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Assembly of micro parts (RIA)

TINKER

FABRICATION OF SENSOR PACKAGES ENABLED BY ADDITIVE MANUFACTURING

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Prototype RADAR sensor assembly

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Executive Summary

The BOS radar concept contains two main areas where ink-jet-based technology was applied. For the processing of high frequency signals an MMIC die is placed in the PCB cavity. The consortium developed technologies for the gap-filling and for the contacting of the MMIC with the PCB traces. These traces are connected to an antenna, which is radiating and receiving the high frequency electro-magnetic waves. Waveguide antennas recently replacing the patch antenna arrays due to their superior high frequency performance and due to their lower power consumption. The consortium is working on the fabrication of such antennas by applying a two-component 3D ink-jet printing technology using acrylic dielectric and silver nanoparticle inks directly on the PCB surface.

Recently the consortium achieved new results on the following fields:

- BESI's contributed to the assembly of the MMIC (currently replaced by a daisy-chain demonstrator). The die was placed and bonded into the PCB cavity.
- NOT built together with BOS waveguide antennas by applying the dielectric and the conductive ink deposition sequentially.
- PRO printed the adapted DC layout and further investigated the spreading behavior of the conductive ink on the dielectric material.

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1. 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.

Figure 1: 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, performance improvement and efficient use of resources is highly demanded.

1.1. Description of deliverable

Fabricated RADAR prototypes via TINKER fabrication approaches

A two-component 3D ink-jet printing technology was used to fabricate the waveguide antenna. A UV curable acrylic ink was used as the dielectric component, and conductive silver nano-particles were used for the metallization of the inner walls and for the metallization of the upper surface of the structure. These inks are solvent free and possess improved mechanical as well as thermal properties, so that the desired applications can be realized. These enhanced thermal and mechanical properties are achieved via chemical interactions occurring during the addition and the polymerization of the components, and through the mixing strategies.

2. Results and Discussion

2.1. Prototype description

Waveguide antenna is an elementary component of Radar sensor package. They are dielectric components with a metallization on their surface. Electromagnetic waves propagate through them. Through to their superior performance it is expected that they will replace the patch antennas, which are used in many of the current radarsolutions. The efficient and stable radiation achieved by these integrated sensors has direct influence on the total power consumption as well, which is an essential requirement for electrical vehicles. As it is formulated in the innovation hypothesis, the introduction of these waveguide antennas will not only offer higher efficiency, but it will also lead to a significant cost reduction. This cost advantage occurs due to the fact, that the high frequency requirements for the antenna dielectric itself are not as stringent as that of for the high-frequency layers of the PCB.

2.2. Assembly of Radar chips

2.2.1. Pick-and-place assembly of radar chips

BESI's contributed to the assembly of the RADAR demonstrator "Concept 1" by providing specialised assembly hardware and process expertise. "Concept 1" involves placing a die into a PCB cavity on an uncured automotive-grade adhesive that was previously dispensed by BESI's machine. This is a particular challenge for pick-and-place equipment, as there is no clear indication of the correct target height, which has to be provided by feedback loops that involve additional tilt and height metrology. The process includes curing the adhesive to fix the dies for further processing, where changes to the adhesive have to be taken into account during placement, e.g. the die "sinking" into the adhesive on the μm-level.

