DT-FOF-07-2020
Assembly of micro parts (RIA)

TINKER

FABRICATION OF SENSOR PACKAGES ENABLED BY ADDITIVE MANUFACTURING

Starting date of the project: 01/10/2020
Duration: 36 months

= Deliverable D5.5 =

Pilot line with inkjet system

Due date of deliverable: 31/01/2023
Actual submission date: 30/04/2023

Responsible WP: Michael Haslinger, WP5, PRO
Revision: V1.3

Dissemination level		
PU	Public	x
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 958472.

AUTHOR

Author	Institution	Contact (e-mail, phone)
Michael Doran	NOTION	michael.doran@notion-systems.com
Michael Haslinger	PRO	Michael.haslinger@PROFACTOR.at

DOCUMENT CONTROL

Document version	Date	Change
V1.0	22.06.2022	Template draft prepared and sent to partners
V1.1	24.04.2023	Partner inputs compiled and reviewed by WP leader
V1.2	26.04.2023	Review by CO, minor adaptations
V1.3	30.04.2023	Final review and finalization by CO

VALIDATION

Reviewers		Validation date
Work Package Leader	Michael Haslinger	28.04.2023
Coordinator	Pavel Kulha	30.04.2023

DOCUMENT DATA

Keywords	Intermediate report
Point of Contact	Name: Pavel Kulha Partner: PRO Address: Im Stadtgut A2, 4407 Steyr-Gleink, Austria Phone: +43 7252 885 431 E-mail: pavel.kulha@PROFACTOR.at
Delivery date	30.04.2023

Executive Summary

Autonomous driving and self-driving cars represent one prominent example for the use of microelectronics and sensors, most importantly RADAR and LiDAR sensors. Their respective markets have a big potential, e.g. it is estimated that the market size of LiDAR in automotive will double itself in the next two years (within 2020 to 2022). The public awareness and the industrial need for further miniaturization of such sensor packages is the main driver of ongoing efforts in the automotive sector to be able to integrate such devices into the car body like in the bumpers, grilles and exterior lamps (headlights & rear lamps) instead of attaching them (e.g. on top of the car in case of LiDAR device). Safety (for the driver and others) is the most important key aspect of the automotive sector. Therefore, highly-value and high-performance RADAR and LiDAR systems are required for advanced driver-assistance systems (ADAS) as well as autonomous cars.

In the period of 3.5 years, starting from 1st of October 2020, European Union´s H2020 funded TINKER project is set to develop a new reliable, accurate, functional, cost- and resource efficient pathway for RADAR and LiDAR sensor package fabrication, following 2 main objectives: *Establishing the TINKER platform based on Additive Manufacturing {AM}* and *Fabrication of RADAR and LiDAR sensor packages as use cases.* TINKER's approaches to use "*key enabling technologies, especially inkjet printing and nanoimprint lithography"*, as disruptive and flexible manufacturing techniques in micro-part assembling is in alliance with the overall scope of the call Transforming European Industry. The proposed TINKER pilot represents a high degree of flexibility and reliability due to its modular character.

Figure 1 TINKER project partner

This report presents the status of the TINKER Pilot Printer developed, assembled and commissioned by Notion. The TINKER Pilot Printer is an essential part in the TINKER Project since it will be used for the prototype fabrication of RADAR sensor packages via inkjet printing. The Pilot Printer is equipped with 4 printheads and integrated post processing tools (UV-LED, NIR-Lamp and Laser-Setup). The Laser Setup is developed by Forth and is used for laser sintering of conductive inks (Ag NP inks, Cu NP inks) and laser drilling of dielectric inks. Additionally, the report presents the upgrades on the existing R&D Setup at PROFACTOR for inkjet-printing and post-processing. This equipment is used for the development of inkjet printing processes for the inks developed in the TINKER Project.

