Pick and Place of sensitive chips with vacuum-free Gecomer® tools

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***Abstract*—To cope the lack of suitable pick and place methods for sensitive chips, we present a new process using a gripper tool from the company INNOCISE called Gecomer®. The tool, made of polymer pillars, is using Van der Waals forces to create adhesion between the gripping tool and the chip surface. Hence, the tool works without any vacuum. While placing, the Van der Waals interactions are reduced by buckling those pillars resulting in a decreased contact area. The challenge is to find the right parameters to avoid a re-gripping of the chip during the Gecomer®-movement away from the chip. In this paper we present results on the placement accuracy including the reproducibility compared to a standard vacuum tool for different process parameters. For that, we used a pick and place machine with built-in inspection camera to examine the deviation from the target position. It is revealed that both vacuum and polymer gripper have a similar deviation of approx. ±15 µm. Hence, the placing accuracy is not negatively influenced by the Gecomer® tool and depends only on the machine parameters. Furthermore, we analyze the surfaces of the chips, whether there are any residues of the gripping tool. In a first optical inspection, no damages or residues could be found. The new vacuum-free pick and place process has the potential to open new opportunities in the assembly of sensitive (MEMS)-chips regarding reproducibility, accuracy, and process throughput.**

Keywords—pick and place, MEMS assembly, die bond, chip bond, gripping tool, chip handling, die sorting

I. Introduction (*Heading 1*)

A. Motivation

MEMS chips are an emerging market. Especially the packaging of these chips is considered crucial, because 60% to 80% of the MEMS device costs are packaging [1]. Hence, efficient packaging processes are required. One example in this context is the MEMS handling and pick and place. Spatial light modulators (SLM) are a subsegment of MEMS chips, using micromirror arrays for lithography and imaging applications. Large SLM-chips have mirror counts in the millions with mirror edge lengths in the micrometer range. For these chips, conventional pick and place processes with tools using vacuum are difficult to use, due to the risk of damaging the movable mirror parts on the chip by getting close to the vacuum. Hence, the chip must be designed with enough space between the mirror and vacuum tool touching area. The alternative is a manual assembly with tweezers or special grippers. However, this is not reproducible, cannot be used for large chips and holds the risk of damaging the edges of the chip.

B. Challenges for MEMS packaging and handling

As already mentioned, pick and place and assembly are a difficult tasks for MEMS and need special attention [2]. Packaging of MEMS is linked to the specific application and in contrast to standard IC packaging, MEMS most often need an interface to the environment [3]. TABLE I shows the challenges for MEMS during the entire packaging workflow and possible solutions. In this paper, we focus on the challenges, which arise during die handling.

TABLE I. Overview of the packaging challenges for MEMS chips [3]

	Challenge	Possible solution
Release	Damaging the movable parts	
Dicing	Risk of contamination or destruction	Release after dicing
Die handling	Device failure, due to a very sensitive die top face to contact	Handling at the side faces
Stress	Performance degradation or device failure	Low modulus die attach, compatible CTE match-ups, cooling
Outgassing	Corrosion, performance degradation	Low outgassing adhesives
Testing	Possible device failure after many assembly steps	Pre-package testing and/or post package testing

For chips, which do not need a dedicated contact to the environment, the standard packaging includes a cap, to cover the movable MEMS parts. This is typically done in wafer-level packaging processes [1] and is used for example for gyroscope MEMS [4]. For MEMS, vacuum tools can be used, if the movable parts are robust enough and/or the sensitive surfaces are far away from the vacuum point or the MEMS part is encapsulated [5, 6]. If the chip is properly protected, it can be handled by standard vacuum pick and place tools [7].

However, sensitive MEMS chips cannot be moved by vacuum pick tools [3]. As pointed out in TABLE I, the state-of-the-art handling method for more sensitive MEMS dies is a gripping at their side faces [8]. Especially, dies where the active area is not protective covered, as it is often the case for SLM [9, 10], need special assembly processes. Since edge grippers are mostly not compatible with standard (vacuum) pick and place tool heads, separate infrastructure and machines are required. However, a handling at the edges has the risk of damaging the chip and more space in the package is required next to the chip for the gripper. Manual assembly with special tweezers is an option as well, but not suitable for a reproducible packaging of higher chip quantities. In every case, chip-package co-design is crucial for MEMS-chips [6] and especially for the die handling. This includes space for the gripping or distances between gripping-/vacuum surfaces and sensitive structures.

