NextFactory

SEVENTH FRAMEWORK PROGRAMME

PROJECT FINAL REPORT

Grant agreement no.:	FP7 - 608985
Project Acronym:	NextFactory
Project full title:	All-in-one manufacturing platform for system in package and micromechatronic systems
Funding Scheme:	Collaborative Project – Specific Targeted Research Project (STREP) Thematic FoF-NMP

Date of latest version of Annex I against which the assessment will be made: 10/04/2013

Period covered: from **1st September 2013 to 31st August 2017**

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1. Executive summary

Mass customization will grow important for many different markets and the ability of fast prototyping is key to be competitive in fast changing and growing technological fields. Both facts are also relevant for microsystems of different types.

Additive manufacturing (AM) could therefore be a future cornerstone for micro-mechatronic systems in the future. Nevertheless, AM-technologies are very limited regarding the demanding application of micro mechatronic systems.

To change this NextFactory is aiming at innovating the production technology for functional prototypes and small lot sizes of micro-mechatronic systems. In the NextFactory approach, the technological fields of additive manufacturing are merged with assistive technologies for the production of individualized Smart-Products-in-Package (SPiPs).

Within the project, interdisciplinary developments lead to a new, hybrid approach to manufacturing such kind of prototypes. The NextFactory system consists of a modular machine including all processes at production level and complete set of materials including conductive, insulating and functional materials that are both – compatible with process- and product requirements. Furthermore simulation models for the hybrid manufacturing process were developed to achieve predictable product quality and closed-loop process control in future. The capabilities of the system were demonstrated based on test-parts which were designed according to the requirements given by three use-cases. Each of the use-cases addresses a different market and application scenario. This was also the basis for business modelling activities to figure out the economic viability of the NextFactory system right in the development phase.

2. Project context and main objectives

Project context

In the future many manufacturing SMEs will have to develop a threefold capability:

- Manufacture themselves three-dimensional integrated circuitry for highly miniaturised products
- Produce full miniaturised mechatronic components and products, i.e. Smart Products-in-Package (SPiP), in an all-in-one process, far beyond today's Systems-in-Package (SiPs)
- Own their manufacturing processes at economically viable conditions

Manufacturing processes for miniaturised and customised smart micro-systems

The market demand for highly compact, individualised and smart electro-mechanical systems and products increases rapidly. Manufacturers therefore aim at advanced production technologies that can integrate in few stages and ideally at one site all (micro-) components of the product into a single package.

Production of three-dimensional integrated circuitry sets new standards for downsizing micro-electronics to single-chip modules. However, SiP manufacturing is usually reserved to large companies, like cell phone and wireless industries, which produce in lots of several hundred thousand or more.

Recent demonstrations of advanced high-resolution 3D printing techniques in SiP manufacturing show the path towards highly scalable in-package production of customised micro-chips ranging from one-piece-at-a-time batches to individual mass production. This makes it a very promising manufacturing process, in particular for European high-tech SME, which frequently focus on niche markets with low production volumes that range from 10 000 units per year down to single pieces. Usually, SME subcontract specific processing to specialised companies in a complex, multilateral process chains. This is time consuming, expensive and inefficient, and in many cases the market introduction of product life cycles fails as applicable process chains are not available or require a disproportionate investment.

All-in-one processes for Smart Products-in-Package manufacturing

The introduction of 3D freeform printing has the potential to trigger a major step forward in SiP manufacturing by reducing the number of process stages and significantly raises the potential for SME to compensate for the disadvantages of small-batch compared to mass market production. At the same time this step opens new possibilities for tailoring product features to the specific needs of individual or small groups of customers. Today first tentative applications using additive manufacturing techniques have been tested for SiP production, but are far from being able to produce full mechatronic devices and products in an integrated single-stage one-location process, including inline quality inspections. Sensors, energy capacitors or similar functional components, still have to be processed and wired to the SiP in consecutive stages. Embedding these micro-devices in an all-in-one production process will advance manufacturing of micro-components from integrated 3D circuitry in SiPs to integral Smart Products-in-Package (SPiP), switching from a multilateral to a holistic approach.

SME ownership of their SPiP manufacturing

The costs of advanced SiP manufacturing equipment, which often has been customised to a specific application need, are in themselves a major obstacle for SMEs to "own" the ir SPiP manufacturing. Their market potential does not justify the investment into their own equipment and if it does, this equipment is not able to scale up to larger customer orders. Therefore next-generation solutions must be highly generic, i.e. the same physical machine must be usable for multiple use cases (UC) by choosing the appropriate materials and programming the process chain, which itself is composed of generic process modules. Combining an all-in-one SPiP approach with a highly generic approach will empower SMEs in many ways:

- The same production machine and the same materials will cover a broad range of application needs for SPiP production. Business models are enabled where different "local" "SMEs addressing a wide range of areas share a single machine.
- By using a modular approach, machines can be clustered to scale up to large batch needs, when the opportunity offers itself.
- A generic machine can be produced in much larger series itself, thus allowing for reduced production costs, which will make the machines more affordable to SMEs.

The other major requirement will be openness to customisation. Machine customisation will continue to be attractive for certain market players, including SMEs. Thus for instance, SMEs producing miniaturised sensors, which will be in direct skin contact, may require the possibility to add further process steps to an otherwise generic solution to deal with biocompatibility and hygiene requirements. Also it must be possible to functionalise materials for specific applications. Future solutions must hence be both generic and open to customisation.

In many ways the step from SiP to SPiP will hence potentiate the role of additive manufacturing in production processes and enable the broad range of small micro-system manufacturers:

- To further miniaturise their products in the order of a magnitude while maintaining or even extending their functionality by application of discrete components and smart materials
- To reach utmost flexibility and scalability in terms of production throughput ranging from small batches (1-10.000/a) up to large batches of 100.000 units per batch and more (high throughput would be achieved by the parallel set-up of several all-in-one production facilities on one shop floor following the concept of individual mass production)
- To dramatically enhance the customisability of their products thanks to individual freeform shaping of the micro-component according to the needs of single users
- To obtain a one-stop-shop service of combined manufacturing and assembly and to avoid time and resource-intensive distributed production chains

- To cut production lead time by factor 10 to 10 (depending on use cases), thereby opening an unprecedented innovation potential
- To reduce the use of resources and residual waste to the very minimum
- To increase the added-value of their contribution to the product design and manufacturing process

Overall objectives

The overall goal of NextFactory is to develop a new kind of manufacturing system for system-in-package and micromechatronic systems based on a combination of 3D freeform printing and ultra-precision 3D-assembly technologies.