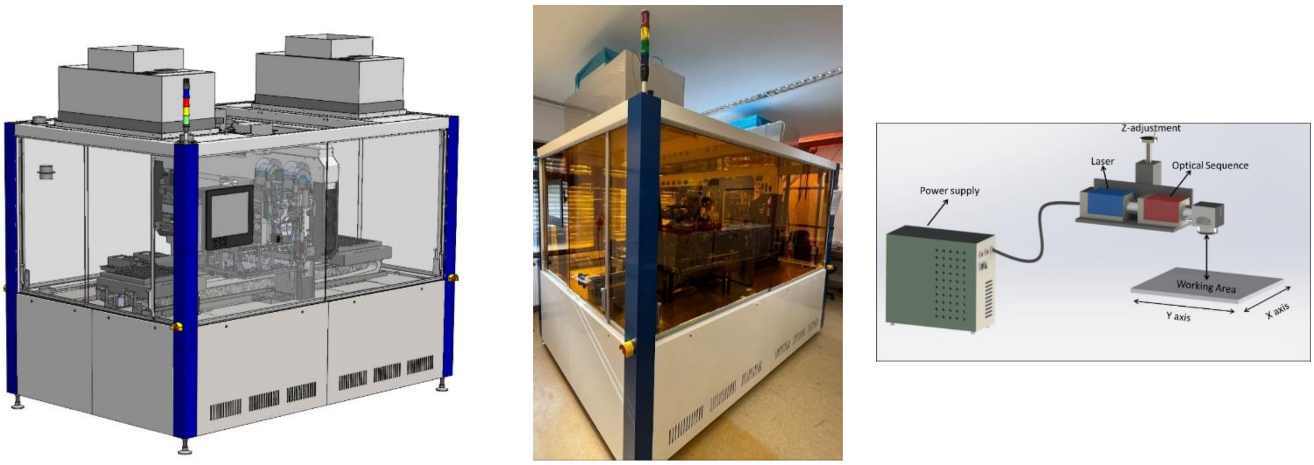


Figure 2 (left) A rendering of the TINKER printer. (middle) built up TINKER printer. (right) Schematic of the laser system.

Table of Contents

Introduction

The vision of TINKER is to provide a new cost- and resource efficient pathway for RADAR and LIDAR sensor package fabrication with high throughput up to 250units/min, improved automation by 20%, improved accuracy by 50% and reliability by a factor of 100 to the European automotive and microelectronic industry via additive manufacturing and inline feedback control mechanisms. Autonomous driving and self-driving cars represent one prominent example for the use of microelectronics and sensor, most importantly RADAR and LIDAR sensors. Their respective markets have a big potential, e.g. it is estimated that the market size of LIDAR in automotive will double itself in the next two years (within 2020 to 2022).

Figure 3: TINKER overview

The public awareness and the industrial need for further miniaturization of such sensor packages is the main driver of ongoing efforts in the automotive sector to be able to integrate such devices into the car body like in the bumpers and head lamps instead of attaching them (e.g. on top of the car in case of LIDAR device). Safety (for the driver and others) is the most important key aspect of the automotive sector. Therefore, high-value and high-performance RADAR and LIDAR systems are required for advanced driver-assistance systems (ADAS) as well as robotic cars. Current bottlenecks are the relatively large size of such sensor devices, their weight and power consumption. Since these factors are highly limited within cars, further miniaturization and improving functionality and efficient use of resources is highly demanded.

Description of deliverable

Inkjet hardware and software based on definitions of D2.5 and concept from D5.2, including pilot printer by NOTION, Laser tools by FORTH and updates on existing equipment at PROFACTOR.

1.1. Description of TINKER Partners working on Inkjet-Radar topics

Notion Systems develops and manufactures inkjet printers for the additive manufacturing of semiconductors, printed circuit boards, displays and other electronic devices. When it comes to solving complicated process needs and highest accuracy, Notion is the first port of call in the inkjet community. Since 2021, Notion is part of the LAB[14] group.

PROFACTOR GmbH is a non-university research institute in Upper Austria based in Steyr. PROFACTOR conducts applied research in the areas of Industrial Assistance Systems and Additive Micro- and Nano fabrication. With more than 15 years of experience, PROFACTOR has gained considerable expertise in the field of Inkjet printing and inkjet process development as well as post processing. As a project leader PROFACTOR is coordinating the developments in the TINKER project. In technical terms, PROFACTOR is developing the inkjet printing processes and post processing steps for the inks developed in TINKER. Namely the conductive Inks by PV Nano Cell and the dielectric and thermoconductive Inks by TIGER. Further PROFACTOR develops respective NIL processes on lab-level within TINKER to then allow upscaling to higher TRL.

FORTH strives to foster a conducive environment that encourages learning, research, and innovation. The organization concentrates its efforts on scientific and technological research in strategic domains that are recognized for their significant scientific and economic contributions. The FORTH R&D team has been working on developing cutting-edge laser techniques with significant industrial potential. As part of this endeavor, they have designed a laser sintering module for TINKER that is optimized for use in Inkjet printer systems. This module offers precise optical energy distribution over ink patterns, without damaging heat-sensitive substrates, at impressive speeds of up to 7000mm/sec.

Besi Austria GmbH forms part of the larger Dutch group BE Semiconductor Industries, N.V., an international group of companies operating in the assembly and packaging sector of the semiconductor industry. BESI's main area of expertise is the development of leading-edge high-precision and high-flexibility assembly processes and die-handling equipment for flip-chip and multi-chip substrate and wafer-level packaging applications in a wide range of end-user markets. BESI's role in the project is to push forward and support the development of highly automated and high-yield innovative electronic packaging solutions through novel in-line inspection in die-attach equipment, especially 3D inspection and multi-axis control for bonding.

PV Nano Cell is a conductive ink manufacturing company focused on development, manufacturing, marketing and commercialization of conductive inks for conductive digital printing applications. The company has developed the SicrysTM family of single crystal nano-metric conductive inks, providing a more cost-efficient and less wasteful alternative to current screen printing and, in some cases, photolithographic processes for photovoltaic and printed electronics applications. In the TINKER project, PV Nano Cell formulates nano silver and nano copper solvent-based and UV-curable inks designed for laser sintering and reaching low electrical resistivity and high printed aspect ratios.