In this paper we introduce a new way of die handling, to overcome the lack of proper pick and place tools for sensitive chips. The Gecomer ® gripper works without any vacuum and uses the top surface of the chip for gripping. This is possible due to the use of Van-der-Waals forces. The basic principle of the Gecomer® tool is briefly introduced in the next section, followed by the results of the pick and place experiments covering the test setup, the placing accuracy, and the comparison to standard vacuum tools. We finish with a short conclusion and an outlook.

II. BASIC PRINCIPLE OF MICROSTRUCTURED ADHESIVE SURFACES

The Gecomer® technology is a sustainable bio-inspired gripping solution suitable for pick and place applications without need of any external energy. It is inspired by hairy hierarchical structures on gecko's feet that enables it to move rapidly on vertical surfaces and the ceiling. These grippers utilize a phenomenon called dry adhesion, which is attained by arranging specific microstructures on the gripping surface.

Millions of fine hairs called setae equipped with spatula-shaped ends on gecko's feet, as depicted in Fig. 1, enables it to strongly attach their feet to different surfaces and quickly detach them. No vacuum tool, glue, or sticky material exists on their feet, and the studies show this strong temporary and reversible adhesion relies on intermolecular forces, i.e., Van der Waals forces between the setae and the surface [11, 12].

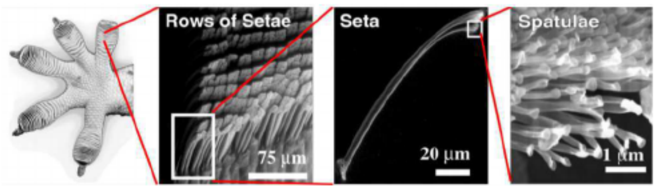

Fig. 1. Gecko's feet comprising of hierarchical structure of fine hairs which is an inspiration for dry adhesives [13].

In the nature, adhesive forces between large surfaces are usually not caused by van der Waals forces, since the real contact area is normally way smaller than the apparent one. Meanwhile, a higher number of smaller sub-contacts can adapt and conform better with the roughness of the counter surface and therefore provide a larger real contact area, which increases the adhesion.

To grasp the mechanism of dry adhesive structures, it is helpful to have a quick review on the contact mechanics. In the Johnson, Kendall, and Roberts theory, adhesive contact of elastic bodies, adhesive force refers exactly to the energy required to create new surfaces through detachment [14]. It also suggests that when a cylindrical geometry is attached to a rigid substrate, the stress distribution through the interface is not uniform and there is a stress concentration at the edge, as it is shown in Fig. 2. Maugis et al. [15] considered a cohesive zone that supports the stress concentration applied to the edge. As long as the work required to overcome the work of adhesion attributed to the cohesive zone is done, the interfacial detachment initiates, grows and detachment occurs [15, 16].

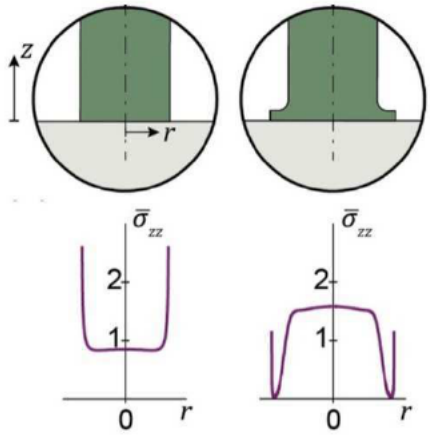

Fig. 2. A comparison of stress distribution at the tip of a flat punch and a mushroom-shaped pillar [17].

For a continuous contact surface, once the detachment starts to propagate, it advances along the whole interface, while in case of a higher number of smaller contacts, e.g., setae of gecko's feet, the detachment initiation results in detachment of just one sub contact, and for the next one there should be another detachment initiation induced [18]. Furthermore, for smaller contacts, the stored elastic energy is reduced [16], so that its dissipation does not provide the required energy to initiate or propagate a detachment in the next sub contact [18]. Also, at an interface with a high number of small sub contacts the stress distribution is more uniform, and defects are smaller and less destructive compared to a large continuous contact.

