Thin wafer handling methods

Christian Fischmann, **Tim Giesen** & **Steve Gao**, Fraunhofer IPA, Stuttgart, Germany

This paper first appeared in the sixth print edition of *Photovoltaics International* journal.

ABSTRACT

Despite the fall in silicon prices, wafer thickness continues to be reduced. The handling of thin wafers between 120 and 160µm is under research at the Fraunhofer IPA, where gripper-dependent and independent variables were determined as parameters for the handling process. Diverse grippers are tested on an automated test platform. Among these are grippers that are specifically designed for wafer handling, as well as others that are not but are used for wafer manipulation. The test platform includes several different test and handling equipments and utilizes critical parameters that might be required for achieving a high production rate via shortest cycle times to investigate the impact on thin wafers. The first results of the position accuracy measurement in relation to the physical movement parameters and other industrial key figures in ongoing handling research are presented within this paper.

Introduction

Without a high level of automation, neither the target of high throughput nor the demanded high quality and low breakage rate of the thin wafers can be assured. Therefore, the researchers at Fraunhofer IPA aim at developing, evaluating and demonstrating methods for the automated handling and transport of thin wafers.

With the current wafer thickness in mass manufacturing, the highest breakage rates mainly result from:

- Separation of thin wafers (the wet separation during the wafering, and the pre-separation in the cell manufacturing and the module assembly)
- Pick-and-place operations which occur before, during and after manufacturing
- Transport operations, especially from alignment functionalities
- Handling in/out of carriers, transport boxes, magazines and stackers.

In short, every production step involves the wafer being on the surface or at the corners, which can stress the sensitive and porous photovoltaic material.

To give an example from actual Fraunhofer IPA tests, wafers with a thickness of 150µm become heavily stressed and bowed during the pick-and-place operations even with the newest gripper generations. Fig. 1 shows such a pick action analyzed with a high-speed camera: with a handling cycle time of 1.5 seconds per wafer, the actual state-of-the-art wafer gets bended about 10mm on the corners before cracking.

Depending on the production principle (batch or inline processing), a multiplicity of pick-and-place operations with a very high throughput under critical physical parameters is necessary. Several grippers like, for example, the Bernoulli grippers, have been developed to overcome these challenges, and some of these have already been applied in the industry. By means of a handling prototype, tests can be carried out in the automation lab of the Fraunhofer IPA to investigate the physical limitations of the grippers. The main objective of the analysis and the evaluation is to optimize the handling of thin wafers, effectively maximizing the throughput without neglecting the reliability.

"The typical handling processes in a thin wafer production line can be modelled with a travelled horizontal distance up to 900mm."

Test platform equipment

For the experimental analysis of the gripper behaviour and the evaluation of gripper qualities, a test platform was set up at Fraunhofer IPA. The goal is to demonstrate industrial state-of-the-art conditions and to determine the future needs of automation for the photovoltaic industry. Wafer handling on the laboratory scale exemplifies an industrial wafer handling application.

The main task of this wafer handling prototype is to carry out pick-and-place operations for mono- and polycrystalline wafers. The typical handling processes in a thin wafer production line can be modelled with a travelled horizontal distance up to 900mm. The required vertical travel can be set up to 50mm. Since the industrial state-of-the-art handling rate of wafers currently levels off at approx. 1.5 wafers per second, the laboratory wafer handling should be able to operate at this rate and even at shorter cycle times.

Two linear solenoid drives manipulate the gripper in the researched workspace. According to the assembled payload, an acceleration and deceleration up to 40m/s^2 and a velocity up to 3.4m/s can be operated. The accurate linear positioning is supported by a ball monorail guidance system (Fig. 2). A feeder module prototype by AMB Automation separates dry wafers from a staple and provides the top wafer with a certain sensor-controlled altitude.