TIGER Coatings GmbH & Co.KG is a globally acting, family-owned company that develops and produces powder coatings and inkjet inks for multiple industrial applications. TIGER's main fields of activity in the Business Unit TIGITAL are acrylate-based inks which are used to decorate facades, floorings and furniture. Furthermore, TIGER manufactures water-based inkjet inks for packaging based on porous and non-porous materials. In the TINKER project, TIGER develops special dielectric and heat-conductive inks for 3D inkjet printing.

2. Results and discussion

2.1. TINKER platform

The inkjet printer platform was developed, assembled and commissioned by Notion.

Conceptually, the 3D printed parts are manufactured on a moving print table that travels below the printing and curing processes to add the functional inks layer by layer. The machine is highly precise and allows for the highest achievable placement and dosing of individual inkjet droplets. Hence, it unlocks the full flexibility of digital inkjet printing for the TINKER consortium. As it carries up to four different process inks simultaneously, its productivity is also orders of magnitudes higher than those of standard laboratory inkjet printers.

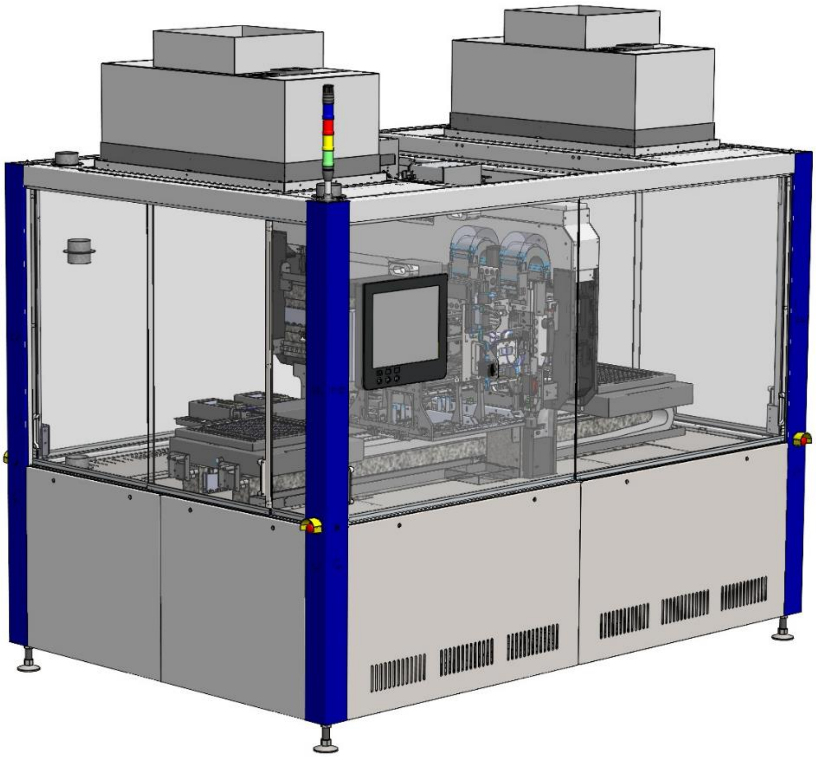


Figure 4: A rendering of the printer is depicted. The long side is 3000 mm, the width is 2000mm, the height is 2800 mm.

The printing process will initially involve installing the printing process as used during the latest print project workshop of Notion and PROFACTOR with UV curable dielectric Ink from Tiger and silver nanoparticle ink from PV Nanocell to reproduce the results of the workshop. As the nozzle-level recirculation capability of Xaar Nitrox print heads are desirable for the inks of the TINKER project with the large particle loads, Notion is using Xaar Nitrox print heads. In this respect, the setup differs from the Konica Minolta KM1024i print head setup of the Notion n.jet lab printer used during the prior TINKER printing workshop.

The process unit is equipped with one LED UV-lamp for curing the UV sensitive dielectric ink from Tiger and one near infrared (NIR) lamp for evaporating solvent content from the PV Nanocell conductive nanoparticle inks. The unit is also equipped with two MegnaJet CIMS II recirculating tank systems for jetting the UV curable inks and two MegnaJet LabJet LFR PV tank systems for jetting the conductive inks. The Xaar Nitrox print heads are installed for the aforementioned setup of the UV curable dielectric ink from

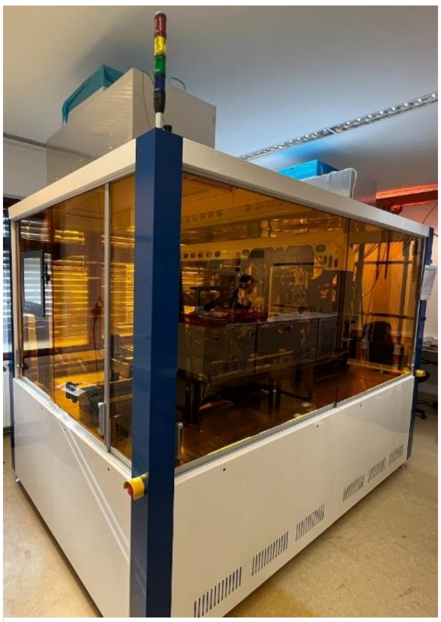


Figure 5: overview image of the printer.