For handling microscopic parts, the challenge is mostly not to pick up the part but to release it again. Microstructures with cylindrical tips, flat punches, show a higher switching between a high and low adhesive state, therefore more suitable for a pick and place cycle in this application, as it is shown in Fig. 3.

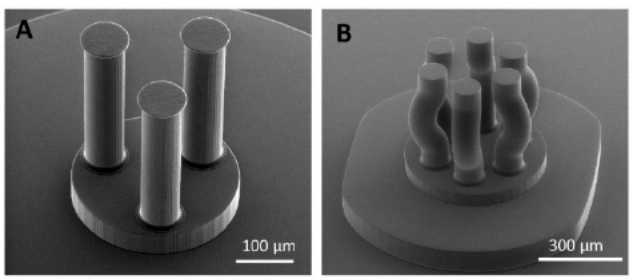

Fig. 3. Micro handling grippers, A) Scanning electron microscopy image (SEM) of a micro handling gripper with three mushroom pillars, and B) SEM image of a micro handling gripper comprising of 5 flat punch pillars.

III. Pick and Place Experiments

A. Test setup

For the pick and place experiments, a Gecomer® tool is used, as it is shown in Fig. 4. There are five pillars with a length of 315 µm and a diameter of 75 µm each. To evaluate the suitability of the tool for chip sorting and placing, a test is performed with a standard pick and place machine. The machine setup is shown in Fig. 5. For the test, blank Silicon dummy chips with edge dimensions of 2.5 x 2.5 mm² and a thickness of 1.4 mm are used. They are picked from a waffle pack (1) to either a Gel Pak® or a second waffle pack (2). The target position is defined in relation to the lines and edges in the Gel Pak® or waffle pack. The Gecomer® tool is mounted in the pick and place module (3), as it is shown in Fig. 6. To ensure precise alignment between gripper and chip, the gripper position is thought to the machine by two cameras (4,5). After placing the chip, an inspection camera (6) controls the resulting position and measures the deviation in x,y direction and the rotation angle around the z-axis. The manufacturer of the machine indicates the accuracy for placing with better than ±10 µm, which represents the goal for the Gecomer® tool. If the placing accuracy with the gripper reaches ±10 µm, the precision is only limited by the machine itself and not by the Gecomer® tool. To proof that, a comparative measurement with a standard vacuum tool is performed as well.

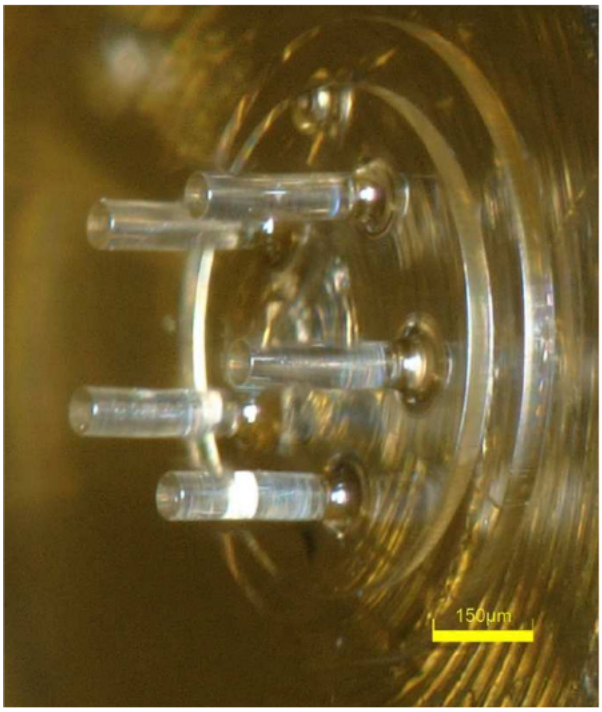

Fig. 4. Gecomer® tool with five pillars, used for the pick and place experiments.

