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TINKER

FABRICATION OF SENSOR PACKAGES ENABLED BY ADDITIVE MANUFACTURING

= Deliverable D3.1 =

Prototype of Placement Equipment

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= Deliverable D3.1 =

Prototype of Placement Equipment

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DISCLAIMER

Executive Summary

The main purpose of this report is to provide a first summary of the pick-and-place equipment in development in the context of project TINKER.

In the course of this first project phase, BESI has set up equipment with potentially suitable metrology for the TINKER platform. In parallel, work has begun with partners like SENTECH to develop complementary, advanced metrology systems. Here, the main focus lies on non-contact 3D measurements on surfaces.

As a first big step, BOSCH and INFINEON have provided samples of their devices, so that first demonstrator samples are assembled using a simulated production workflow with BESI's equipment. This sample build provides valuable insights into the baseline performance and limitations of the state-of-the-art. Preliminary data analysis shows that the variability across the samples is high and cannot be compensated by the current setup.

We conclude that the prototype pick-and-place equipment is ready and that implementing the TINKER platform – especially setting up the feedback loops – is important for the overall success.

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1. Introduction

The vision of TINKER is to provide a new cost- effective 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 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).

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 and improving functionality and efficient use of resources is highly demanded.

The pick-and-place hardware setup developed in WP 3 is strongly influenced by the demonstrators (WP 6), processes (e.g. WP 5) and feedback loops (WP 4) established within the TINKER project. It builds heavily on the specifications defined in the first phase of the project in WP 2 (e.g. D2.3). In the current phase, these specifications are translated into practical action plans and first gaps are identified based on the validation of early prototypes. Moreover, the data collected is important for interoperability, to facilitate cross-site data exchange for metrology and the (process) feedback loops.

1.1. Description of deliverable

Deliverable D3.1 titled "Prototype of Placement Equipment" relates to Task 3.1 "Setup of placement equipment" as part of WP 3 "Placement processes". The main focus of this task is to set up the relevant placement equipment for use in the TINKER project.

This deliverable report provides a high-level overview about the activities centred on the pick-and-place equipment and shows an early prototype of the RADAR demonstrator. We will also touch on the metrology systems that are developed by BESI and SENTECH. For more details, please see also deliverable D4.1.

2. Results and Discussion

This chapter highlights various aspects of the equipment setup, the metrology, and the first sample builds in more detail.

2.1. Prototype Pick-and-Place Equipment Setup

The main workhorse for this phase of TINKER is a modified *Datacon 2200 evo*^{plus} multichip bonder, exemplary shown in Figure 2. The system at hand is an R&D machine equipped with a complete set of prototype optical height measurement sensors, accompanied by a versatile time-pressure dispenser for the application of adhesive.

Here, we use this multichip bonder to understand the implications of running a simulated production workflow of a TINKER RADAR concept. More specifically, we want to evaluate how to:

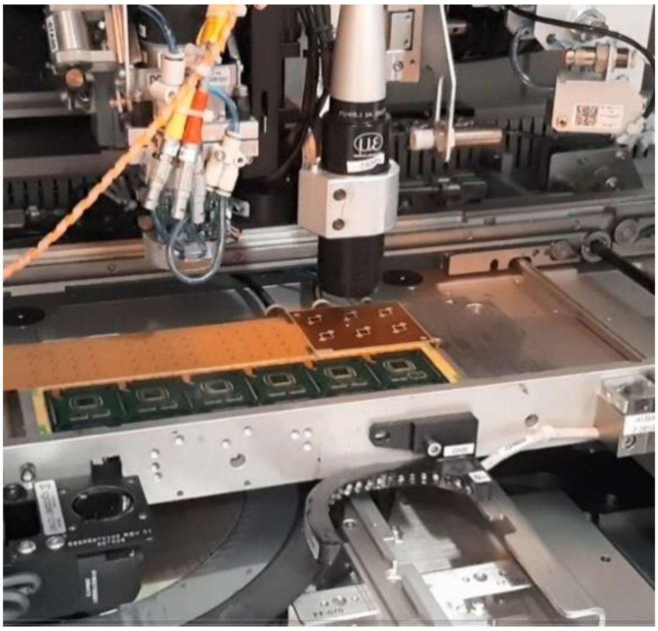
- Set up the right tooling
- Configure and calibrate the subsystems, like the height measurement sensors
- Set up a workflow for the different processing steps
- Define the correct reference positions and heights
- Set up the adhesive dispensing
- Run in-situ pre- and post-bond inspection
- Collect data (logs) and image snapshots during production