Tiger (TIGER 150/3.1K) and the conductive nanoparticle based inks from PV Nanocell (silver ink, copper ink).

The process unit has the following slots:

- 2 x XAAR Nitrox (or alternatively Konica Minolta KM1024i) print head slots for conductive nanoparticle inks from PV Nanocell
- 2x XAAR Nitrox (or alternatively Konica Minolta KM1024i) print head slots for UV curable dielectric inks from Tiger
- LED-UV lamp including UV light traps (before and after the lamp) for curing the UV sensitive inks from Tiger
- Near Infrared (NIR) lamp for drying and sintering of the solvent-based nanoparticle inks from PV Nanocell
- Laser-sintering process area for the sintering of copper nanoparticle ink from PV Nanocell

Overall, the printer can print four different inks simultaneously.

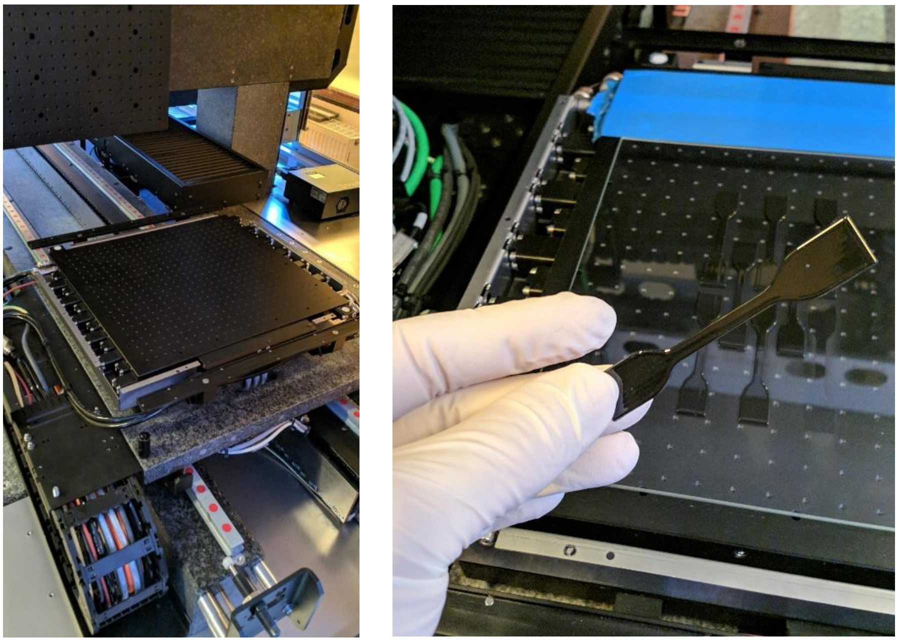


Figure 6: The image shows the print stage with high precision motor driven rotation correction capabilities. (right) In the upper right corner, the controller for the NIR lamp can also be seen. A 3D-printed dog-bone printed on the platform using UV-curable ink from Tiger (left).

On the back side of the inkjet process unit, there is a second axis (Figure 7) on which the laser sintering unit from Forth will be mounted.

Figure 7: Image of second axis on which the laser sintering unit from Forth will be mounted for Laser processing inside the TINKER platform.

To generate 3D printed samples for the TINKER consortium prior to the commissioning of the TINKER inkjet printer platform, a n.jet lab printer at Notion was upgraded to print UV curable dielectric Ink from Tiger and conductive nanoparticle silver Ink from PV Nanocell using a MegnaJet recirculating tank system and KM1024i print heads from Konica-Minolta. This setup was used to produce 3D printed samples with the two materials.

The Figure 8 (left) shows a 3D test structure using black UV-curable ink from Tiger that was printed on the n.jet lab setup at Notion. The goal was to achieve a smooth surface. On top of this smooth 3D printed surface, silver conductive nanoparticle ink was printed – again in test patterns (right). The following image is an example of how such a printing looks like without process development:

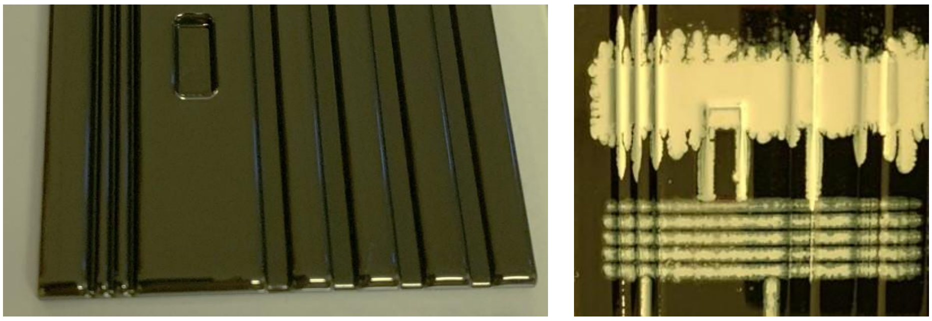


Figure 8: 3D test structure using black UV-curable ink from Tiger that was printed on the n.jet lab setup at Notion. Silver conductive ink was printed on top of this smooth 3D printed surface (right)

Clearly, the silver ink shows bleeding on the 3D printed Tiger ink (Figure 8) and hence the silver tracks are not well defined and unusable for the purpose of the TINKER consortium. After process development which happened in a workshop of Notion and PROFACTOR, good results were achieved as shown in Figure 9.