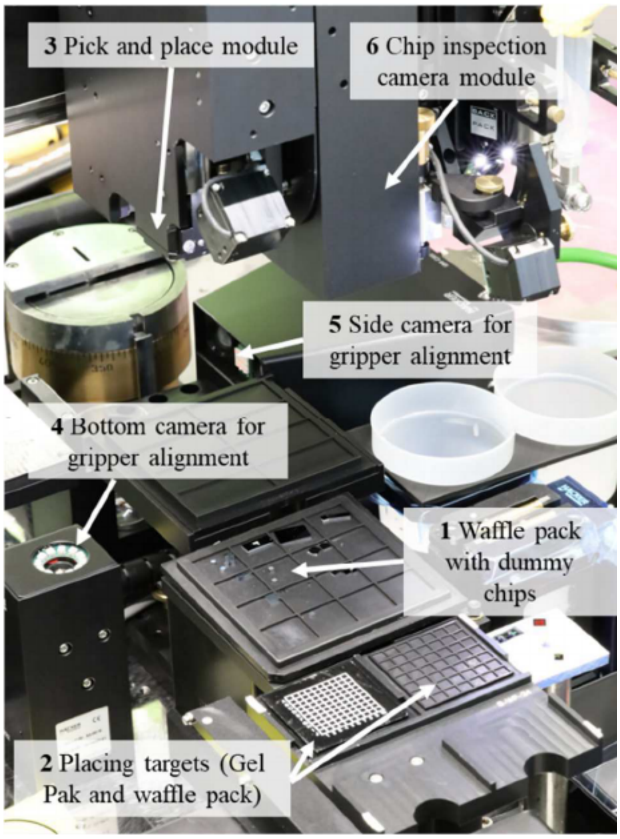

Fig. 5. Setup of the pick and place machine with the waffle pack in the middle for providing the dummy chips and the Gel Pak® and waffle pack at the bottom as placing target

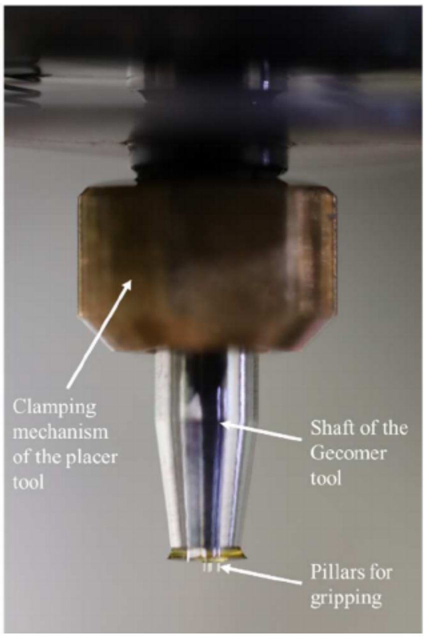

Fig. 6. Detailed picture of the tool head of the machine with the Gecomer® gripper.

The first challenge is to pick the chip from the initial waffle pack. For that, the gripper is positioned above the chip, which is to be picked. After that the pick and place head is moved down until 0.5 mm above the chip surface. From this point the head's moving speed is reduced to 0.1 mm·s^{-1}, to allow a soft touch. For a proper touching the pick and place head is programmed to move 50 µm below the chip surface level. Because of the elastic behavior of the Gecomer® tool, the pillars and the chip surface huddle against each other and the gripping mechanism, described in section II, starts. After that, the head moves slowly upwards (again 0.1 mm·s^{-1}) until he reaches a height of 0.5 mm again. This ensures, that the chip sticks to the gripper. If the movement is too fast, the chip may drop. The successful lifting of a dummy chip is shown in Fig. 7. It also illustrates the small area, which is effectively used for gripping, showing the potential for chips with large active areas and only few space for gripping.

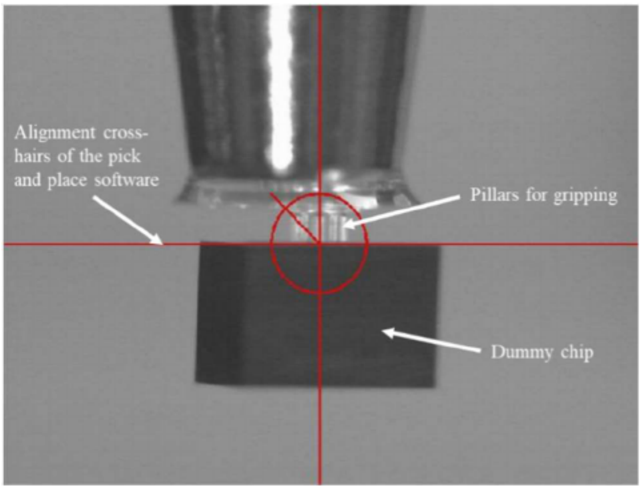

Fig. 7. Image of a dummy chip attached to the pillars of the Gecomer® tool captured with the monitoring camera built-in in the pick and place machine.