The project objectives are as follows:

- To develop the overall generic and open NextFactory Process Chain Concept for the entire manufacturing freeform SPiP process and NextFactory System Architecture, with special focus on the combination of 3D printing and microassembly;
- To design, model and develop a generic and open NextFactory Machine based on the overall NextFactory Process Chain Concept and thus merging 3D printing & microassembly into a holistic solution
- To design, develop and progressively fine-tune an extended and extendable range of generic processable and smart / functional materials with the necessary properties to enable full freeform SPiP production and assembly, in particular adding substantial functionality, conductive materials as well as additive filled materials to functionalise printed parts and leveraging the capabilities of the new NextFactory printheads and dispensing technologies for specific UC
- To design, model and develop supporting technologies and process modules for the NextFactory Solution including 3D freeform printing process modules, 3D microassembly techniques (in particular to combine them with 3D printing), simulation tools (integrating 3D printing and microassembly), and quality management methods
- To trial and improve the generic NextFactory Solution in selected application areas by customising it to the needs of high-profile Use Cases (UCs), including the development of application specific product design models and then validate the NextFactory Solution in a Proof-of-Concept Demonstration
- To optimise external impact and sustainability of project results by launching, developing and fostering a dedicated NextFactory Community to attract and federate a critical mass of stakeholders around the NextFactory Solution, stimulating the emergence of new NextFactory applications

3. Description of the main results/foregrounds

This section describes the main results achieved in NextFactory.

WP1 – NextFactory Use Cases

Work package 1 “NextFactory Use Cases” gives the rationale for the development of the NextFactory solution. Within three distinct areas use cases have been defined, specified and developed.

The three application areas are photovoltaic modules for solar-powered products, micro sensors for dissolved oxygen monitoring and a radio module for medical devices.

In a first step functional requirements and mock-up prototypes with state-of-the-art materials, components and processes have been designed and developed. Those prototypes have been evaluated and based on the NextFactory process model a version 2 “super prototype” has been designed.

Use Case 1: Solar Modules

The integration of solar energy harvesters into products is often hindered by the clumsiness and expensive integration work. Although solar cells and related components such as junction boxes are mass produced and hence very reasonable priced the real hurdles are often the tailoring and miniaturizing of these standard components to the specific needs of an application or product design.

Based on this shortcomings of the “state-of-the-art” Sunplugged conceptualized the idea of a 3D printable junction box for photovoltaic modules. This printed junction box has a smaller footprint in comparison to commercially available junction boxes and can be placed anywhere on a photovoltaic module because the printing and other additive manufacturing steps can be digitally controlled. The base plate of the printed junction box will also act as a platform for further component integration such as diodes or electronics for undervoltage protection while solar charging.

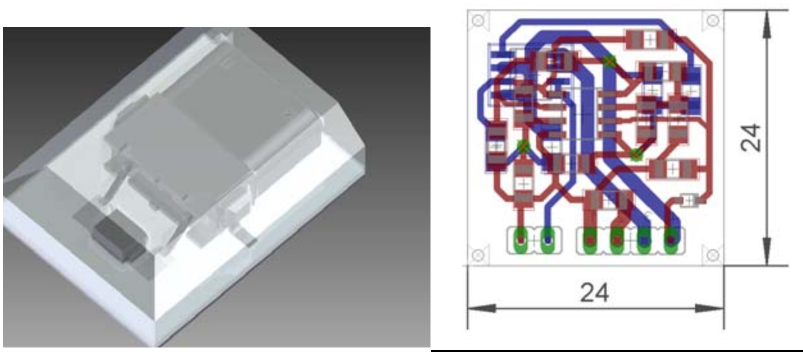

Figure 1: Generic UC1 designed and developed- Printed Junction box including basic functions like,under voltage protection while charging.

After the design phase materials and processes for the realisation of such printable junction box have been investigated and finally a working toolbox for 3D printed junction boxes has been developed.

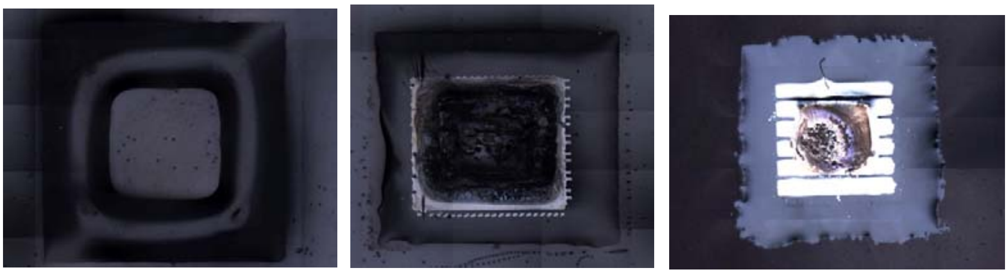

Figure 2: Processes, Material combinations for additive back-end processing (printed current collection and printed junction boxes) successfully developed. Pictures show printed via in dielectric base plate.

Within the course of the project it has been demonstrated that NextFactory is a viable solution for a new breed of photovoltaic energy harvesters with miniaturised PV module designs. The additive manufacturing approach allows in a short-term perspective the replacement of conventional current collectors, junction boxes and is in a longer-term perspective a platform for further component integration. Besides the proof of concept for additive back-end processing of thin-film solar modules, the relevant processes (deposition by inkjet printing, curing), the material combination, the process parameters for printable current collector and the junction box have been developed and printed components were validated on laboratory scale. Based on this findings a concept for the implementation of a NextCactory "station" in the pilot line of Sunplugged has been developed. The idea here is to concatenate a dedicated NextFactory process station with the preceding photovoltaic module manufacturing in an economical Roll-to-Roll operation.

Use Case 2: Micro sensors

Cellasys GmbH led the use case micro-sensor where a small device for monitoring oxygen concentration in a sealed compartment was realised. Furthermore Cellasys supported the consortium with its certified quality management knowledge and tested new materials for biocompatibility.

A production process of the dissolved oxygen logger with the NextFactory approach was developed. In contrast to conventional design the components have to be flipped and integrated into the dielectric material. This new design allows additive manufacturing of the whole device and gains further miniaturization in contrast to conventional production. The task was successfully completed and a functional NextFactory dissolved oxygen logger with sensor-module, A/D-converter, I/O-module, micro-processor, EPROM and USB-interface was developed and tested.

The newly developed dielectric material was positively tested for biocompatibility which makes it suitable for further developments towards the usage of living cells as biosensors.

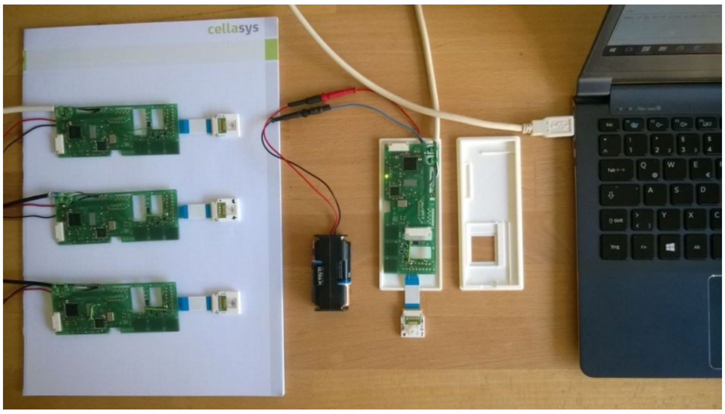

Figure 3: UC2 dissolved oxygen loggers manufactured in accordance to the NextFactory process.

Use Case 3: Oral sensor and radio module

During WP1 MSL specified the module requirements for its oral sensor and radio module, additionally MSL specified the requirements and design for V1 and V2 prototypes.