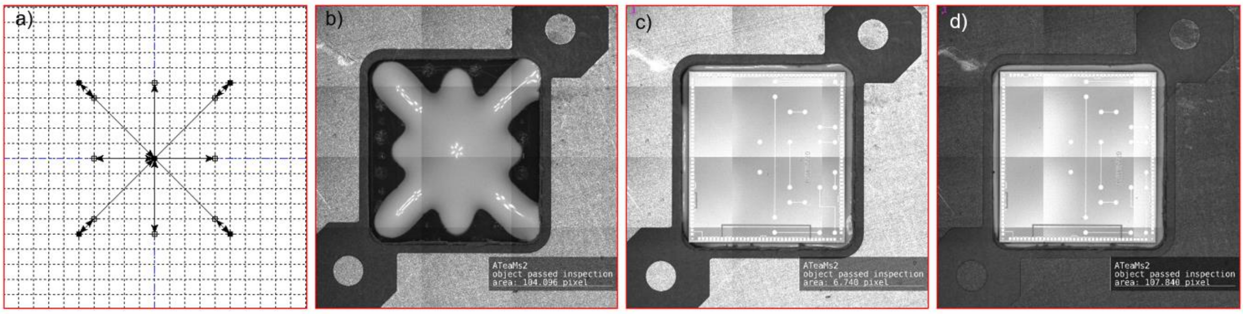

Figure 2. Die placement process snapshots. a) adhesive dispensing strategy, b) dispensed adhesive pattern, c) die placed, d) final product after curing. The flowing behaviour of the adhesive is especially visible in the left corners. A sinking of almost 30 μm was accounted for, which is a significant factor to the target accuracy of +/- 20 μm die placement height error.

For the prototype reported in this deliverable, BESI used the hardware developed throughout the TINKER project to assemble multiple batches of PCBs that are subsequently processed by PROFACTOR and NOTION. Most recently, BESI reported in the M30 WP3 update the details about a production run covering 42 PCBs (= 252 dies), which served as the basis for WP4 and WP5 developments. BESI will continue to provide assembled PCBs with optimizations based on feedback from the TINKER consortium partners.

2.2.2. 3D Printing of the dielectric material and electrical bonding of the Bare Dies via Inkjet

The goal of the development was to print a dielectric layer filling the gap between the radar chip and cavity. Consequentially, conductive interconnections were printed as a replacement of conventional wire bonding. Process flow is depicted in Figure 3.

a) b) c)

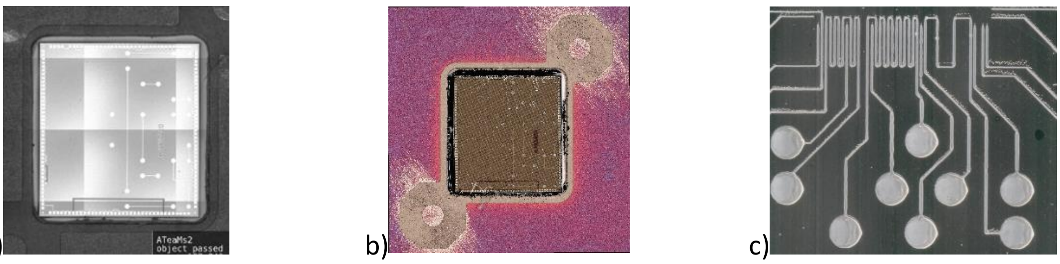

Figure 3: Process flow – P&P of the radar chip (a) ⇒ Gap filling by inkjet (dielectric material) (b) ⇒ Inkjet printed interconnections (c)

DC-layout adapted by BOS was printed on the dielectric material and further investigate the spreading behavior of the conductive ink on the dielectric material. TINKER printer was used, equipped with the two printed materials being the TIGER 150/3.1K and the PVN I50TM-119. Firstly, the TIGER 150/3.1K was printed as the flat base material on glass (Ink curing due to UV LED 365nm) and afterwards the DC-Layout was printed on it with the I50TM-119 (Drying of the conductive ink was performed with NIR lamp). The glass substrate was pre-treated with an adhesion promoter to improve the adhesion of TIGER 150/3.1K. The printing results can be seen in the images in Figure 4.