The metrology sub-system contains several sensors and valves such as a vacuum ejector, a solenoid valve, pressure sensors, an accelerometer and a thermal mass flow meter, among others. A high-speed camera allows the detailed observation of pick-and-place processes (Figs. 1 & 7). Wafer deformations and the critical behaviour of the handled object can then be evaluated separately. Furthermore, a position accuracy study is carried out by a

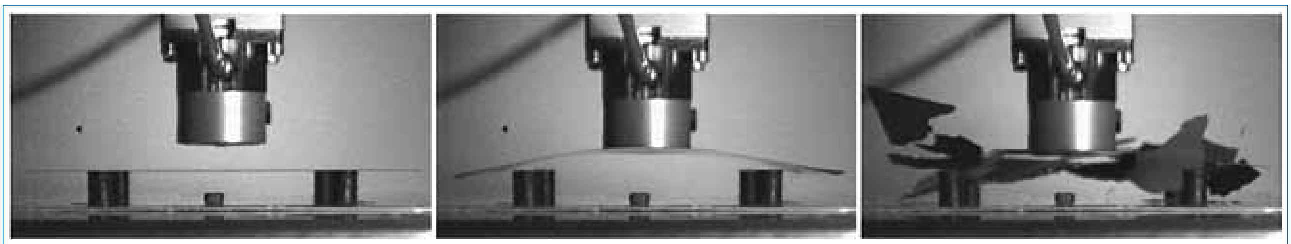


Figure 1. Wafer-gripping sequence with critical parameters.

visual displacement measurement. Gripper-dependent placement deviations can be measured accurately by as little as 20µm within an area of 1mm². An upcoming extension of the demonstration line will be a micro-crack detection instrument. The quality validation will be executed by Manz's industrial state-of-the-art system which is implemented into the control system of the test platform.

The steering and controlling of all single components was integrated via Ethernet and Profibus into one control system. The parameters setting, a log-file generation, diverse handling process adjustments and the start/stop of handling operations are executed via an adequate graphical user interface.

A further extension of the test platform will gradually turn the laboratory handling process into an industrial application. In the near future, pick-and place processes from/on conveyor belts will be analyzed. Moreover, other equipments will broaden the range of the wafer handling module. The flipping and the alignment of wafers as well as a carrier loading port will be included in the evaluation of thin wafer handling.

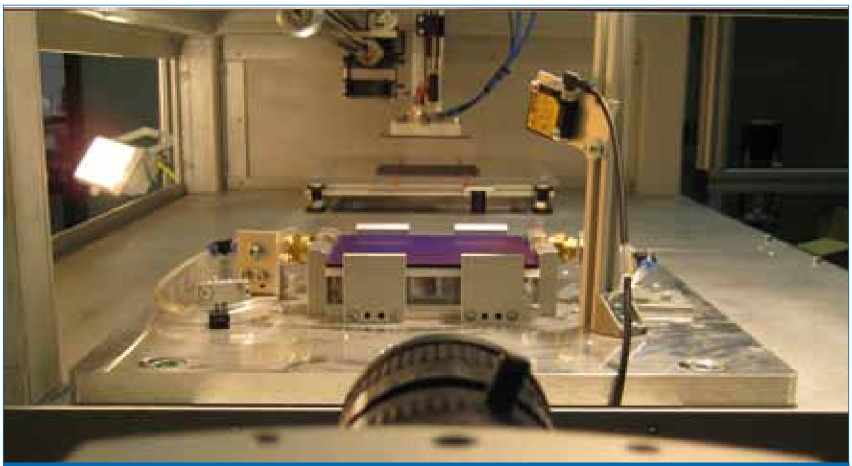


Figure 2. Two-axis handling module with gripper.