MSL also performed successful validation testing on V1 prototypes using industry recognised package reliability test methods. During WP1 MSL went on to documented the potential reliability of the V2 prototype if manufactured using the NextFactory machine drawing on extensive knowledge of manufacturing and product validation.

	Test condition	Quantity tested	Comment
Temp cycling	JESD22-A104 C (Target condition G; +125C/-40C)	3/0	Passed
Hot temp storage	Mil-Std-883, Method 1008 (Target condition B; 125C/24 hrs)	3/0	Passed
Cold temp storage	JESD22-A119 (Target -40C/1000hrs)	3/0	Passed
Damp heat	JESD22-A101-B (Target:1000hr 85/85 with bias)	3/0	Passed
MSL Testing	JEDEC J-STD-20 (Level 2a)	3/0	Passed
Shock & Vibration	Mil-Std-883 Method 2002 & 2007 (target condition B)	3/0	Passed
Chemical resistance	1 month in fruit juice	3/0	Passed

Table 1: Task 1.3-D1.2-Summary table of V1 validation testing

Likelihood of failure	Expected result						
	Temp cycling	Hot temp storage	Cold temp storage	Damp heat	MSL Testing	Shock & Vibration	Chemical resistance
Unlikely		X	X			X	X
Possible	X			X	X		
Probable							
Certain							

Table 2: Task 1.3; Summary of risk based prediction of V2 prototype validation testing methodology

Modelling

The University of Greenwich have used their expertise in numerical analysis of microelectronics packaging systems to assess the performance of the NextFactory manufacturing approach. The primary aim of the study was to determine the benefits and drawbacks of using the NextFactory system comparative to a traditional copper/FR4 based approach. The project developed three distinct demonstrator products; use case 1 is a solar power junction box and use case 2 is a dissolved oxygen sensor. The third use case is a generic microelectronics structure with features commonly found in microelectronics systems. This use case was evolved as the project progressed. Modelling has been performed on all three use cases, including the version 1, version 2 and superprototype versions of use case 3.

Modelling of use case 1 focussed on evaluating the Joule losses in the conductor materials in assemblies manufactured using both NextFactory and standard approaches. The NextFactory system uses a printed silver nanomaterial for conductive tracks which has inferior electrical performance to pure copper. As such, results showed that losses were greater in the NextFactory part. However, this issue could be mitigated through thickening the conductive parts or through utilising the systems pick-and-place functionality to position pre-formed copper tracks into the product during the build process.

The Use case 2 dissolved oxygen sensor modelling looked at the electrochemical processes involved in the system. A complex three parameter Nernst-Planck Poisson electrochemical model was developed for this analysis. The model provides an insight into the operation of the sensor and allows the influence of variation in design and printing inaccuracies to be assessed. Use case 3 modelling assessed the thermomechanical behaviour of the various design iterations of the board. Models were used to evaluate how different design parameters influenced stresses within the device. Analyses comparing the thermal cycling behaviour of the superprototype design formed using NextFactory and using standard manufacturing approaches were performed. The results indicated that the combination of high coefficient of thermal expansion mismatch and relatively soft acrylic material results in significantly higher warpage in the NextFactory board. However, material pliability may result in lowered stresses in package interconnects.

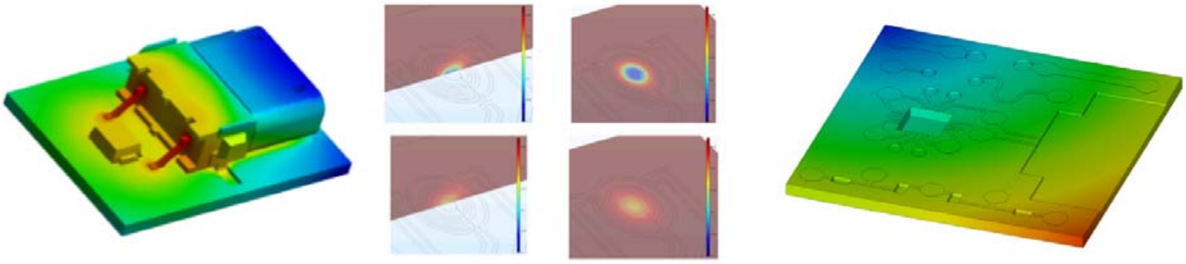

Figure 4: Numerical modelling of NextFactory use cases

WP2 – NextFactory Process Chain Model and System Architecture & Technical coordination

The overall goal of WP2 was to provide a common basis for all developments leading to the Nextfactory system and to align and the developments throughout the project. The objecitves in particular are listed below:

- To identify all necessary process steps including post- and pre-processing steps, considering the compatibility with the possible material classes.
- To develop the NextFactory Process Chain Model, considering the different individual limitations of materials and process technologies
- To Define the overall NextFactory System Architecture and establish a generic specification for each process module out of the process chain definition. This will include: mechanical specifications, supply (energy media and information) and control
- To define specific process module specifications for each module describing functionality
- To define machine specifications considering specifications of process modules
- To define material requirements and corresponding constraints on process and sub-systems to ensure compatibility between materials and processes.
- To screen standards and to align the NextFactory Process Chain Model and System Architecture correspondingly.
- To prepare prenormative work related to the NextFactory Process Chain Model and System Architecture identifying those parts to be submitted later to standardisation processes.
- To prepare a public document on the NextFactory Process Chain Model and System Architecture to make it broadly available to the NextFactory Community.
- To provide a generic input for Life-Cycle Assessment and Cost / Performance Balance evaluation of UC in WP1 and extrapolate to the more general lessons

All actions undertaken, were done in order to ensure the development of comprehensive system, covering all aspects that are necessary to start with further development and commercialization right after project end.

In three iterations, a complete set of specification documents were developed, involving all partners of the project. This gave a common basis to develop the initial mock-up at the beginning and also V2 of the NextFactory system. The final version will provide the basis for all post-project developments in future and also to provide an official statement to the public. This was also an important prerequisite to start communication with potential partners.

In parallel to those specific activities, technical coordination throughout the whole project was one of the major issues for WP2.

In summary, all objectives could be fulfilled which is also proven by an operational and industrial machine setup in combination with process- and use-case-compatible materials.

WP3 – Development and Integration of NextFactory Machine

The Workpackage 3 had to achieve the following objectives:

- Set up an automated and highly flexible manufacturing process according the process specifications given from WP2 by chaining all necessary process steps.
- Develop an early mock-up by emulating the process and the supporting machine to obtain a first early feedback to optimise the quality of the full prototype.
- Provide a human machine interface allowing easy control of the complete manufacturing process without detailed knowledge of single process steps.
- Prove the feasibility of the NextFactory process in an industrial context by setting up a machine prototype fulfilling the needs of industry.

At the end of the project, the Consortium managed to succesfully attain the aforementioned goals. The result of all this develelopment work is concretely represented by the machine currently working at the FhG-IPA laboratories.

On one hand, it was desired to allow the process and product developers to use a tool mature enough, to let the developers concentrate themselves on the process and product development and go beyond the "proof of concept" stage.

On the other hand, the flexibility was required. Thus, modularity came as a natural response. Modularity in all aspects: the machine (hardware and software) was designed to allow upgradeability and exchangeability for each module itself.