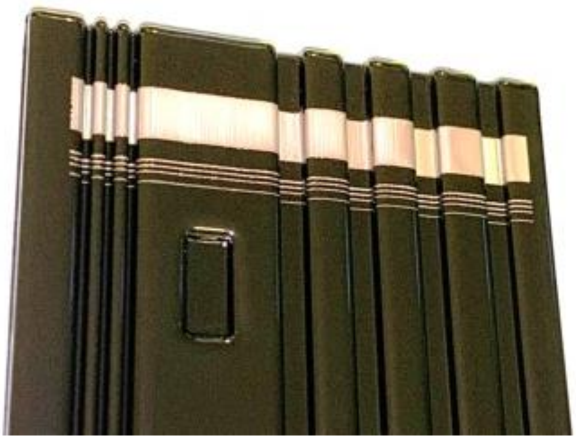


Figure 9: Silver conductive ink was printed on top of this smooth 3D printed surface after the print process development

2.2. Laser Drilling and sintering setup

FORTH is responsible for the laser sintering and drilling processes and the design and the realization of in-situ integrated laser system on the TINKER inkjet platform. The inkjet printing platform was designed with respect to application-specific requirements related to the RADAR TINKER case. The characteristic of the light source, active cooling, optics related and connectivity optimization were achieved towards fast and accurate laser processing.
Forth team has developed both a dedicated hardware to support the additional optics and a customized software to control the parameters for laser processing at the TINKER Inkjet platform. The optical path of the initial laser source was modified in order to vary the optical output power with respect to the rotational axis of the polarization of the laser beam.
The wavelength of the laser source was chosen for both in-situ laser sintering and drilling of the TINKER materials at Inkjet platform. The laser emits pulsed radiation at 532 nm and repetition rates up to 150 kHz in the nanosecond regime, with M^2 <1.5 with variable exposure time. The adjustable beam focal point, high scanning speeds and optimization of laser processing parameters resulted in a resolution of a few tens microns and process speeds up to 7000 mm/sec. A schematic of the Forth laser system is shown in Figure 10.
The interface of the Forth software dedicated to the laser system is shown in Figure 11 a). It is evident that the marking speed, jump speed, pulse width, laser repetition rate and the set laser power in synergy with the optical sequence enable the user to vary the laser parameters towards the optimization of the process. Finally, the BMP file of a sample to be laser sintered and uploaded at the dedicated interface can be seen in Figure 11 b).

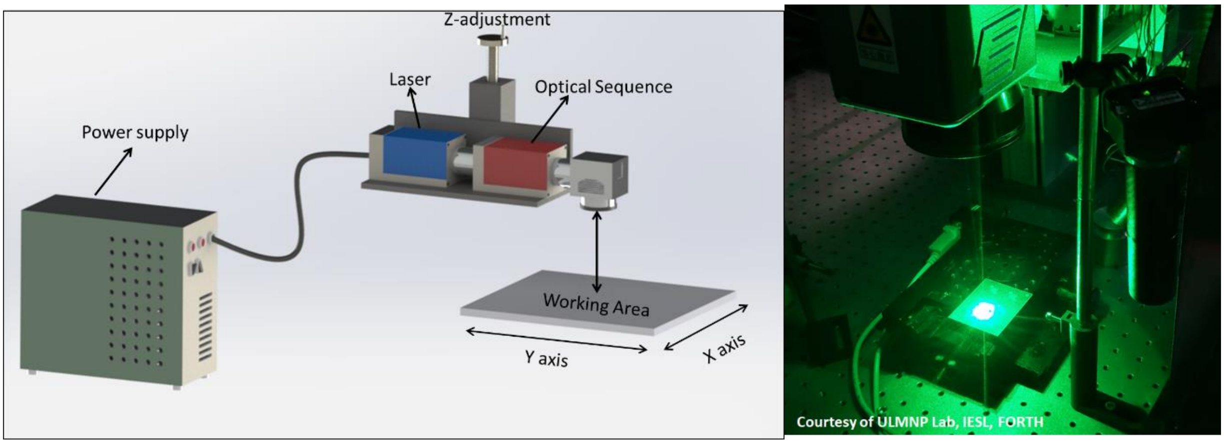


Figure 10: Schematic of the laser system developed by FORTH for the TINKER inkjet platform (left). FORTH Laser system during processing (right).