Gripper No.	Function Principle	Size (incl. adapter) [mm]	Weight incl. Adapter [g]	Direct Wafer Contact Area/Area Geometry	Features
1	Bernoulli	Ø 40 x 18 (Ø 40 x 37.5)	126	3 x 0.24cm²/punctual	Light and robust
2	Bernoulli	Ø 147 x 20 (Ø 148 x 36)	292	41.5cm²/ring-shaped	Contact area not planar
3	Bernoulli	Ø 148 x 20 (Ø 148 x 36)	301	64.5cm²/ring-shaped	Contact area not planar
4	N/A	146 x 146 x 79 (146 x 146 x 84)	485	160cm²/rectangular	Exhausting of sucked-in air Blow-off function Attenuators
5	Vacuum	173 x 153 x 74 (173 x 153 x 80)	494	3 x 0.85cm²/punctual	Designed for delta kinematic robots Blow-off function
6	Vacuum	150 x 150 x 14 (150 x 150 x 33)	555	220cm²/rectangular	Soft contact area Blow-off function

Table 1. Tested grippers from different manufacturers and their specifications.

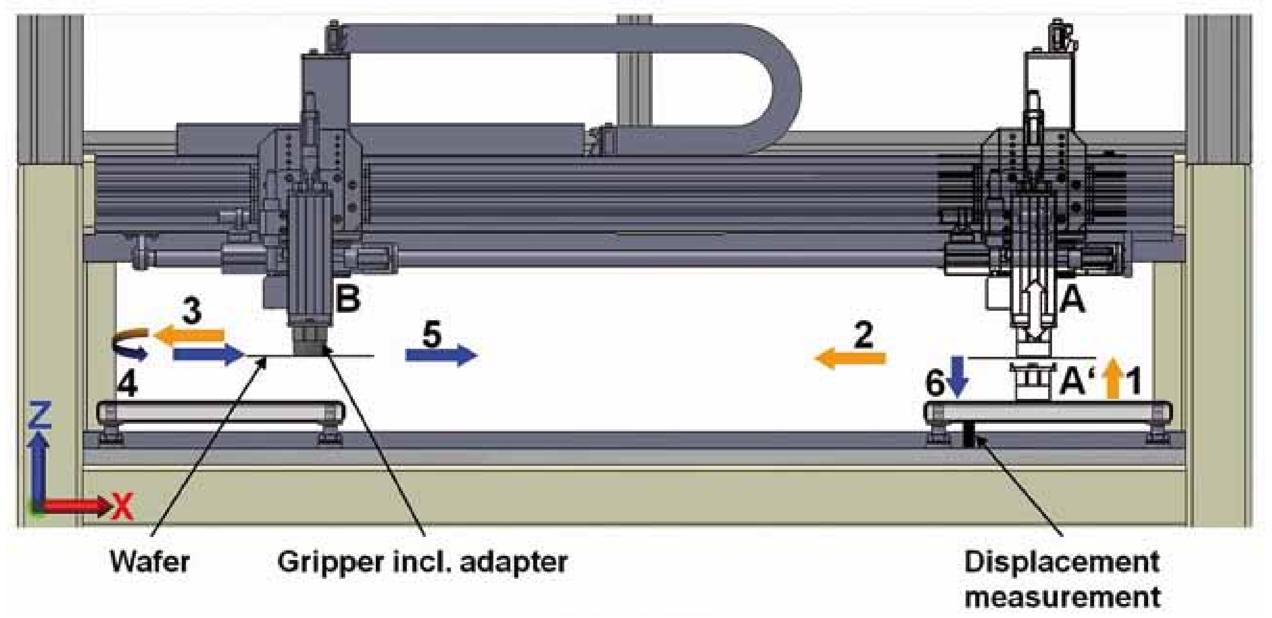


Figure 3. Exemplary procedure of a test cycle in the wafer handling module. 1. Pick-up and vertical travel; 2. Horizontal travel; 3. Stop after certain travel distance; 4. Short waiting time; 5. Horizontal return; 6. Vertical return and placement incl. waiting time.

The gripper system within the test platform has a significant influence on the thin wafers. Depending on the gripper geometry and the force-generating principle, several different gripper test cycles are performed until the optimal parameter settings are determined. In handling different thin wafers and in varying the gripper-dependent parameters of the overall system the suitability of the pairs of wafer and gripper are evaluated. Focusing strictly on the position accuracy and the intactness of the handled object allows for the optimization of economical and productive key figures. For example, the minimization of the air consumption as well as the cycle time are in turn restricted by the minimization of the breakage rate.