With the early availability of test samples from the RADAR use case via BOSCH and INFINEON, all these aspects can be evaluated by this setup. We note that the fundamental accuracy of the specific prototype version used is currently rated at ±7 µm @ 3σ in XY While it is not the ultimate achievable accuracy of this platform – in fact BESI is pushing beyond ±3 µm as part of TINKER – the prototype is well configured in terms of wafer table type installed, additional sensors and dispensing capabilities. This “complete package” is an excellent fit for early feasibility tests of the TINKER workflow.

This provides us with valuable baseline data to understand how all parts play together and develop first action plans for the next steps of the TINKER platform – especially taking novel metrology systems into account.

2.2. BESI's metrology development

BESI is actively developing various metrology systems for its equipment. For the TINKER applications, non-contact 3D topography sensors are of special interest. They are used to measure the actual geometry of the products and adjust the bonding parameters in real time. Moreover, data from upstream processes can be taken into account at stage.



The bonder at hand is equipped with optical height sensors (OHS). They measure the relative distance of the system to the surface via analyzing the spectra of the back-reflected light (confocal-chromatic principle (1) (2)). A comprehensive calibration routine during machine setup enables the bonder to do non-contact absolute position measurements in the reachable volume of the slider. In Figure 3, the OHS can be seen in operation: the measured point is tightly focused white light spot.

Beyond the OHS, BESI is developing a 2D/3D camera system. It combines high resolution 2D imaging with an interferometer-based acquisition of spatially resolved height data. The setup of a prototype 2D/3D camera is planned in the near future to evaluate the applicability for TINKER devices.

2.3. Integration of SENTECH's white-light-autofocus height measurement system

SENTECH's white-light-autofocus system uses proprietary real-time data analysis algorithms to measure the height of multiple predetermined points in a certain field-of-view simultaneously. To support SENTECH's system in BESI's equipment, a precise z-move needs to be done by BESI's bonder. SENTECH's sensor system has the benefit of providing a "single-snap" approach to tilt measurements, even on difficult to measure surfaces (glossy, diffractive or diffusive).For example, one can measure the height of several points on the surface of a die. Then, the relative orientation between die and camera system can be estimated.

BESI's pick-and-place machines are fast, precise and modular. Thus, integrating a third-party system might prove challenging. The collision risk in complicated geometries needs to be managed and the equipment has to be compatible to the environment of the bonder (e.g. accelerations and vibrations), leading to size restrictions and strict requirements for mounting points (see Figure 4, for example).