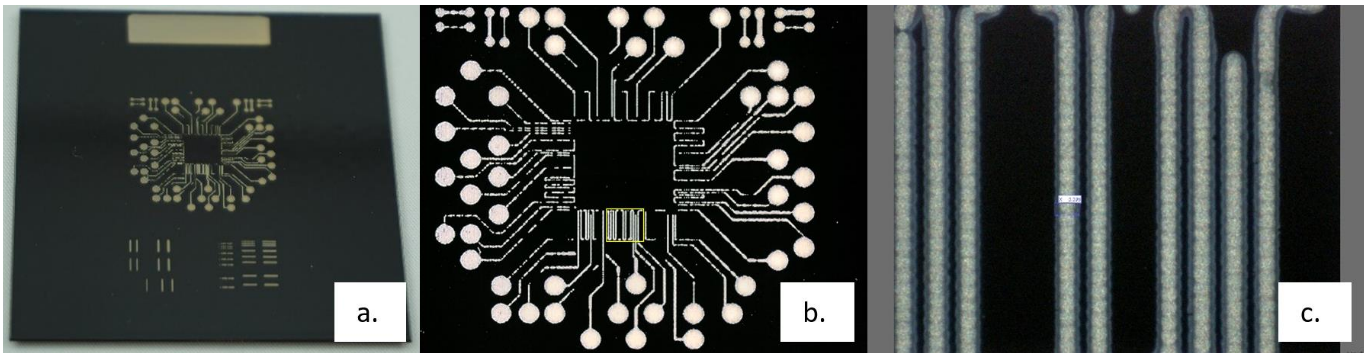

Figure 4: Printed DC-layout on flat TIGER 150/3.1K substrate. 1 Layer of I50TM-119 printed with 1440 dpi and 33% pixel reduction. Individual nozzles failed during the printing process. Smallest measured printed line width was 90 µm without shortcuts (Pitch of IFAG Microchip: 125 µm).

2.2.3. Closed error compensation loop for inkjet processes

PRO has received inspection data from BESI, which includes details about the quantity of adhesive within each substrate and the orientation data of the chips. Utilizing this information, a deep learning model was incrementally trained to make estimates regarding the missing adhesive, as part of T4.3 (refer to D4.3 and D1.5). Additionally, a data processing module was developed to leverage the same data for calculating the corresponding printing layers and the positions of fiducial points. This calculation is aimed at compensating for the missing adhesive within the gap, using the Tinker inkjet printer at NOT (refer to D6.4). Following the gap-filling process, the substrates undergo another round of inspection by the metrology system at BESI. This inspection serves two purposes: to assess the quality of the print and to measure the amount of printed ink. If the gaps are not completely filled, another gap-filling iteration was performed. In instances where successful gap filling is achieved, the chips are connected through the filled gap using the inkjet printer at NOT (see D6.4).

2.3. Printed Radar antennas

2.3.1. Antenna design and simulation

The main technological challenge in the printing of radar waveguide antenna is the process of metallization of vertical walls. In order to tackle the issues concerning the metallization of the vertical walls, the geometries of the two straight waveguide configurations were altered: the incline angle of the walls of WG1 and WG2 was changed from 90° to 85° and the height of WG2 was reduced by 1mm. Although the overall height of the structure was reduced, the cross-section of the internal groove of the waveguide was not altered. The RF experts of BOS carried out CST simulations to analyze the changes in the RF characteristics caused by the altered geometry. Results from the frequency analysis for vertical wall geometry and for modified design are depicted in Figure 5.

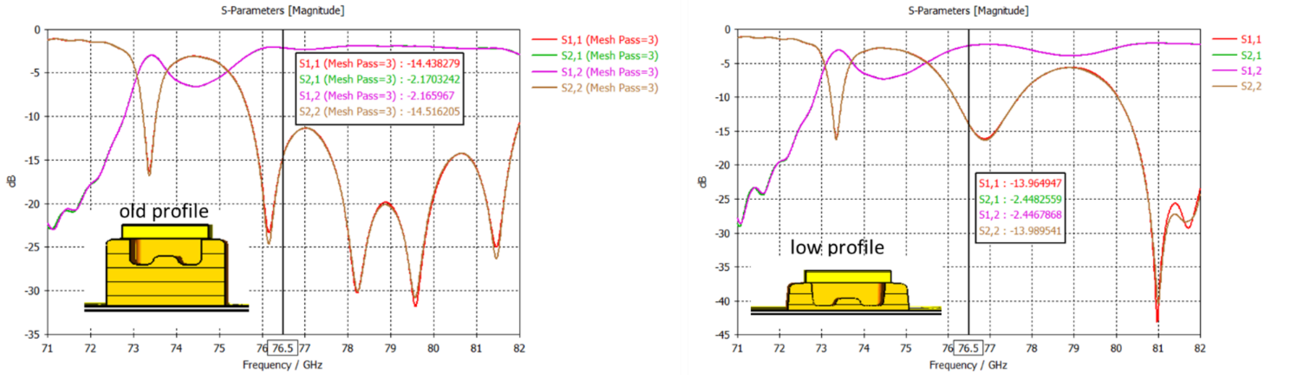

Figure 5: The reflection and transmission characteristics of WG1 (left straight walls, right tapered walls, and low profile)