There are several different state-of-the-art grippers available for photovoltaic and semiconductor applications, such as those listed in Table 1, as well as tested prototypes of international partners. Further gripper developments are waiting to be tested and evaluated for market entry, reengineering and product benchmarking.

Thin silicon wafer handling means the transportation of wafers from one certain position to a required position and orientation with the least rate of damage caused and the shortest cycle times. In short, the optimal handling of wafers must be able to realize the highest rate of wafer production. In order to achieve this, many new grippers have been designed and developed in due consideration of the new requirements and challenges.

Grippers can be classified sensibly into groups by distinguishing the models on the basis of their working principles (see Table 1). The lifting force generation can be very different, even among grippers within one group.

A Bernoulli gripper gets its name from the Bernoulli law which explains the correlation between the velocity and the pressure of a fluid. An increase in velocity means a decrease in pressure. Using compressed air and an adequate gripper geometry, the object can be lifted due to the pressure reduction between the fluid stream and the object at ambient pressure. One advantage of the Bernoulli grippers for thin wafer handling is the fact that there is minimal tactile handling. According to the generated strength of the Bernoulli effect, the wafer needs to touch the gripper slightly to overcome inertia forces with static friction, especially in high-speed applications.

"Depending on the gripper geometry and the force-generating principle, several different gripper test cycles are performed until the optimal parameter settings are determined."

Vacuum grippers operate by evacuating the ambient pressure between the handling object and a suction cup. In order to generate a vacuum and therefore a lifting force it is necessary to touch the object because without it the suction cup would not be sealed and ambient air would disturb the evacuation. The size and the amount of suction cups vary up to wafer area-covering models. A blow-off function of a gripper-independent ejector enables a faster placement. There are many different vacuum grippers available that work with enormous tactile handling for wafer or cell movement.

A recent development is [2] which uses an ultrasonic sonotrode to avoid the wafer contacting the gripper surface. Ultrasonic grippers generate lifting forces by applying a vacuum. Furthermore, they use ultrasonic waves in combination with ambient air and the sonic reflecting handling object as a spacer. A clearance of a few micrometers remains between the object and the gripper. Lateral forces which are generated by a gripper manipulation are counteracted by self-centering interactions of the vacuum and compressed air. In [2], a high accuracy is achievable with accelerations up to $3.6 m/s^2$.

The electrostatic gripping principle uses electrostatic induction as a holding force. An electric field is generated by isolated electrodes, and can be used as a chuck for fixing wafers, [3].