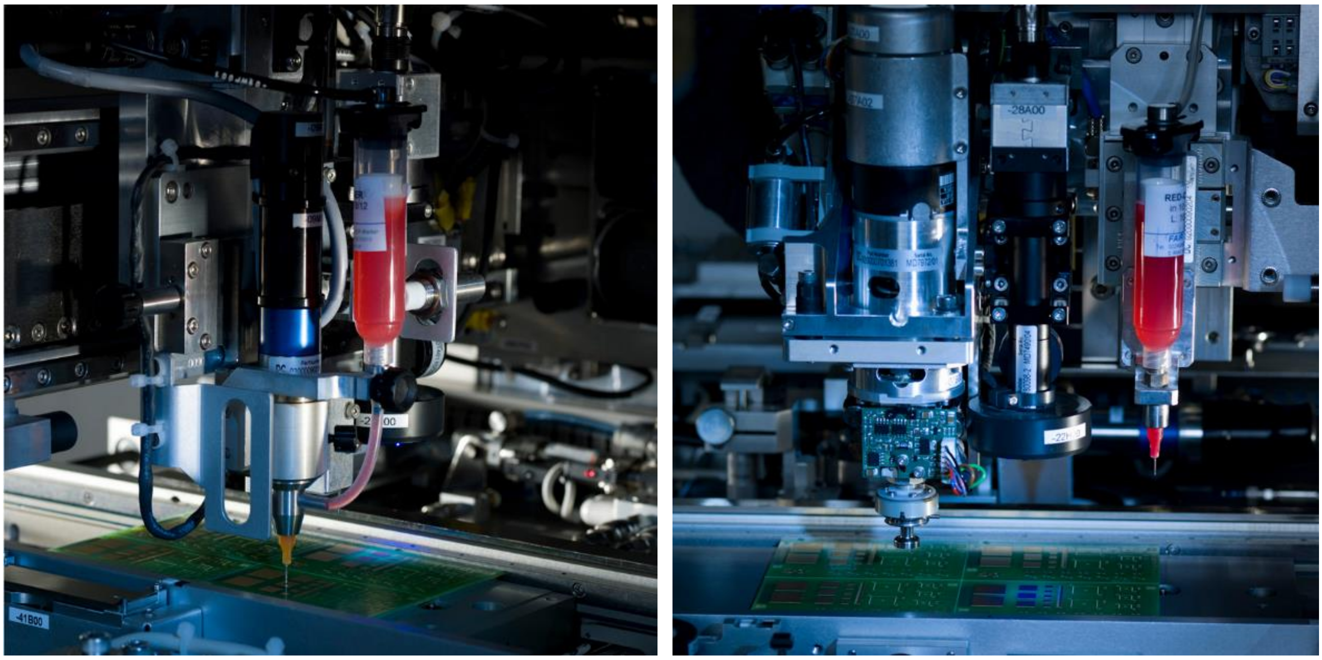


Figure 4. The 2200 evo^{plus}'s two systems are connected by a transport unit. Left: "System 1" can perform basic measuring and dispensing tasks; right: "System 2" - the modular bondhead assemblies allow the mounting of third-party equipment. In this case, a volume of roughly 20x20x200 mm³ was identified to fit SEN's white-light-autofocus system near the camera.

An integration study was carried out to establish the size constraints of any potential inspection equipment that is to be integrated. As there are precision axes present in the bonder, BESI plans to directly interface the encoder output to SENTECH's controller. This leads to a highly compact, fully integrated sensor package whose acquisition parameters can be optimized for each application. No particular showstopper has been identified so far, a space of roughly 30x30x200 mm³ is available to fit the system.
During initial alignments, the working distance has been identified as risk for BESI's collision geometry. This risk will be reviewed once the optical path is fully laid out by SENTECH. Additionally, SENTECH has verified the operation of their prototype system on samples identical to the ones from this report. Please refer to deliverable 4.1 for more information.

2.4. RADAR demonstrator sample builds

A full set of prototype devices available from the TINKER partners at BOSCH and INFINEON allows us to do some first validation of the overall process flow with the prototype system. At this project stage, the feedback loops are not set up yet, so these sample builds serve to establish a baseline for the state-of-the-art.

For the demonstrator, a die is picked "contact face-up" and placed inside a pocket (cavity) in the printed-circuit-board (PCB) fulfilling the defined assembly requirement. The cavity was previously filled with a dispensed die bonding adhesive. The main benefit of this approach is to achieve a more compact form factor compared to a traditional flip-chip approach using the pre-packaged integrated circuit. The tighter integration is also beneficial for thermal and signal routing.

BESI's *Datacon 2200 evo^{plus}* has two systems installed that are used for different purposes; On "System 1", the dispensing pattern is programmed; on "System 2", the die placement and post-bond inspections are performed. Both systems are connected by a transport system. This represents a workflow that is prepared to achieve a high throughput, as both systems operate independently. A top view of the machine depicting the workflow can be seen in Figure 5, a detailed view of a typical configuration of the Systems in Figure 4.