At the very end, the modularity is enhanced so far that the current machine may be still populated with several new modules, being integrated through standard interfaces.

Flexibility was a paramount because you need to search and define the suitable process chain for each use case. Thus, it helps when you know that the carrier will go wherever the process needs to.

This machine is practically already available to the market. The modularity and lay out possibilities may allow to address numerous market requests.

Among all the deliverables, the machine and the within integrated modules constitute one of the key achievements of the Consortium.

Figure 5: NextFactory machine

WP4 – NextFactory Materials

The activities of work package 4 focuses on the development on inkjet inks compatible with 3D printing strategy of the NextFactory solution. During the scope of the project several materials investigated, adapted and developed: temperature stable insulating, electrically conductive, functional and smart according to use case specifications and support material for 3D printing.

Insulating and support material: project partner TIGER Coatings GmbH & Co. KG (TIG) developed this material for inkjet printing acting as the base material for use case designs.

Figure 6: insulating material [TIGER IJ176-KK] printed simultaneously with support material [TIGER IJ176-KE]

This type of ink plays a key role within the NextFactory material sets. On the one hand, it has to protect the conductive inks from environmental influences like humidity and mechanical distortions. On the other hand, it provides the structure of the system. Depending on the use case, these structures have to withstand different thermal conditions. Furthermore, a good compatibility with the support ink is of utmost importance which in this case means that the two types of inks shall form sharp edges when printed directly next to each other and do not start to mix. A test structure printed with these two materials is shown in Figure 6.

The final chosen insulating ink consists mainly of acrylates forming the low viscous reactive diluent for the acrylate-based epoxy-resins that form the backbone of the formulation. The ink does not contain any solvents.

Electrically conductive materials: project partner PROFACTOR GmbH was responsible for adapting electrically conductive materials compatible with the NextFactory machine. For this purpose, a particle free silver ink was developed and evaluated. Besides that, commercial available inks were evaluated. Two inks from different suppliers showed appreciable performance with NextFactory printing and sintering approaches. Besides inkjet inks, also two dispensable conductive adhesives were selected for integration purpose of discrete microelectronic components (e.g. SMD components). Integration of such an SMD component is shown in Figure 7.

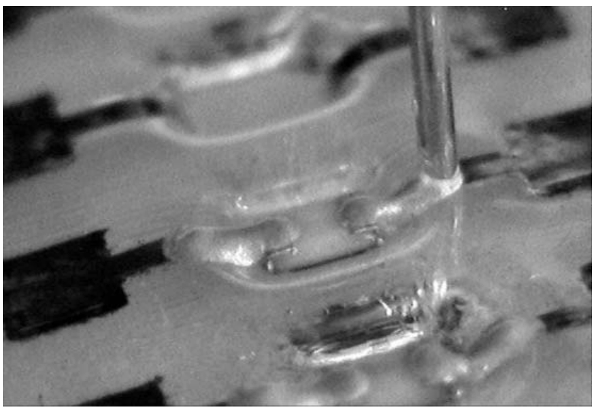

Figure 7: Contacting a 0402 SMD resistor (1mm x 0.5mm) with conductive adhesive

Connected to the equipment evaluation, potential sintering strategies matching the NextFactory solution were tested. Sintering via near infrared (NIR) gave appreciable performance with the selected material without damaging SMD components. In addition, photonic sintering a.k.a. intense pulsed light sintering has proven to be a potential alternative during performed trials within NextFactory.

Smart and Functional materials: Usually, additional functionalities are necessary for the NextFactory use cases as well as in conceivable devices that will be manufactured in the future with the NextFactory process. For example, waterproof or biocompatible layer around a printed device is necessary, since the insulating acrylate-based material does not provide such features. For this purpose RISE ACREO (ACREO) developed several materials compatible with the NextFactory processes including barrier materials, as well as functional materials for example for sensing applications (e.g. humidity, pH sensing). However, this comes along with special types of curing methods. Within the NextFactory project, ACREO developed an alternative curing methods based on gas treatment to overcome issues related to thermal stress and material limitations. A envision of such a tool is illustrated in Figure 8.

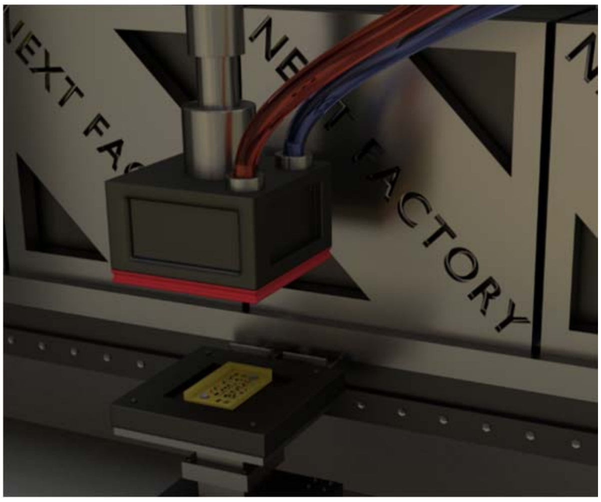

Figure 8: Vision of a gas and vacuum treatment tool, curing compartment and plunger

WP5 – NextFactory Processes Modules & Process Development

The main objective of WP5 was to develop the Nextfactory relevant processes and to realise suitable process modules to be integrated into one main machine. The objectives in detail are:

1. Development of a 3D printing module based on inkjet technology to produce parts made of different functional materials in high resolution. Aspects for combining this manufacturing process with a Micro-Assembly module to integrate discrete components right in the building process have to be taken in account.

The 3D-printing module has been developed and realized (see Figure 9). To print different materials, three printing heads are integrated. It has been shown that, dielectric, conductive and support material can be printed with this module. With its high resolution it is possible to print e.g. conductive lines with a linewidth of 250µm, dielectric cavities of 500µm x 500µm or vias with 500µm diameter. In interaction with the assembly module, it is possible to integrate discrete components into printed material. This has been shown in various test samples.

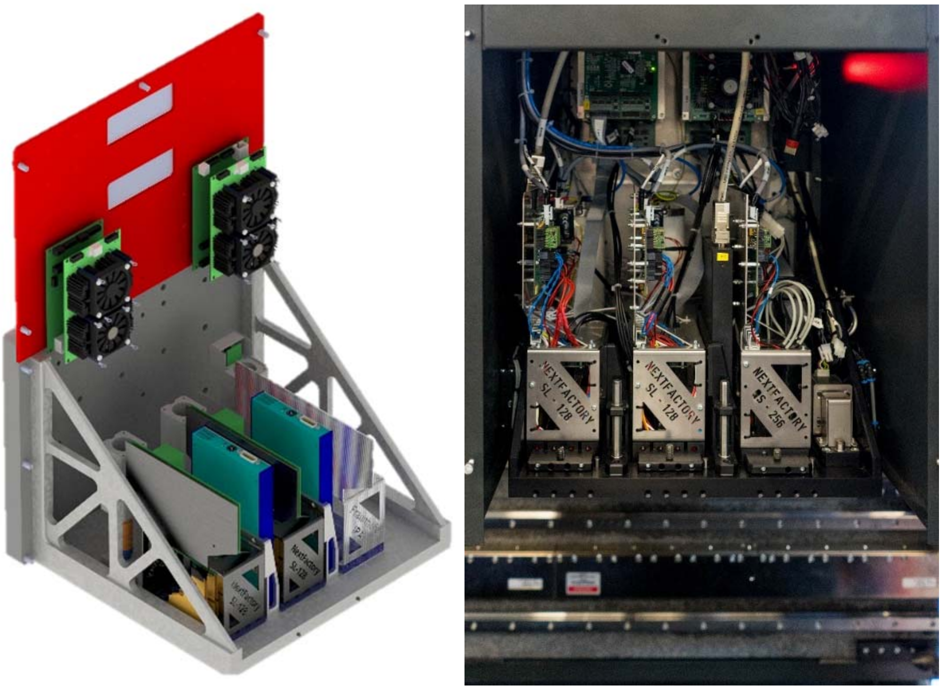

Figure 9: Ready manufactured printing module

2. Development of a microassembly module with 3D capabilities to attach discrete components on freeformed surfaces in order to integrate these components in the additive building process.