2.3.2. 3D Printing of the waveguide antennas with inner metallization

Metallization of antenna structures was investigated by PRO and NOT in multiple workshops at NOT. TINKER printer which is capable of printing 2 different materials was used. At first, the 3D antenna structure (Ink: TIGER 150/3.1K) was printed on glass as substrate (Ink curing was performed with UV LED 365nm) and in a second step I50TM-119 was printed over the 3D structure for full metallization (Drying of the conductive Ink was performed with NIR Lamp). The substrate was pre-treated with an adhesion promoter to improve the adhesion of TIGER 150/3.1K. The sintering process of the printed was done in the oven at 130°C for 30 min. Printing results can be seen in the images below. The quality of the 3D printed antenna structures printed at the TINKER Printer is high and also sharp. The edges of the printed structures are more rounded than the original STL file. however, these have a positive effect on the subsequent metallization, since it seems that the walls are better metallized when the edges are round. The metallization of the inner antenna structure and walls worked very well in the middle part of the antenna structure by simple overprinting (Figure 6). However, there was understandably more printed material on the lower part of the antenna than on the walls, since printed material runs down the walls. This surplus material ran down to the bottom of the antenna openings which would prevent the wave from entering the waveguide antenna (see Figure 7). Additionally, the walls at the openings are not fully metalized, which is mandatory for a functional waveguide antenna (see Figure 7).

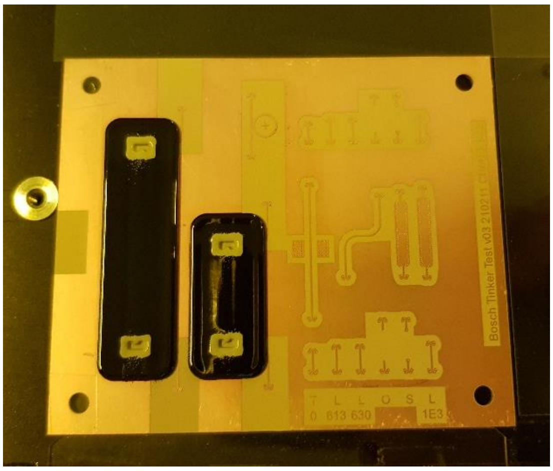

Figure 6: Base of the waveguide structure, with intermediate conductive layer at the coupling openings for proper metallization of the walls.

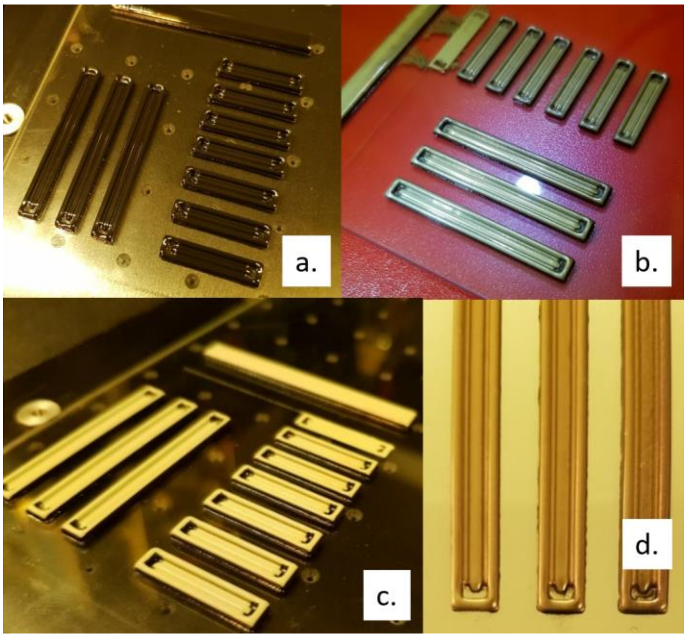

Figure 7: Printed antenna structures before (a.) and after the overprinting with silver ink (b.). Non-covered parts of the antenna are visible at the openings (c.); surplus material is found in the openings of printed antenna structures (d.)

