductor industry: physical vapour deposition and photolithography.

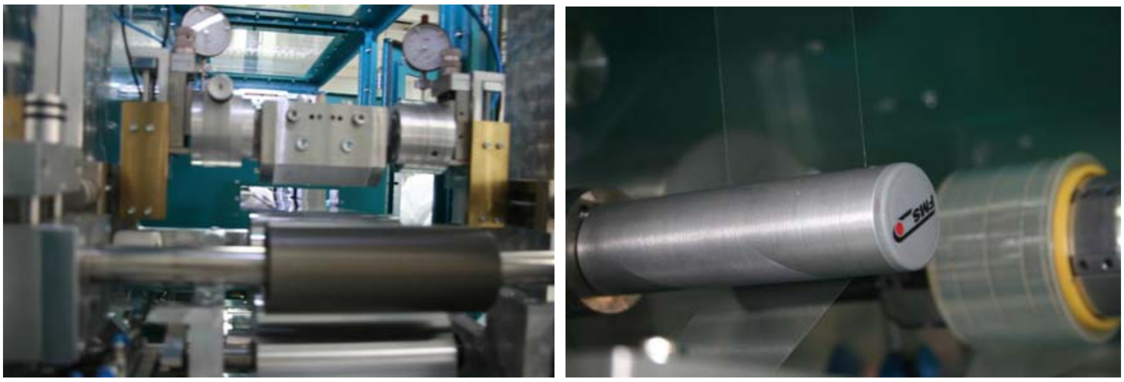


Figure 6: Overview of roll-to-roll process in printed electronics. (Source: CeNTI facilities)

According to NanoMarkets, in their article “Printed Sensors - A New and Emerging Family of Sensors”, they compare what could be regarded as ‘established’ with ‘new’ printed electronics:

> “Printed electronics is either a new business or an old one, depending on how one defines the term. Thus, screen printing has been used for many years to create electrodes, membrane switches, capacitors, PCBs, etc. In these cases, printing was used almost as a coating technology or for the creation of large features. The new form of printed electronics, which has mostly emerged in the last five years, is intended to create complete devices with relatively small features, including sensors, although sensors has not been the area where most of the focus of printed electronics has been.
>
> Both kinds of printed electronics are important, because of the more established areas of the printed sensor business (e.g., DNA assays) use printing in a traditional way. However, the new kind of printed electronics seems to offer the potential for fabricating complex sensors at very low cost points. In addition, as we have already noted, printing seems a natural fit for creating sensors in a large-area substrate.
>
> This is the dream anyway. However, the new kind of printed electronics has had teething problems and has not arrived as fast as expected, a fact that needs to be considered in assessing the future of printed sensors. The current thinking on printed electronics is that initially printing will be used only for certain layers of making a device; the idea of creating a device entirely with functional printing has been put off for a while.”

The processes used in the semiconductor industry are regarded as suitable for the creation of sensors, in cases where the cost outweighs the performance. Otherwise some of the advanced tools of nanotechnology, such as nanoimprint lithography (NIL) or dip pen nanolithography (DPN), may play an important role.

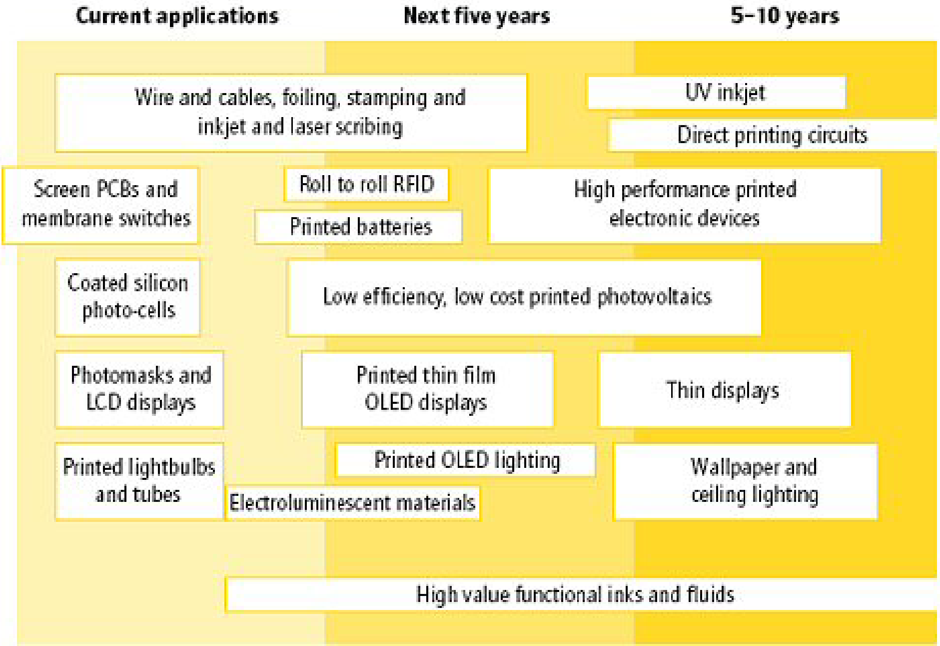


Figure 7: Technologies for Printed Sensors in the next years. (Source: Pira International Ltd.)

E. Human Applications

E.1 Personalised Diagnostics & Drug Delivery

Personalised Diagnostics & Drug Delivery systems are at the forefront of modern medicine. The use of fundamental printing techniques such as ink jetting will allow the creation of systems to diagnose, monitor and prescribe at point of care and, as such, will have a significant positive effect on patient safety, drug efficiency and overall quality of care. The market for personal diagnostics is currently small in relation to the overall pharmaceutical market, and the lack of technological infrastructure is a significant barrier to growth. Specific research challenges are:

- In materials processing, very low lead time, automated processing of proteins and resorbable polymers, with controlled doses of specific pharmaceutical products.
- In machine development, diagnostic printer platforms, able to produce diagnostic devices for a range of conditions from the same basic unit.
- In the clinical sciences, identification and development of biomarkers for drug compatibility and disease identification, greater understanding of the relationship between drug dosage and personal genetic predisposition, and the development of biosensor bioreceptors.

Close collaboration between the clinical sciences, biomaterial scientists and machine developers is the key to bringing the promise of printable personalised medicine to the clinic and market.

E.2 Medical Microfactories

- For medical device microfactories, very low lead time, automated processing of biocompatible polymers and composites (going beyond what is currently possible), is required, with 3D printing at the centre of a single stage additive manufacture or hybrid manufacturing process.
- For tissue engineering microfactories, clean co-processing of resorbable biomaterials with cells and proteins - to create complex 3D structures - is required. Materials with a combination of excellent mechanical properties and excellent biological properties are a key need.
- Integration: the development of medical microfactories for specific healthcare applications (for example for arthritis, diabetes, cancer, assistive devices for the ageing population, or for orthotics and prosthetics) - with the active involvement of healthcare professionals - provides the best environment for integrating the technologies into a healthcare setting.