The microassembly module has been developed and realized (see Figure 10). The process for the mechanical and electrical integration of discrete components into 3D-printed material has been developed and transferred into this module and demonstrated with various test samples. The main machine provides 3 axis: X, Y and Z. For the rotation of the component, rotation axis are integrated in the grippers. For the integration of component onto tilted surfaces, space is foreseen under the moving table of the main machine. The machine is designed and prepared, to integrate this axis if required. It has been decided to not integrate the axis yet, due to practicability. It would delimit the processing area.

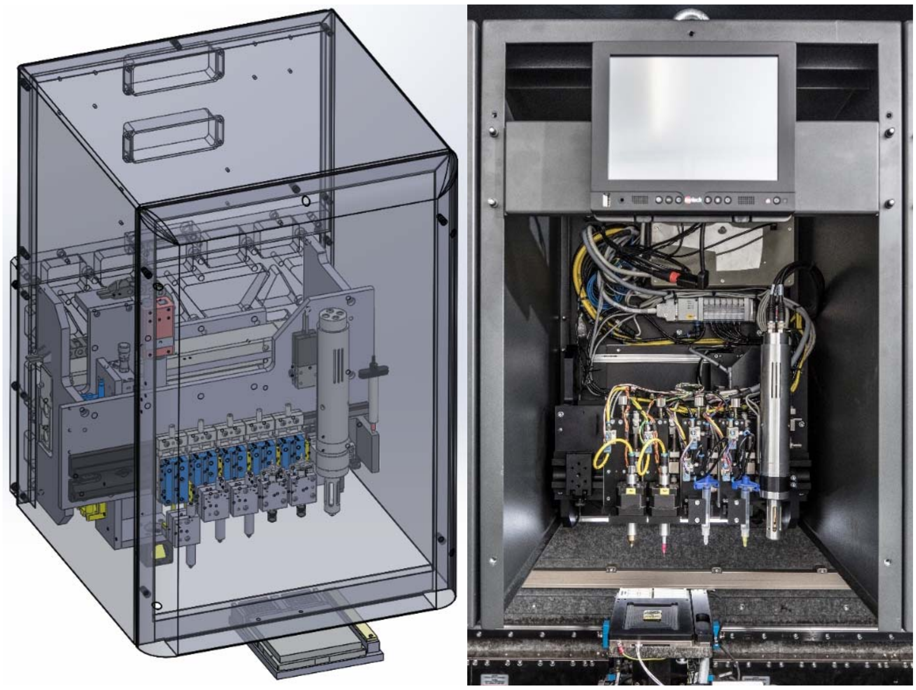

Figure 10: Ready manufactured assembly module

3. Development of a vision based measurement & inspection system to correct errors and inaccuracies of the building process and to achieve a 100% quality control of each manufactured part.

The inspection module has been developed and realized (see Figure 11). It contains different sensors to provide a wide variety of detection possibilities. With this module it is possible to measure the position of the parts to be picked, to detect their placing position and to detect printing errors (e.g. intermittent tracks, deviations from design). All measurements are automated to make a 100% quality control available.

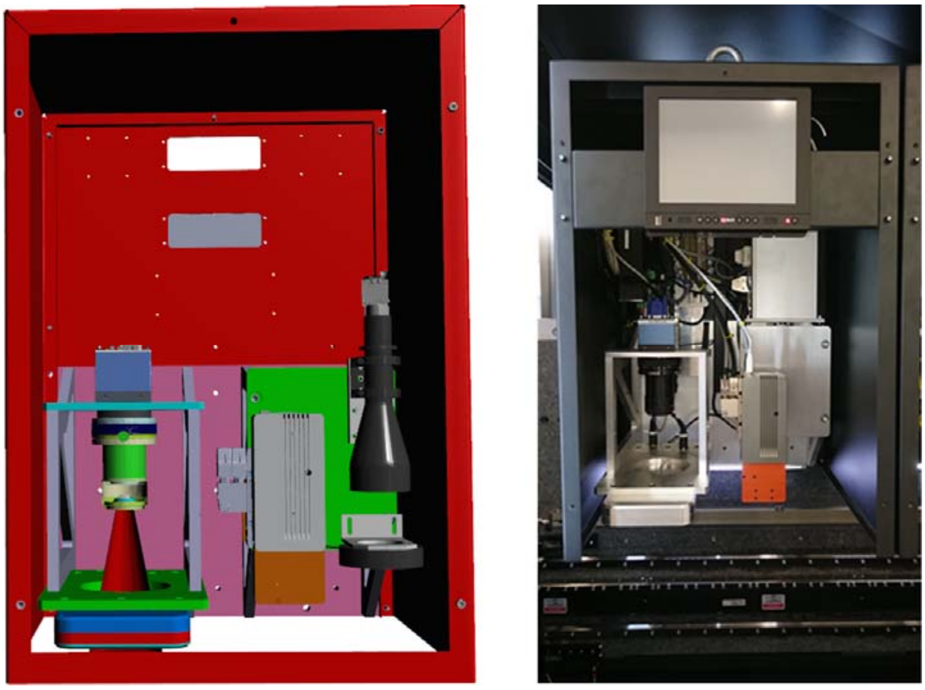

Figure 11: Ready manufactured inspection module

4. Implementation of pre- and post-processing steps according to the needs of microparts manufactured in an additive way.

A curing module has been developed and realized (see Figure 12). It contains different systems (UV-curing, NIR-sintering, IR-heating) to provide a wide variety of curing methods. Various printed and dispensed material can be processed with this module.