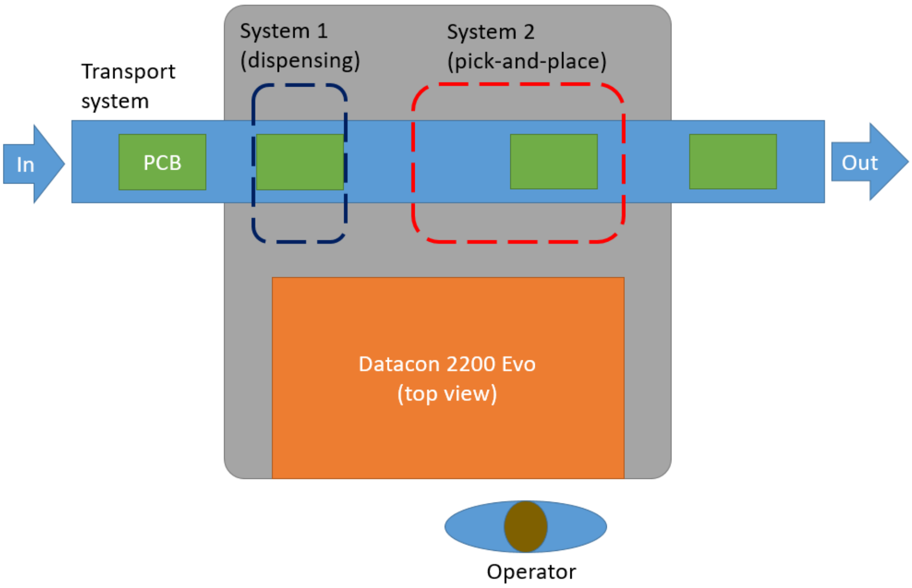
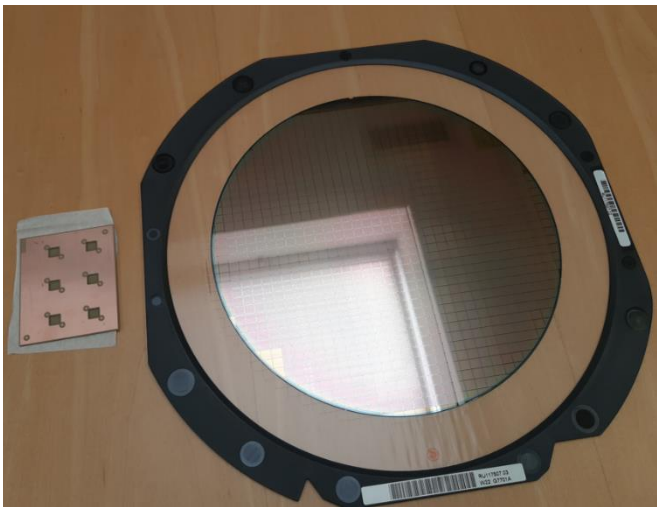
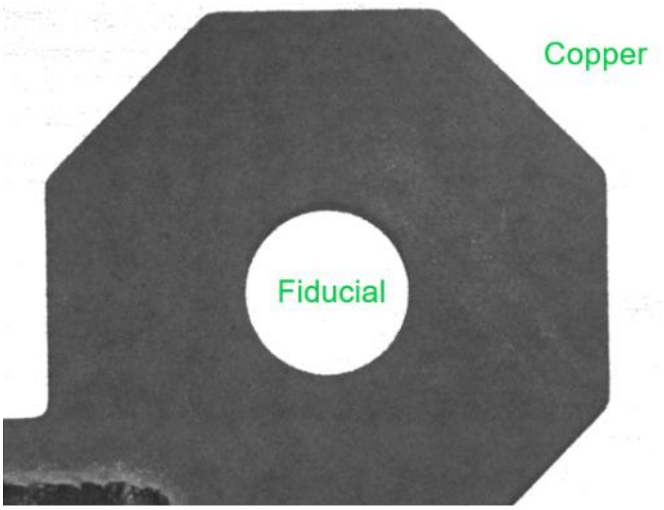


Figure 5. Schematic top view of the machine showing the locations of the two Systems for dispensing and placement. PCBs enter from the left, are processed sequentially and leave via the right side of the machine.

The material we used is shown in Figure 6. Before setting up the bond recipe, dry cycles without adhesive are run, where dies are placed at their final position repeatedly. This run includes a first machine vision validation, to check whether the alignment marks (fiducials) can be recognized with sufficient accuracy and reliability. Placing the actual dies in an empty pocket reveals the tolerances and provides an indication on how to set up the calibration of the dispenser. Nevertheless, the bulk of the process parameters are set “blind”, using existing CAD data, specifications and conversions taken from datasheets.





The final live production run starts with dispensing the adhesive into the cavities using “System 1”. A special “snowflake”-like pattern from BESI’s proprietary dispensing pattern library is chosen. It is slightly scaled to accommodate for the aspect ratio of the cavity and the dies. Pre-dispensing is used to get a more consistent volume. To goal is to achieve a homogenous, isotropic and stable underfill that is neither “squeezed out” nor shows any voiding on die placement.