B. *Pick and place from waffle pack to gel-pak*

After lifting the chip with the Gecomer® gripper, the next challenge is to find the right parameters for placing. The chip must detach from the gripper while it must not change its position on the placing target. This could be the case if the chip briefly stays attached to the gripper and drops after lifted again.

To overcome this challenge, we used Gel Paks® as a first placing target. Since the Gel Pak® has a sticky surface, the force between chip and Gel Pak® is higher than between chip and gripper. Hence, the chip is easily released from the Gecomer® tool. This effect could also be used for a placing in wet adhesives for die bond procedures.

During the test, we varied the movement speed of the pick and place head to see, if there is any influence. For every different speed, 20 chips were picked and as mentioned above, we inspected the placing result visually and measured the accuracy. Fig. 8 shows the deviation in x and y direction for three different movement speeds.

The test reveals that most of the chips are placed with an accuracy within the machine specs of ±10 µm. Only a total of six chips does not fulfill this requirement but are still in the range of ±15 µm. Furthermore, the movement speed has no significant influence on the placing accuracy. As a result, it can be summarized, that the pick and place from waffle pack to Gel Pak® with a Gecomer® tool is working properly.

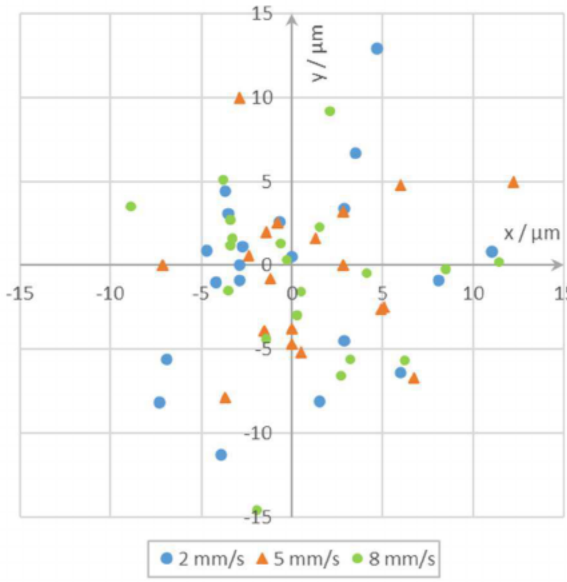

Fig. 8. Lateral deviation of placed chips for a WP-to-GP picking compared between different movement speeds of the tool head.

C. *Pick and place from waffle pack to waffle pack*

For the next test, we want to pick from a waffle pack to another waffle pack, to see whether it is possible to detach the chip from the gripper on a non-sticking surface. To release the chip, the pillars of the Gecomer® tool need to be buckled, until their surface no longer attaches to the chip surface. This is achieved by a movement of the pick and place head in z-direction towards the chip surface. For these tests we moved the tool head 150 µm further downwards after the chip touches the waffle pack, which corresponds to roughly the half of the pillar's height.

After buckling the pillars, the chip is detached from the Gecomer® tool. Nevertheless, the challenge is to move up the pick and place head without re-grip the chip again. For the 5 mm·s^{-1} speed used in the previous test, we observed "jumping" chips. These chips only detach when the pick and place head was already back in the air. Although that was only the case for the minority of the chips, we increased the speed to 50 mm·s^{-1} and 100 mm·s^{-1} to overcome this issue for all of the chips.