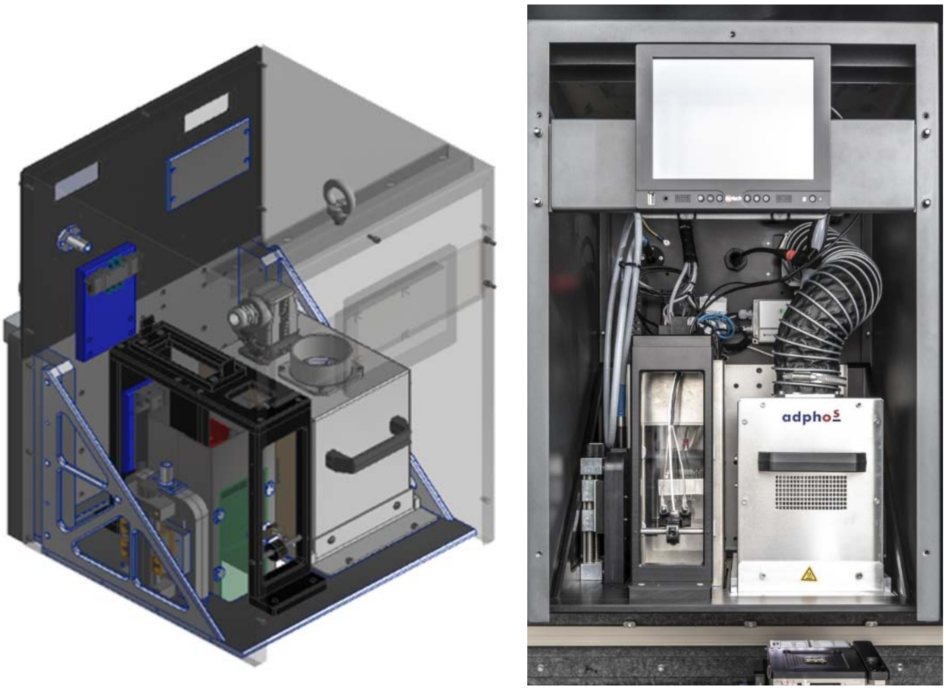

Figure 12: Ready manufactured curing module

5. In interaction with WP2, integration of the individual process steps into a strongly interwoven and automated process chain model as well as optimisation of the resulting overall process in a way that it can be implemented right into NextFactory machine within WP3.

Together with WP3, mechanical, electrical and software interfaces has been defined for all modules. A generic module has been developed, into which the processes were integrated. Also together with WP3, a communication structure from the modules to the PLC has been defined. In this way, on the main machine generated recipes can be executed which triggers the single processes in the modules. The overall machine with integrated process modules are available (see Figure 13)

Figure 13: Integrated process modules

WP6 – NextFactory Software Suite

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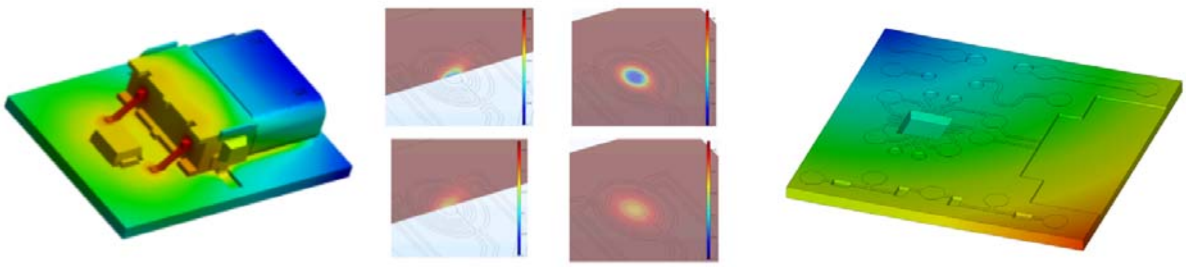


Figure 14: Numerical modelling of NextFactory use cases

WP7 – Proof-of-concept demonstration

Using the V1 prototype as the demonstrator MSL provided proof of concept for the NextFactory processes and materials by successfully performing a suite of industry recognised package reliability tests.

This demonstrates that the overall concept, processes and materials developed during the NextFactory project can be further improved post project to give an exploitable outcome for the NextFactory FP7 project.

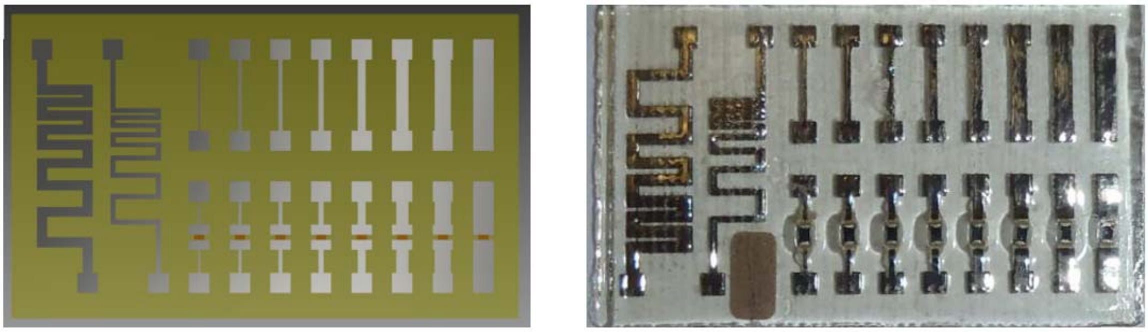


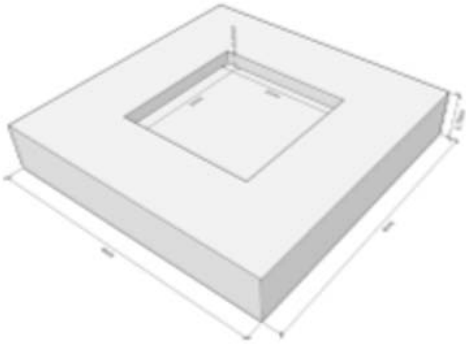
Figure 15: Realisation of NextFactory V1 prototypes

The package reliability testing performed was selected by comparing the requirements of 3 specific UC's where appropriate selecting the most aggressive package reliability test. Some testing was performed twice (once during WP1) to gain high confidence in the proof of concept.

	Test conidtion	Quantity tested (WP 1)	Quantity tested (WP 7)	Comment
Temp cycling	JESD22-A104 C (Target condition G; +125C/-40C)	3	3	Passed
Hot temp storage	Mil-Std-883, Method 1008 (Target condition B; 125C/24 hrs)	3	3	Passed
Cold temp storage	JESD22-A119 (Target -40C/1000hrs)	3	3	Passed
Damp heat	JESD22-A101-B (Target:1000hr 85/85 without bias)	3	N/A	Passed
MSL Testing	JEDEC J-STD-20 (Level 2a)	3	3	Passed
Shock & Vibration	Mil-Std-883 Method 2002 & 2007 (target condition B)	3	N/A	Passed
Chemical resistance	1 month in fruit juice	3	N/A	Passed

Table 3: Validation test results of demonstrator V1 prototype

Additional successful validation work was performed on two other test structures realised during the NextFactory project pathing the way for further improvements in process capability and module complexity.



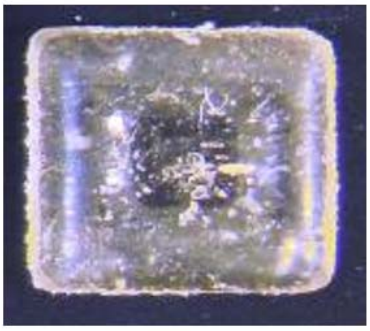


Figure 16: Realisation of NextFactory dielectric test structure

Test method	Qty	Results	Comments
Reflow as per JEDEC J-STD-20 (260°C peak)	5	5/0	No visual change after reflow
Component/die shear as per MIL-STD-883 Method 2019.7	5	5/0	Minimum shear value recorded at 2.3Kg.