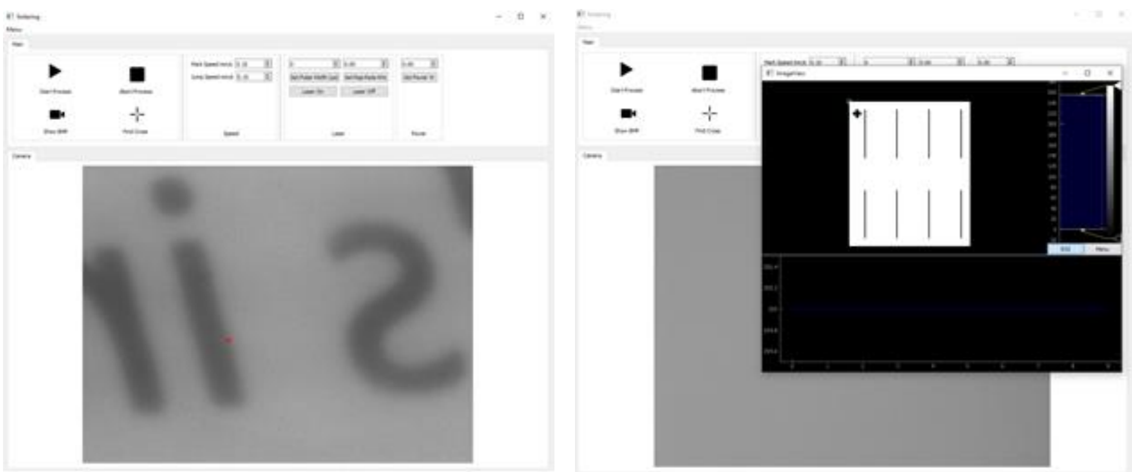


Figure 11: The interface of the FORTH software (left) and uploaded bmp of a sample to be laser processed (right).

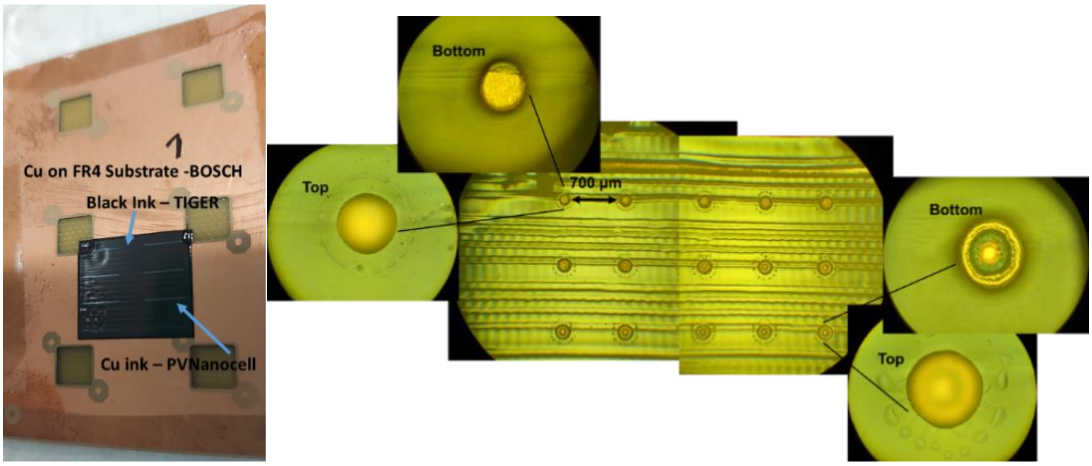


Figure 12: Photo of Cu ink lines on black ink film deposited on FR4 substrate. (left) Optimization of laser drilling of 40 µm thick dielectric UV-curable black Tiger Ink on Cu topmost BOSCH substrates using the Forth laser system at 532 nm. (right), laser sintering picture?

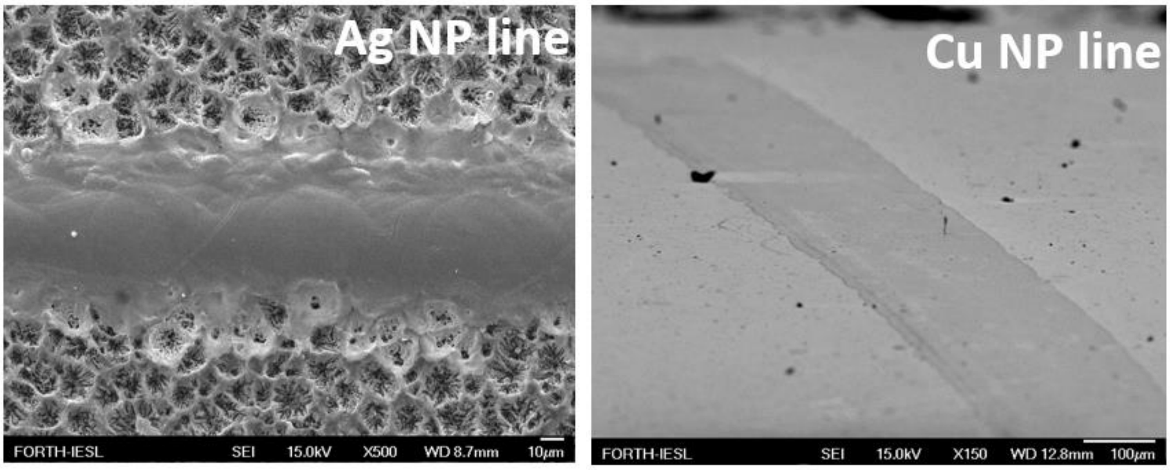


Figure 13: Example of sintered silver and copper ink on FR4/Kapton substrate

The FORTH developed prototype laser sintering and drilling station is used for laser sintering of both Ag and Cu nanoparticle based inks and laser drilling of dielectric inks, providing resistivities of 2-4 times of Ag and Cu bulk values and drilling of via interconnections, respectively. Examples of metallic lines for laser sintering and via drilled holes are shown in Figure 12a and b, respectively. Both laser advances techniques will enable the realization of Radar PCBs at the TINKER inkjet platform.