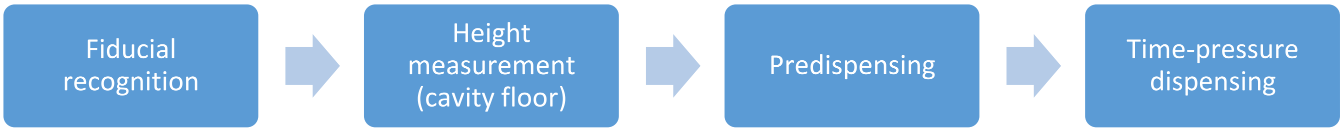


Figure 7. Workflow of System 1 for dispensing (simplified).

After dispensing, the PCBs are placed into “System 2”, where the pick-and-place loop is running. Following a standard needle-ejection process for UV treated tape, the dies are placed using the workflow depicted in Figure 8. The target height is a virtual plane 20 µm above the average copper level surrounding the cavity in order to avoid any excessive adhesive spill, if there would be a gross mismatch between required and actually dispensed volume.

Figure 8. Workflow of System 2 for die placement (simplified).

Finally, a custom post-bond-inspection (PBI) recipe is run to measure the heights of the global and local heights of the PCBs, and the final die height. It is identical to the workflow shown in Figure 8, except that the last step is a measurement of the die height instead of the placement. The adhesive is highly viscous and needs thermal curing, so the PBI is run pre- and post-curing to estimate any shifts happening during handling and curing.

During the trials, a special focus was put on data collection in a real production environment, as it is an integral part for the success of the TINKER platform. Several log files, with combined more than 100 000 entries were collected. In-situ images of critical process phases were taken, resulting in total data package size of approx. 100 MB per PCB. This helps to define the logging level, the data processing interfaces and subsequently refine handling the data.

A total of 18 bonds are split across 3 sets of dispensing parameters, corresponding to the 3 PCBs. This provides a first estimate of trends in post-cure behavior and intra-PCB variance. An example of the results of the sample build is shown in Figure 9. Not all PCBs and dies were bonded, to allow further comparisons of the bonded and the unprocessed devices.

2.5. Preliminary data analysis

Preliminary data analysis, comparing the centroids of the height of the dies shows a significant variance within each PCB. Some of this variance is visible with the naked eye in Figure 9: In the overview photo on the right, the white glue pattern at the edge of the die is not completely isotropic, despite being bonded with the nominally same parameters.

One notable exception is PCB #2, which seems to show a z-placement variance of only ±5 µm @ 1σ. This is a surprisingly good result, considering that 1) no active feedback was implemented yet, 2) that the pick-and-place parameters were set blindly with limited calibration and 3) that the PCBs are just a first evaluation samples. We note, however, that the other two PCBs are at multiples of that variance and exhibit clear outliers.

Looking at the raw sensor data, there is evidence of tilted dies, which has to be analyzed further. Moreover, the adhesive shows a clear shrinking behavior upon curing, lowering the dies by approximately 30 µm relative to the reference copper layer. This offset can easily be corrected, but the batch-to-batch variability has yet to be studied. For best results, the actual geometry of the cavities and the volume of the dispensed adhesive has to be taken into account. The next steps involve defining sensitivities for each.

The raw data of the OHS further reveals that its measurements are consistent, potentially reaching submicron accuracy already. From the basic working principle, it is known that the local topography and surface condition affect non-contact height measurement sensors. However, so far, no suspicious outlier has been found for the material at hand.