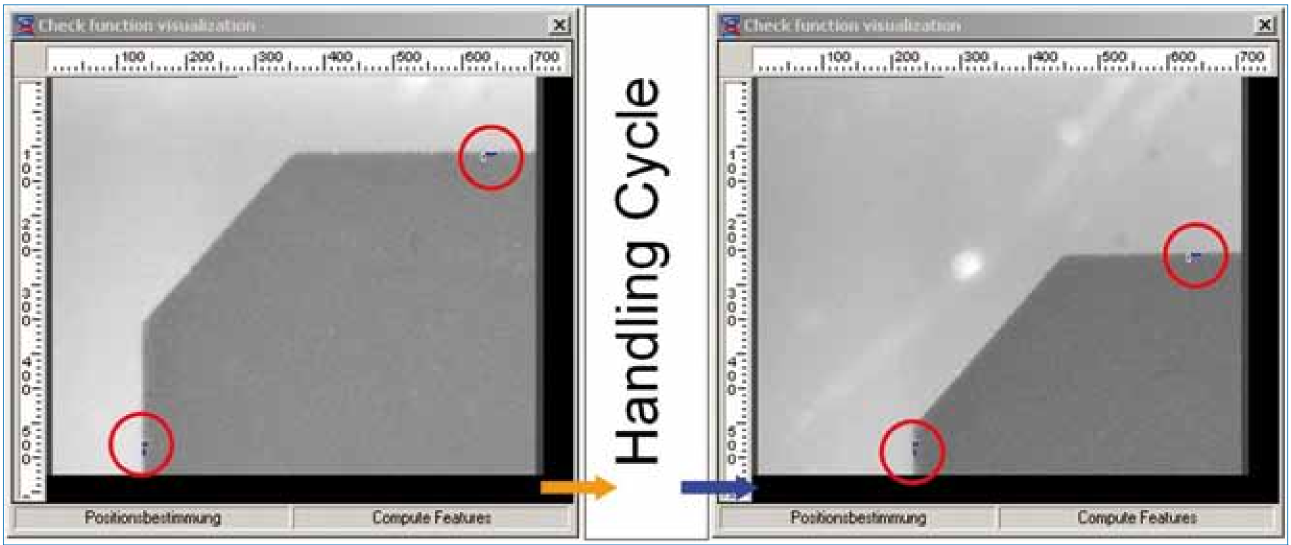


Figure 4. Position of the wafer before the test run is executed (left) and position of the wafer after the test run (right).

Handling methods and testing

The grippers shown in Table 1 were tested in a first-handling method evaluation. These grippers were primarily analyzed in terms of position accuracy and air consumption, and operated with the same cycle procedure as shown in Fig. 3.

Firstly, the program places the gripper into the specific start position A. Within the first step the gripper is moved in z-direction down to position A'. The next program command activates the pressure or vacuum valve. For the generation of gripping forces the gripper needs to wait a certain period of time, t_{pick}, at A'. A certain amount of time is needed for the pick-up process to ensure the full generation of the required gripping forces. In the following step the gripper moves in positive z-direction back to A for horizontal travelling. After a travel distance of approximately 900mm, point B is reached within the next program command. At B, the gripper waits for 100ms and then moves back to position A, before approaching A' again, at which point the active valve is deactivated. Due to the relief of pressure, a waiting time t_{place} is necessary. If the gripper allows a blow-off function, this function will be activated at that very moment. After the placement the gripper travels back to the initial position A. The gripper travels a cumulated stroke of 200mm in vertical and 1800mm in horizontal direction. The displacement of wafers, which might occur after handling, is optically measured by laboratory software and evaluated by a pre-post position comparison, shown in Fig. 4.

The accuracy of the handling system was analyzed to investigate the influence of the gripper manipulating machine. Therefore, an adapter was designed and a piece of wafer was attached to the adapter. The adapter which was assembled on the z-axis should simulate the wafer during the handling cycle. In this case the adapter is securely assembled on the machine, so that the wafer cannot slip during the transportation. The slip-off of the wafer may occur during the regular wafer transportation when the gripper carries the wafer. Instead of capturing the position of the handled wafer, the corner of the fixed wafer on the adapter was taken for the displacement measurements.

> "Oscillation of the wafer can be absorbed by a large contact area during pick-up and transportation. These oscillations may be one cause of wafer breakage."

By evaluating the pre-post comparison of the adapter positioning the deviation and thus the real accuracy of the whole system, including the measuring system and the biaxial wafer handling system, is reflected. The experiment shows that the average accuracy of the system is about 10μm for x- and y-direction. This experiment confirms the expectation that the resulting position inaccuracy of a handled wafer is mainly caused by the used gripper. A detailed analysis and evaluation of various wafer grippers will show the differences in the placement accuracy.