2.3. R&D Setup for Inkjet-Printing and Post-Processing at PROFACTOR

During the TINKER Project upgrades were made on the existing R&D equipment at PROFACTOR. These upgrades include upgrades on Printers (LP50, Multi-Material-Printer) as well as upgrades on Post-Processing Devices (Laser Stage). The upgraded equipment was used by PROFACTOR for the investigation of inkjet printing processes incl. post-processing in WP5. The individual upgrades are described further down below.

2.3.1. Upgrade of LP50

The LP50 at PROFACTOR is compatible with the following printheads: Konica Minolta 512, Spectra SL128 and the Dimatix Material Cartridges (10pl). During the TINKER Project the LP50 was upgraded to be capable of operating the Konica Minolta 1024i and the DMC Samba Cartridges.

- Konica Minolta 1024i
  The KM1024i is the successor of the KM512 and is used more and more in the printing industry. The advantage of the KM1024i over the KM512 is that it has twice as many nozzles (1024 vs 512) while maintaining the same native resolution of 360 dpi. Furthermore, due to the all-nozzle-independent drive system, the individual nozzles do not influence each other, which leads to a better print result with fewer misfiring nozzles. In the TINKER Project, the KM1024i is used for the printing of the conductive Inks from PVN
    - Upgraded Parts: PHC, Software
- DMC Samba Cartridges
  The DMC Samba Cartridges are the successor of the Dimatix Material Cartridges and differ in that the drop volume of the printhead is smaller (2.4pl vs 10pl). Therefore, finer printed structures can be obtained. In the TINKER Project, the DMC Samba Cartridges are used for the printing of the high refractive index material from Inkron
    - Upgraded Parts: DMC Update, Software

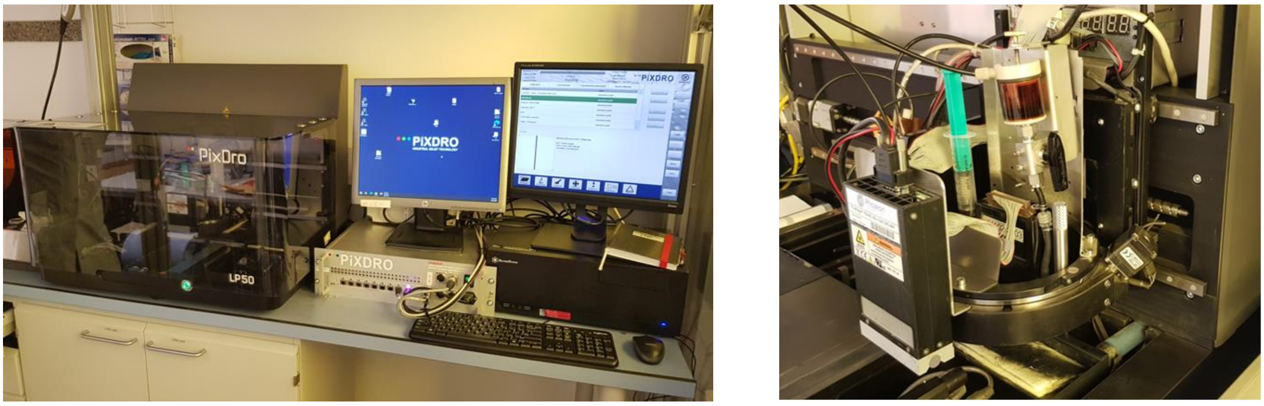
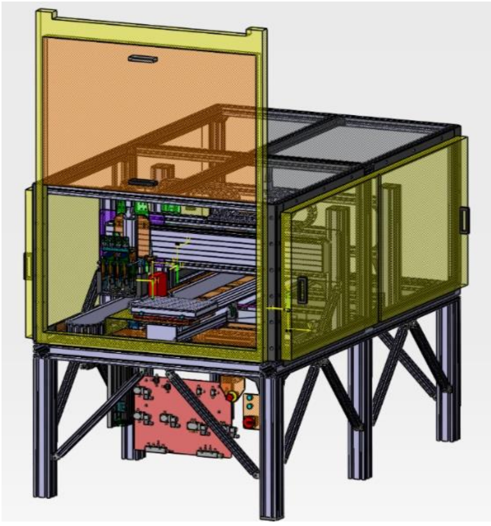


Figure 14: Upgraded LP50 at PROFACTOR (left), KM1024 built in LP50 (right)