Again, we measured the accuracy of the placed chips. The results are shown in Fig. 9 and Fig. 10. At a first glance, it seems all placed chips are again in the range of ±10 µm for the x and y deviation, even for the 5 mm·s^{-1} speed. Only a look at an enlarged axis division (Fig. 10) shows the outliers. While for the two higher speeds all data points lie in the ±10 range, at 5 mm·s^{-1} three chips "jumped" off the Gecomer® tool, resulting in deviations up to 450 µm. Nevertheless, for 50 mm·s^{-1} and 100 mm·s^{-1} the placing is very accurate and within the machine's specs.

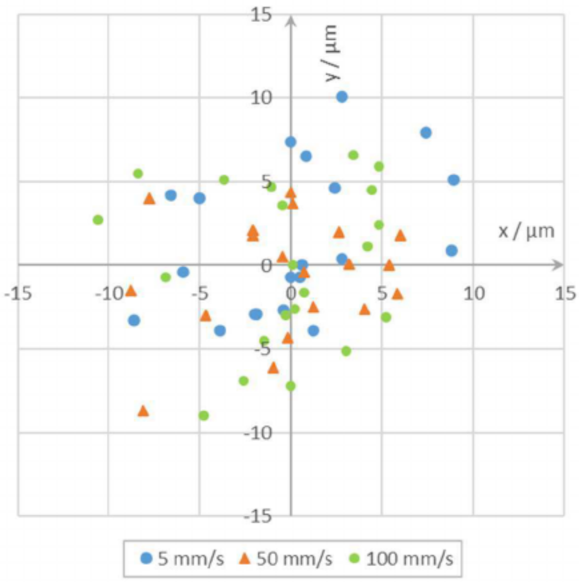

Fig. 9. Lateral deviation of placed chips for a WP-to-WP picking compared between different movement speeds of the tool head.

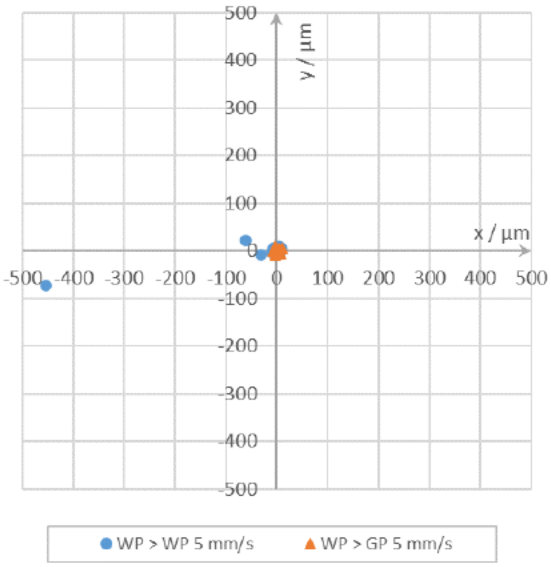

Fig. 10. Lateral deviation of placed chips compared between waffle pack (WP) and Gel Pak® (GP) as placing target; The greater axes scale reveals three outliers, which were not placed properly.

D. Comparison to standard vacuum tools

In the last experiment, we compare the placing accuracy of the Gecomer® tool to a standard pick and place tool, which uses vacuum to hold the chip. The advantage of the latter one is the easier release of the chip. Simply interrupt the vacuum and the chip is no longer attached to the tool. Since this avoids chip movement after placing, this might be beneficial for the accuracy.

Fig. 11 shows the lateral deviation of 20 chips placed with Gecomer® tool and standard vacuum tool respectively. It is revealed that there is no significant difference between the two tools, proving the pick and place process is only influenced by the machine itself and not by the used gripper.

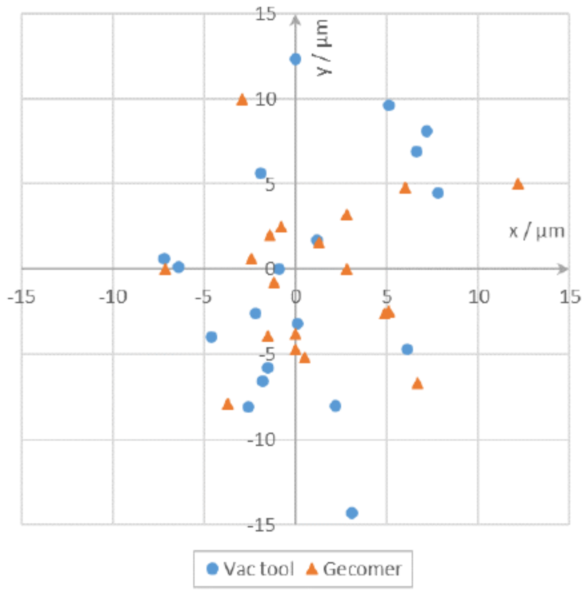

Fig. 11. Lateral deviation of placed chips compared between standard vacuum tool and Gecomer® gripper for pick and place from waffle pack and gel-Pak at 5 mm/s