Results of handling tests

The grippers in Table 1 were tested and evaluated for different pressures, velocities, accelerations and distances between the gripper and the wafer during the pick-and-place operations. Due to the geometric design of the gripper, the material of the contact area and the gripping principle, the results were different. In general, the results of the experiment show that the position accuracy decreases if the acceleration or the velocity is increased. Fig. 5 shows (partial) results of the position accuracy investigation. Grippers 1 and 6 do not appear since the set suction forces were

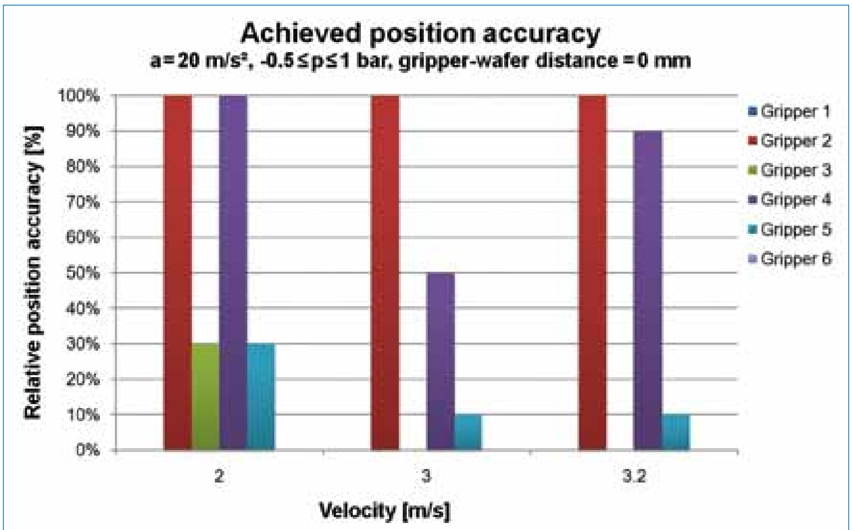


Figure 5. Dependency of restricted position accuracy and physical parameters.

insufficient in relation to the restricted position accuracy.

The results show the significant influence of the operating pressure whereas gripper 4 does not follow the general conclusion. As a result, a short cycle time is associated with an inexact gripping. The gripper tests were performed with a cycle time between 1.5 seconds to 2 seconds. The long cycle times are based on the long waiting periods during the pick-up (t_{pick} = 200ms) and the placement (t_{place} = 200ms). Short waiting times lead to slippages at the pick-up process as well as to an unregulated vacuum effect at the placement. Therefore, a short t_{pick} or t_{place} has a big influence on the position accuracy. A long cycle time can be reduced either by lowering the pressure or by using the blow-off function for the placement. If a blow-off function is applied the waiting period t_{place} can theoretically be set to 0ms.

Another point of interest is the operating pressure which is relevant not only for commercial reasons (Fig. 6). A high operating pressure is associated with high air consumption. The experiments show that in general a high operation pressure by no means results in a better position accuracy. Furthermore, a high operation pressure may lead to a fast wafer breakage with certain grippers because the wafer is highly stressed by the strong suction power. An operation pressure above 2 bar may be very harmful to the wafer if grippers 2 and 3 are applied. At 2 bar, the operation is already very loud and the position accuracies are above 400µm. A high wafer breakage rate was noted up from 3 bar. If a low operation pressure is sufficient a shorter t_{place} time is possible which again shortens the cycle time of the wafer handling.

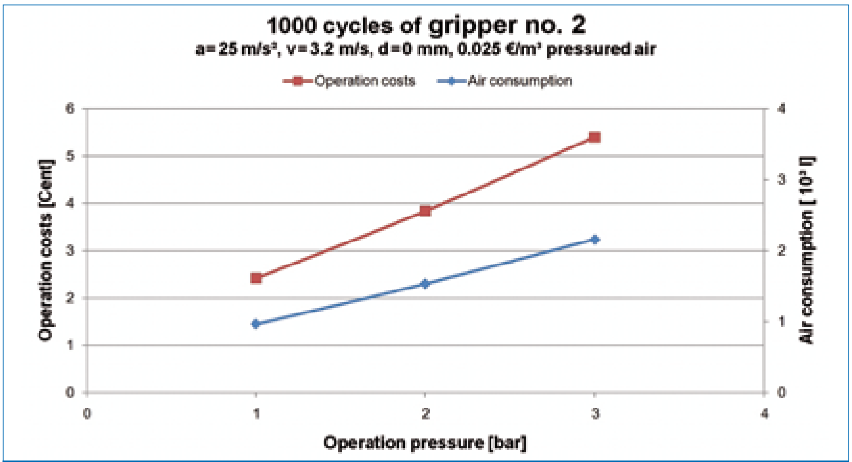


Figure 6. Relation between operation pressure, operation costs [4] and air consumption.