2.3.2. Upgrade of Multi-Material-Printer

The Multi-Material-Printer is a R&D prototype inkjet printer developed at PROFACTOR which is capable of printing up to 4 different materials in one printing process. The lamps for post-processing integrated in the Multi-Material printer are UV LEDs (395nm) for curing processes and a high-power NIR Lamp for drying and sintering processes. This makes it possible to print both dielectric and conductive inks in a single printing process with subsequent curing/sintering in a single machine. The following parts of the Multi-Material-Printer were upgraded during the TINKER Project:

- Konica Minolta 1024i for printing of conductive Inks
- Xaar 1003 GS12U, Xaar 1003 GS40 for printing of dielectric Inks
- Fiducial Camera for Alignment and Inspection



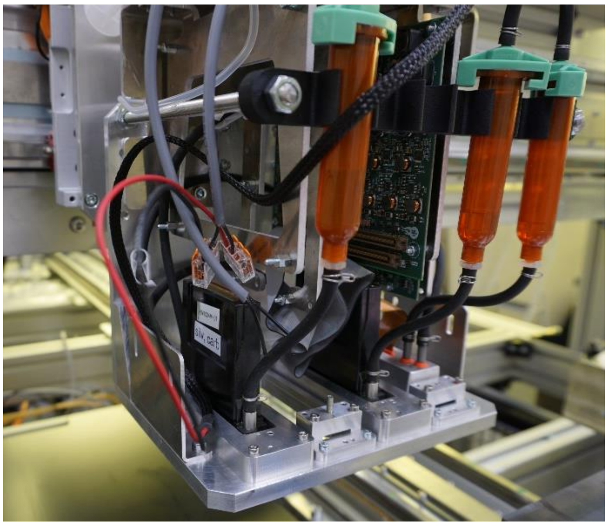


Figure 15: Sketch of Multi-Material-Printer (left), Assembled Konica Minolta and Xaar Printheads (right)

2.3.3. Upgrade of Laser Stage

The Laser Stage at PRO was equipped with a new laser source incl. galvo-scanner. The laser has a power of 10W and operates in pulsed mode with a wavelength of 532 nm (green laser). The wavelength was chosen for the optimal sintering conditions of the conductive Inks from PV Nanocell, especially for the copper ink (copper shows high absorption at this wavelength). The galvo-scanner enables the sintering of printed tracks on a surface of 100*100mm.

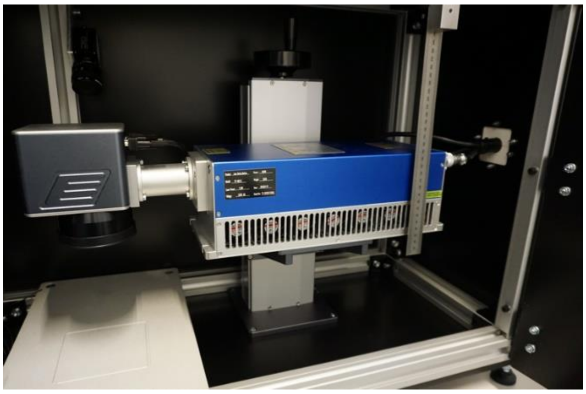


Figure 16: Laser Stage at PROFACTOR

3. Conclusion

The TINKER Pilot Printer is in the commissioning phase and ready to print demonstrators for the RADAR sensor package Use Case. These demonstrators are:

- Inkjet Printed Waveguide Antenna Structures on PCB
- Assembled and connected daisy chain bare dies in cavity (Inkjet Wirebonding)

The development of the laser system from Forth for the Laser Sintering and Laser Drilling processes is complete and the laser setup is ready for the integration into the inkjet printing platform.

All the prior planned upgrades on the R&D Setup from PROFACTOR (LP50, Multi-Material-Printer, Laser Stage) during the TINKER Project are complete.

4. Outlook

It is expected that the TINKER Pilot Printer printer is printing the first samples using black UV curable dielectric ink from Tiger and silver nanoparticle ink from PV Nanocell starting in April. From April on, it can be used to generate 3D printed structures at high throughput for the TINKER consortium. Additionally, there are two main ongoing tasks which are:

- Integration of the laser process provided by Forth
- Implementation of the interface for interoperability for the demonstration of the closed loop capability of the TINKER process chain

The upgraded R&D equipment at PROFACTOR is heavily used in the development of inkjet printing processes incl. post processing for the inks from Tiger (dielectric Ink, thermal-conductive Ink) and PV Nanocell (solvent-based Ag and Cu Inks / UV curable Ag and CU Inks) and will be further used in the optimization processes of these inks.

The consortium is preparing a number of publications and to participate in a series of conferences throughout 2023 and 2024 to present the good results of TINKER. Announcements of the conferences can be found on the TINKER homepage as well as on TINKER linkedin or twitter pages. Already planned publications are at the NILindustrial Day 2023 (posters (PROFACTOR), presentations by EVG and INKRON), booth (PROFACTOR)), EMLC2023 (talk and poster by PROFACTOR), PIC international 2023 (talk by EVG) ECTC 2023 (paper and talk by LETI, IITC 2023 (talk and paper by LETI)