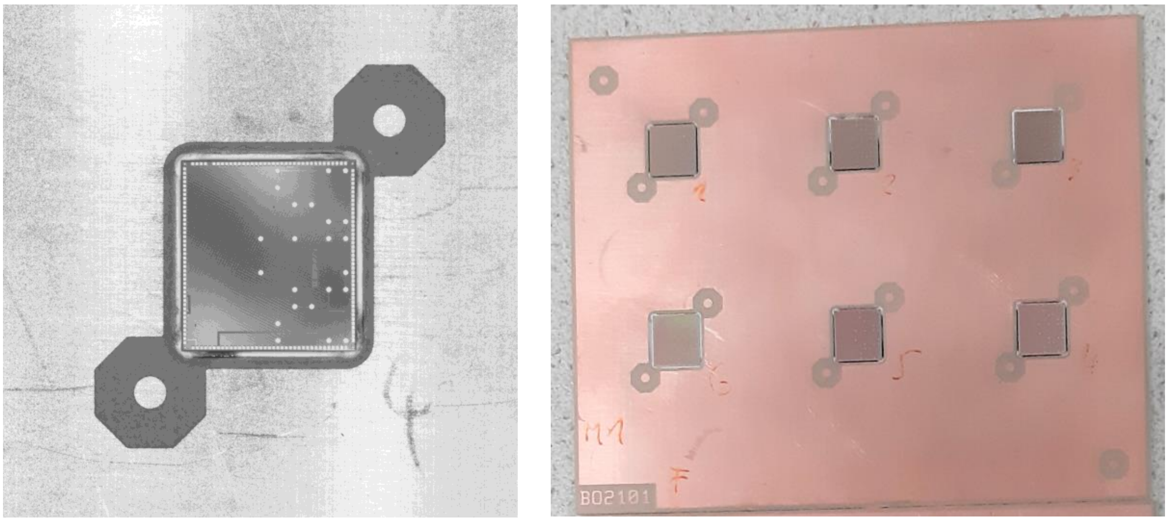
3. Conclusions

Running the fabrication showed no anomalies, the recipe worked as intended. At the time of submitting this report, data reduction and analysis are still ongoing. Preliminary data confirms that the proposed TINKER process is indeed challenging for state-of-the-art systems and needs the full treatment as laid out in the project plan.

Forward looking, analyzing the local geometry will give more insight into parameter sensitivities, such as the gap volume, the dispensing parameters and placement offsets. This analysis is done by examining the data taken during the process, but also with additional offline metrology.

An important result in terms of the pick-and-place equipment development in WP3 is the demonstration of the feasibility of the OHS. It detected all measurement points without error and preliminary repeatability data shows submicron accurate measurement on these samples.

In conclusion, BESI's prototype pick-and-place equipment was set up and shown to be ready for the first demonstrator production (Figure 9). Special care was taken towards establishing the important cornerstones to achieve the TINKER goals: non-contact height sensors were fitted and extensive data collection can be performed. The additional metrology provides data for feedback loops that are set up not just for a single machine, but also between the consortium partners.



4. Degree of Progress

The first phase of WP3 consists of the task 3.1 “Setup of placement equipment” that transitions into task 3.2 “Placement process development including implementation of feedback loop” by month 9.

In this deliverable, we have used prototypes of key systems together for first feasibilities of the pick-and-place step of the TINKER platform. Most notably, a novel, non-contact metrology system has been used to dynamically place the dies on the adhesive. The data gathered through these sample builds will be used to start developing the feedback loop together with PROFACTOR. All of this is still in agreement with the original task planning.

The work will continue to optimize both hardware and software of the pick-and-place equipment to meet the required accuracy and throughput. The necessary in-situ metrology will be further developed and improved.

5. Outlook and deviation

In the short term activities include the data analysis and alignments between the partners on the subsequent "lessons learned". Since the adhesive is now fully cured, the PCBs allow further metrology and processing at partner sites. For example, BESI plans to investigate PCBs with the 2D/3D camera upon availability and wants to leverage its access to high-end equipment, like a scanning acoustic microscope (SAM) or a high-resolution infrared microscope, for a deeper study of the adhesive-die interaction.

Work with SENTECH will continue, in order to develop and test an integrable version of the white-light autofocus system. Having now established a baseline performance with BESI's OHS, allows us to judge and optimize the performance of the autofocus system. We note that at this stage, a small deviation consists in adding the in-situ polarimetry as an alternate method to the autofocus system, as the polarimetric image was identified to increase image contrast at films as thin as 20 nm. This has a chance to improve the pick-and-place step of the TINKER platform.

The results of the data analysis will be used to fine-tune the design of the next samples, for example, with respect to the cavity geometry and PCB layout (together with BOSCH). Regarding the recent sample builds, the effect of the pick-and-place equipment needs to be analyzed thoroughly, especially methods to improve dispensing accuracy. In parallel, fundamental development on the machine platform will continue to push an increase of the accuracy beyond ±3 µm @ 3σ.

The data collected will be used to establish the first interfaces between the partners, most notably between BESI and PROFACTOR. This includes advanced data processing techniques, like machine learning (ML). The number of real bonds is still too little for true ML, but defining the bounds and distributions can help augmenting the data for such purposes. BESI also continuous development work on streamlining the collection of data on our platforms.

In conclusion, these sample builds help drive the TINKER platform pick-and-place steps forward on various sides: hardware, software and interoperability.

6. Appendix

6.1. Tables Reference

No table of figures entries found.

6.2. Figures Reference

6.3. Bibliography

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