For vacuum grippers, a direct contact between the gripper and the wafer is necessary; otherwise the vacuum cannot be generated. Bernoulli grippers allow a variation of the gripper-wafer distance between 0mm and 3mm. However, due to a close positioning of the gripper a compressive load caused by direct contact may stress the wafer before the pick-up and the placement is performed. In addition to the high acceleration and the velocity, the risk of provoking micro-cracks or wafer breakages increases. If a certain distance between the gripper and the wafer is assured, only the suction force will affect the wafer. If the gripper-wafer distance is too large, the wafer falls down during the placement operation. Air turbulences and remaining flows of the degrading pressure can affect the position accuracy negatively if the wafer is placed by free fall. Based on that knowledge, the tested Bernoulli grippers should be operated with a gripper-wafer distance between 0.5mm and 1.5mm during the pick-up and the placement procedure.

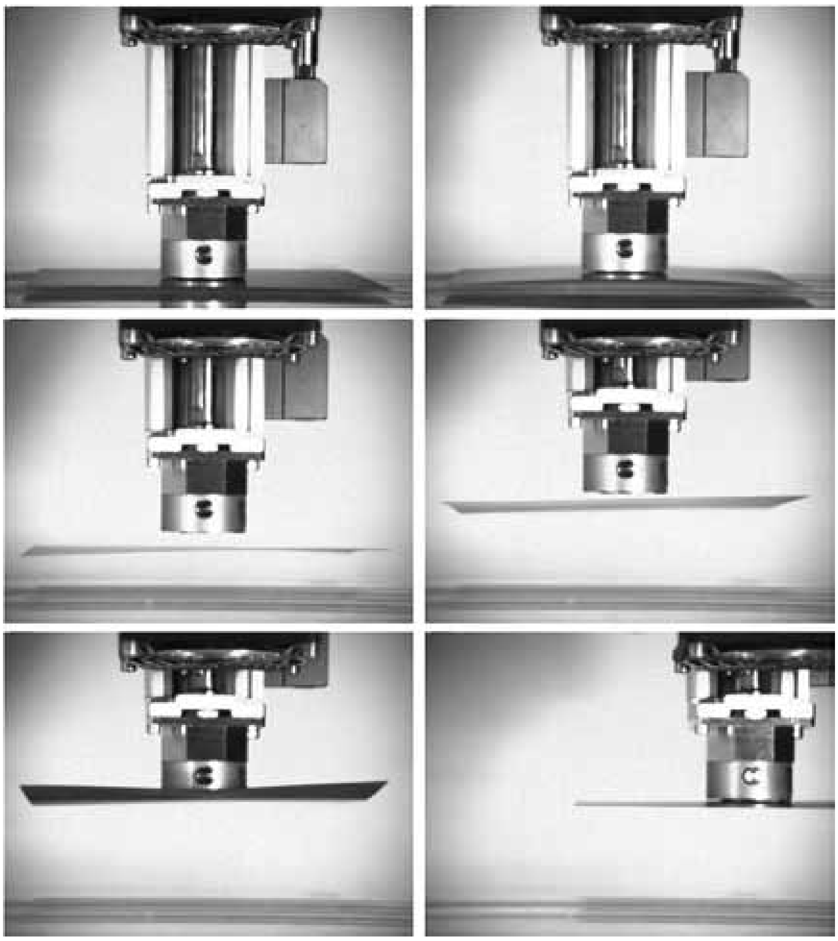


Figure 7. Moments of a pick-up procedure with a Bernoulli gripper. Where do micro-cracks occur?