Table 4: Validation test results of dielectric test structure

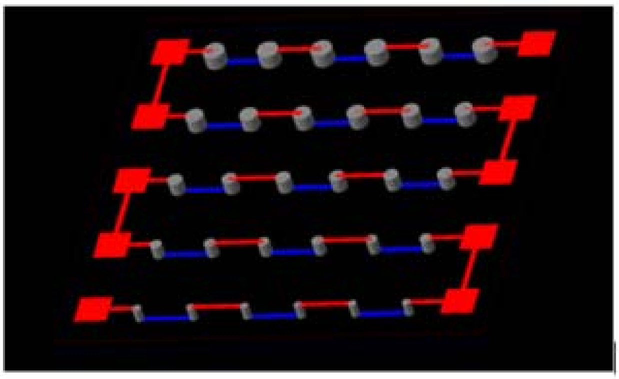


Figure 17: Realisation of NextFactory daisy chain via test structure

Daisychain via prototype	Test condition	Quantity tested (vias)	Comment
Temp cycling	JESD22-A104 C (100 cycles @ +125°C/-40°C)	65/0	100% passed continuity

Table 5: Validation test results of dielectric test structure

CEL demonstrated proof of concept for their dissolved oxygen logger (UC2) during WP7 using conventional fabrication techniques, this paths the way for future modules with their sensor to be realised by the NextFactory machine.

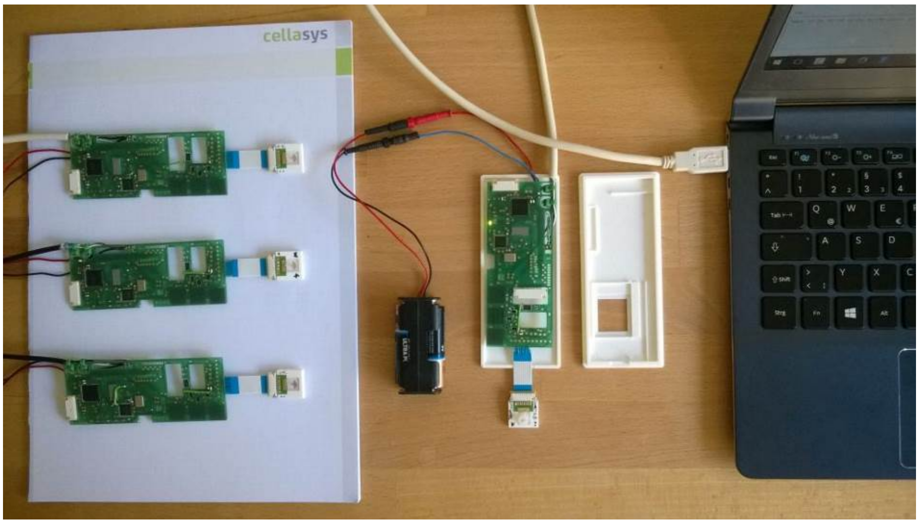


Figure 18: Task 7.3-proof of concept for CEL dissolved Oxygen logger

Finally, SUN provided proof of concept for its PV solar panels using NextFactory materials and additive manufacturing processes equivalent to those deployed in the NextFactory machine, the additive manufactured junction boxes on flexible solar panel applications were validated and their performance compared to standard PV solar panels as part of WP7.

Figure 19: Task 7.2-proof of concept for SUN flexible PV solar panels (external benchmarking testing)

WP8 – Impact, Sustainability and Exploitation

See Section 4.

WP9 – Project Coordination, Governance and Coordination

WP9 was dedicated to the overall strategic as well as financial and contractual management of the project. At the beginning of NextFactory, a dedicated project office was set up to establish the management infrastructure consisting of the general assembly, the executive board, management procedures, a quality assurance process for project deliverables, a deliverables and milestones plan, a risk register, project management tools (e.g. for financial and person month monitoring), and a secure collaborative internal website (for data repository and internal information sharing).

Throughout the 48 month of the project, the Coordinator, supported by the project office, organised, chaired and followed-up a total of 12 project meetings (a kick-off meeting, 3 review meetings, and eight consortium meetings) as well as regular Executive Board teleconferences. In addition, a total of 42 scientific meetings and 18 exploitation meetings took place at WP level (in person or via conference calls) in the course of the project. Project quality control was ensured through continuous monitoring of the project progress against contractual commitments (deliverables and milestones). In addition, the project office maintained and updated the contractual documents, provided financial control for the project, and supported all financial reporting aspects and the distribution of EC payments. The project office acted as central contact point for all project partners.

All contractual periodic reports were submitted to the European Commission with the contractual deadlines (at M18, M36, M48), including the scientific/technical reporting and financial statements. Rules and regulations as stipulated in the Grant Agreement and Consortium Agreement were implemented throughout the project.

Figure 20: NextFactory Final Review Meeting, August 2017, Stuttgart

4. Description of the main results/foregrounds

Socio-economic impact

NextFactory had an overall positive impact on employment and workforce distribution in the participating organisations (industry, universities, SMEs).

Over the 4 years of the project, more than 125 people have contributed at some point to the project. They provided their expertise to the different work packages when required. About 40% of the people who worked on the project were experienced researchers. Five additional researchers were recruited specifically for NextFactory.

In the last year of the project year, a position at one of the project partners was created for the development of additive manufacturing technologies in the realm thin-film solar cells based on the positive outcome of the NextFactory project for this application.

26 women have contributed to NextFactory, i.e. 11 experienced researchers and 15 other staff members.

NextFactory researchers were involved in outreach and education activities with students (conferences, girls day). Master and Bachelor students have also been involved in the project.

NextFactory did not directly work with or target policy makers. However, results originating from the project could be used by policy makers in the relevant fields, especially in the areas of research and innovation and new production technologies.

Several articles were published in peer-reviewed journals; other publications were prepared for conference contributions.

Wider societal implications of the project

NextFactory contributes to strengthen and advance EU’s position as a fast growing supplier of micro-mechatronic systems. Indirectly, this project contributes to the attainment of the objectives of EU policies:

- Increased industrial competitiveness: NextFactory will empower micro-systems developers to miniaturise their products while maintaining or even extending their functionality, to dramatically enhance the customisability of their products thanks to individual freeform shaping, and to cut production lead time by factor 10 and more, thus contributing to their competitiveness and enabling them to penetrate new markets.
- Protection of European jobs and more attractive jobs: Increased industrial competitiveness and high quality products protect European jobs and therefore promote social and economic cohesion. NextFactory will enable micro-systems developers to manufacture and work in Europe.

- Environmental protection and quality of life: NextFactory can contribute to the reduction of pollutant emissions and to a more rational use of natural resources. NextFactory will allow to lower the use of ressources and residual waste to the very minimum. In addition, in a one-stop-shop approach, NextFactory will enable developers of micro-systems to manufacture their products completely on one machine, thus reducing the need to transport semi-complete work to specialist 3rd parties often located in Asia and the associated environmental costs. NextFactory can also help foster technologies contributing to energy consumption reduction.