E. Inspection on residues on the chip surface

The last question to be answered in this paper is, whether there are any residues or damages on the chip surface induced by the Gecomer® gripper. For that, we inspected the chip by microscope before and after the pick and place process. As shown in Fig. 12, no changes or residues on the surface are visible. Hence, the gripper is suitable to touch, e.g. on bond pads without affecting the pads.

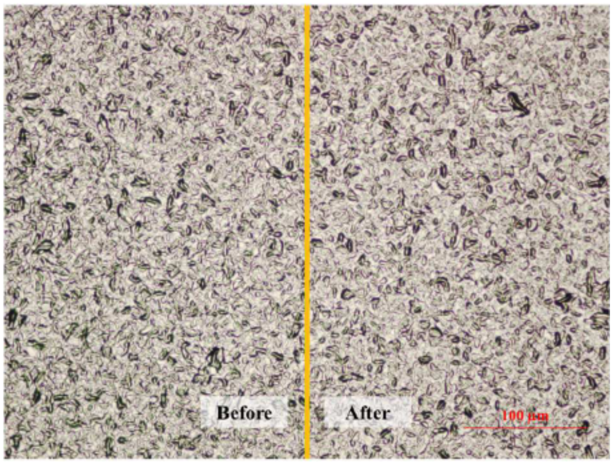

Fig. 12. Surface of the dummy chip, which can be picked with the Gecomer® gripper.

IV. Conclusion

In this paper, we introduced a vacuum-free technology for pick and place of silicon dies. To our best knowledge, it is the first time this is demonstrated without using edge-grippers. The Gecomer® tool allows for safe handling of chips and a placing accuracy at the same level as standard vacuum tools. The achieved precision of ±10 µm is only determined by the xyz-portal of the machine and is not negatively influenced by the new gripping technology. Furthermore, an advantage compared to side grippers is the compatibility to standard pick and place machines. This allows for easy changeover on established equipment.

However, the limit of the gripping technology is the dependance on the chip surface. An example can be seen in Fig. 13, which shows the surface of a dummy chip with oxide coating. The coarse-grained finish prevents a sufficient contact of the Gecomer® pillars, which is why the Van-der-Waals interactions are not developed.

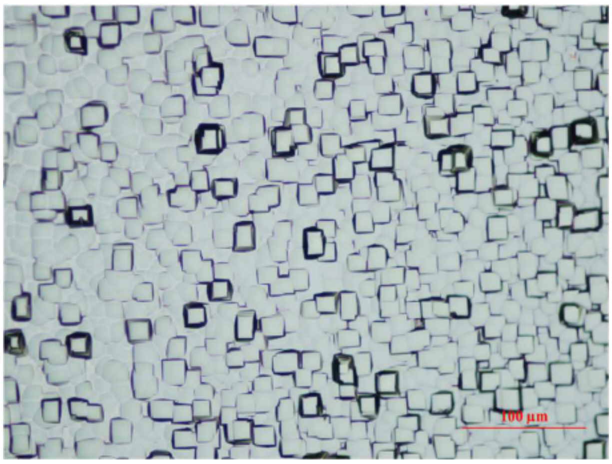

Fig. 13. Surface of a dummy chip with oxide coating, which was not pickable. The rough surface prevents a proper adhesion to the gripper.

The next step is to design a chip specific Gecomer® gripper, which is adopted to the chip layout. The idea is to align the pillars to the bond pads. Hence, the gripping is done only on the robust surface of the pads, while the sensitive MEMS parts are spared. The exact alignment is challenging and needs to be tested as well as the machine parameters for the new tool. Furthermore, the boundaries of the gripping regarding surface of the chip need to be identified.

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