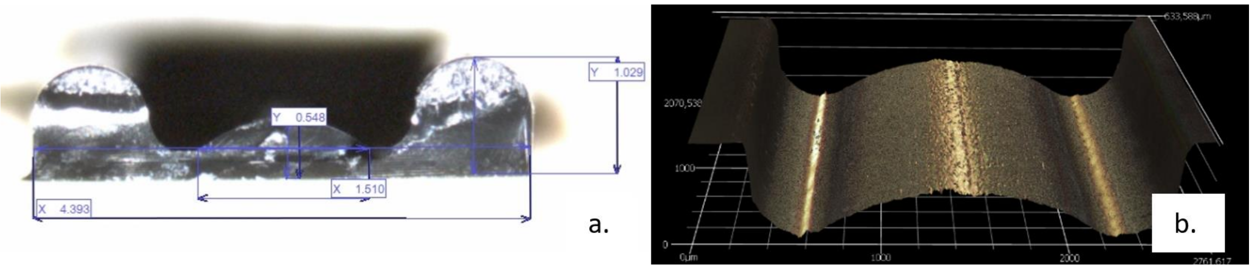

Figure 8: Cross-section of printed antenna structure (a.); 3D-Image of the inner structure of the metallized antenna (measured with a Laser Scanning microscope, (d.).

Printing process optimization was performed in a following workshop by PRO and NOT directly on the Tinker pilot Printer at NOT to prevent surplus material to flow down the antenna openings and to fully metallize the walls at the antenna openings.

3D structures for waveguide antennas were printed using the dielectric ink and the metallization strategy of printing conductive layers for wall metallization consecutively with the dielectric layers, was tested. Previously a similar experiment showed that the conductive layers need to be printed more frequently in order to avoid uncovered areas or ink flowing down the wall and gathering excessively at the ground of the antenna structure. The new attempt enabled better results than previous attempts, however a proper alignment procedure and finetuning of the material amount and conductive layer frequency were still required and thus performed by NOT after the workshop. Furthermore, the NIR curing settings were varied in order to evaporate the solvent at a suitable speed and also substrates with and without pretreatment were tested. A pre-treatment with oxygen plasma and application of a primer from PRO is mandatory to avoid delamination of the antenna from the copper surface. PRO will provide such substrate pre-treatment for printing experiments at NOT for upcoming experiments.

3. Conclusions

The BOS radar concept contains two main areas where ink-jet-based technology was applied. In both fields advancements in technology development are visible and radar sensor assembly process prototypes and printed radar waveguide antenna prototypes have been shown. The consortium is now focusing on the optimization of the fabrication process steps towards the realization a small series demonstrator utilizing the TINKER pilot platform.

4. Outlook

After receiving the 3DP waveguide antennas a covering lid will be bonded on it. First, the lid will be laser cut from a 200µm copper sheet. An adhesive will be dispensed by using a Datacon or an Infotech bonding device and finally, the lid will be placed.

After the adhesive is cured, the PCB with the WG1 and WG2 antenna configurations will be characterized in the high frequency lab of BOS. A CT inspection is carried out on one WG1/WG2 geometry to assess the condition of the antennas before any cycling experiments.

Temperature-humidity cycling will be carried out on the samples.

After the temperature-humidity cycling, high-frequency measurements will only be carried out if a measurable performance was determined during the pre-cycling HF examination.

CT and light microscopy inspections will be carried out again in order to search for any possible cracks, or delamination.

Further improvements however are still needed to obtain a continuous metallization on the surfaces where it is needed, and to avoid the deposition of the inks at the bottom of the openings of the waveguide.

5. Deviation and mitigation strategies

- Due to the delay in the realization of the TINKER printer platform and fulfilment consequent project tasks and deliverables a prolongation of 6 month was requested and granted by EC.
- BOS hired an intern as a support concerning the ink-jet printing technology development.