Main dissemination activities

The results of NextFactory were published in peer reviewed journals and presented at national and international conferences. A dissemination activity highlight includes the final public workshop as well presentations of the NextFactory project in several conferences and workshops.

The final project public workshop took place on 30th of August 2017 at the Fraunhofer Institute for Manufacturing Engineering and Automation (IPA), Stuttgart, Germany. This workshop included a demonstration of the NextFactory Machine and Processes and expert talks about the processes, machine concept, materials and quality assurance. It attracted participants from various fields, including the measurement, circuit board production, pharmaceutical, and electronics industries.

Figure 21: NextFactory Workshop and Demonstration Event

Examples of events at which the project was presented include:

- Analytica 2014, Trade fair for Laboratory Technology, Analysis, Biotechnology and analytica conference (01- 04.04.2014, Munich, Germany)
- LOPEC 2015- 7th International Exhibition and Conference for the Printed Electronics Industry (3-5.3.2015, Munich, Germany)
- Rock Stars of 3D Printing event in USA (17.03.2015, San Jose, California, USA)

- Higher Value production technologies and KET enabled applications, a joint initiative of several EC projects (30.04.2015, Milan, Italy)
- 4M/ ICOMM 2015, 4M Conference Series (31-2.04.2015, Milan, Italy)
- Austrian 3D-Printing Forum (10.05.16, Vienna, Austria)
- RISE and Shine (7.05.2015, online seminar)
- Austrian 3D-Printing Forum (10.05.16, Vienna, Austria)
- Analytica 2016 (10-13.05.2016, Munich, Germany)
- IEEE Conference – 39th International Spring Seminar on Electronics Technology (18-22.05.2016, Pilsen, Czech Republic)
- IMAPS Additive Manufacturing & 3D Printing Workshop (22.10.2015, Loughborough, UK)
- INPRINT – Industrial Print Show, Exhibition for Industrial Print Technology (10.11.2015, Munich, Germany)
- Productronica, the leading fair for electronics development and production (10-13.11.2015, Munich, Germany)
- DDMC 2016 – Fraunhofer Direct Digital Manufacturing Conference (16-17.03.2016, Berlin, Germany)
- IEEE Conference – EuroSIME, Thermal, Mechanical and Multi-Physics Simulation and Experiments in Microelectronics and Microsystems Conference (17-20.04.2016, Montpellier, France)
- IMS-Additive Manufacturing Project Clustering Workshop, International Manufacturing Society (2.05.2016, Barcelona, Spain)
- AM platform meeting (25.05.2016, Brussels, Belgium)
- FoFAM Workshop (26.05.2016, Brussels, Belgium)
- IEEE/CPMT Conference - Electronics System-Integration Technology Conference (13-15.09.2016, Grenoble, France)
- IMAPS UK / NMI Conference on Embedded Device Technology (22.09.2016, Caldicot, UK)
- 3D Printing Electronics Conference (24.01.2017, High Tech Campus Eindhoven, Netherlands)

Project results have been the topic of a total of 12 publications (including articles in peer reviewed journals and conference papers) prepared by the project partners (in addition, 2 publications are currently under review/planned to be published in 2017/2018).

NextFactory also had a dedicated website (www.nextfactory-project.eu) on which news about project events and publications were regularly provided.

Exploitation of results

Although the production of demo parts for the three NextFactory Use Cases could not be achieved within the 48 months project duration, a fully operational machine could be delivered, covering with its modules the entire production process. The materials, developed or selected during the project, allow for a stable and accurate processing, as shown by the manufactured test structures. This provides the

NextFactory Consortium with a very solid and promising starting base to do the final steps to the serial production of less complex electronic packages, such as the junction boxes for solar panels of Use Case 1, in relatively short time. 18 months of focussed further development and system adaptation would be sufficient. For the other two Use Cases, the defined R&D Roadmap targets specific KPI as milestones for the further development in a mid and long-term perspective.
At the end of the project, all key- partners of the consortium made the necessary legal arrangements to enable the joint future R&D work. Localisation and access rights to the machine as well as the supply of the required materials have been agreed. Furthermore, the machine will remain complete with all integrated modules and fully operational for at least 18 months after project end. The entire consortium shares the strong motivation to advance the NextFactory Solution to the required maturity for market entry and commercial production.

Exploitation plan

The exploitation potentials and business models for the NextFactory Use Cases have been investigated in a dedicated deliverable (D8.4 First use scenarios and generic business models). A second deliverable (D8.5 Exploitation plans, Sustainability Plan and Standardisation Concept) provided a consolidated outlook to the future use and development of the NextFactory System, directly derived from the fully integrated System, encompassing the machine framework and its modules, the materials and software developed during the project.
The starting base for the exploitation planning were the project UC and their potential to trigger the development and manufacturing of similar products within the specific product family and markets, hoping for later spill-over effects across larger segments of the electronics market.
The three project Use Cases were analysed, assessing their respective market-maturity and indicating the related target products. For UC1 (Junction box for solar panels), it exists a clear timeline and overview of RTD requirements to adapt and use the Machine for serial production in a mid-term perspective. UC2 (Bio-compatible data-loggers) will focus on rapid prototyping, due to relatively large product dimensions, which make a profitable serial production unlikely. UC3 (Radio modules) follows a long-term industrial strategy, exploring the possibility of a further development of the Machine in exclusive RTD partnerships with selected customers. Specific target products/services have been identified for each UC, as well as their potential end-users and target markets.

R&D Roadmap

A R&D Roadmap, which analyses the technical dimension of the future use and application, was also developed. This Roadmap first assessed the maturity of the different technical components of the NextFactory Solution. The overall system has reached a high TRL-level and is ready for prototype production. The modules are fully operational and integrated into the machine framework, ready for demo-part manufacturing. All materials can be processed and also interact according to the set requirements. However, it is still not known, how material behaviour will look like, if bigger structures are built up. The Software Suite for quality management and inline inspection has been successfully parametrised and interfaced with all process modules.

The R&D Roadmap introduced four product classes, each of them representing a distinctive level of product complexity and major milestone for the further development of the NextFactory System. These product milestones structure the R&D Roadmap and timeline for the further development. It is expected that sufficiently resourced R&D could advance the System within 4 years to the production of complex, personalised and smart electronic packages.

Finally, the R&D Roadmap specified the necessary R&D steps for each of the underlying technologies and outlines the overall standardisation concept.

5. NextFactory consortium

The NextFactory consortium gathers 11 partners – research institutes, SMEs, companies and universities.

The NextFactory consortium is composed of the following organisations:

- **Fraunhofer Gesellschaft zur Förderung der Angewandten Forschung E.V (FhG-IPA)**
- **Microsemi Semiconductor Limited (MSL)**
- **Profactor GmbH (PRO)**
- **Sunplugged – Solare Energiesysteme GmbH (SUN)**
- **Cellasys GmbH (CEL)**
- **Heliotis AG (HEL)**
- **TIGER Coatings GmbH & Co KG (TIG)**
- **Unitechnologies SA (UT)**
- **University of Greenwich (UOG)**
- **ACREO AB Electrum (ACREO)**
- **ARTTIC (ART)**

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