A comparison of the gripper tests with respect to the gripper size shows that those with a large gripping area can be operated with lower pressure. While gripping is optimal at 3 bar for gripper 1, grippers 2, 3 and 4 can be operated at 1 bar or even lower. In addition, oscillation of the wafer can be absorbed by a large contact area during pick-up and transportation. These oscillations may be one cause of wafer breakage. Thus, the material of the contact area also has an influence on the handling of wafers. If the contact material is hard and smooth then the static friction is lower and the suction force can be quickly generated and reduced. If the material of the contact area is soft and rough, like foam, the static friction is high on one side and the handling is very gentle at the pick-up procedure. Suction force, however, can only be generated slowly because the vacuum generation needs to overcome the material structure.

Besides the advantages, there is also a disadvantage to the large-area gripper. During the placement procedure, when the gripper releases the wafer and quickly travels away vertically, the large area of the gripper causes a strong unregulated side effect. Causing a kind of vacuum, the placed wafer becomes uncontrollably sucked by the gripper and moves slightly away from the planned end position.

Summary and outlook

The present tests at Fraunhofer IPA show that even with the newest gripper generations, the wafers with state-of-the-art thickness become heavily stressed and bowed during pick-and-place operations. By means of a handling prototype, tests can be carried out in the automation lab of the Fraunhofer IPA to investigate the physical limitations of the grippers. The typical handling processes in a thin wafer production line can be modelled and further researched with a diversity of measuring instruments. Further extension of the automation handling platform will gradually turn the laboratory handling process into an industrial application. Handling tests with some state-of-the-art grippers as well as with prototype grippers have been performed, with results suggesting that a sensible use and regulation of the operating pressure can affect the handling cycle time positively. Testing continues to be carried out on textured 120µm wafers and evaluation results are expected soon.

Acknowledgements

This work is co-funded by the **European Commission** within the 6th Framework Programme. Thanks to all partners of the **HighSol-project consortium** for their contributed work and input.

Further information can be found on www.highsol.eu.

References

[1] Reddig, K. 2009, "Overview of automation in the photovoltaic industry", *Photovoltaics International*, 4th Edition, pp. 18-29.

[2] Schilp, M. 2007, "Auslegung und Gestaltung von Werkzeugen zum berührungslosen Greifen kleiner Bauteile in der Mikromontage", Diss. TU München.

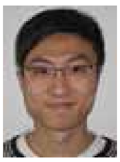
[3] ProTec Carrier Systems GmbH, information available online at http://protec-carrier-systems.com/cms/upload/Download/Broschre_Racket.pdf.

[4] Festo AG & Co. KG: "Energieeffizienz in pneumatischen Anlagen", information available online at http://p31726.typo3server.info/fileadmin/redakteure/energie_arena/pdf-Dateien/Antriebe_Juergen_Billep_Pneumatische_Anlagen.pdf.

About the Authors

Christian Fischmann is a project manager at Fraunhofer IPA. He joined the IPA in 2005 after having finished his studies in mechanical engineering at the University of Applied Sciences Konstanz. He focuses on the development and the evaluation of logistics concepts and also has experience in equipment automation in both the semiconductor and photovoltaic industry.

Tim Giesen received his diploma degree in industrial engineering from the University of Applied Sciences Kaiserslautern in 2008. After graduation he joined Fraunhofer IPA in the department of ultraclean technology and micro-manufacturing. He works in the field of production engineering, material flow automation and product development mainly in the photovoltaic industry.



Steve Gao completed his diploma thesis at Fraunhofer IPA where he worked on the analysis and the evaluation of handling issues for photovoltaic wafers. While studying mechanical engineering at the University of Stuttgart, he focused on industrial management and control technology.

Enquiries

Tim Giesen
Fraunhofer IPA
Nobelstrasse 12, 70569 Stuttgart
Germany

Email: giesen@ipa.fraunhofer.de