INVESTIGATIONS ON THE IMPACT OF WAFER GRIPPERS ON OPTICAL AND ELECTRICAL PROPERTIES OF ALKALINE TEXTURED AND A-SI PASSIVATED SURFACES

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ABSTRACT: Automated wafer handling is inevitable during the production of crystalline silicon solar cells. Additional to the risk of wafer breakage, the influence of wafer handling devices on the optical and electrical properties of the solar cell proofs to be of great importance. This work investigates the influence of different wafer grippers on the optical properties of grown random pyramids as well as their impact on the quality of hydrogenated amorphous silicon (a-Si) passivation layers. The homogeneity of the random pyramids is characterized by examination of scanning electron microscopy (SEM) images and reflectance measurements. The influence of the wafer grippers on the electrical properties is investigated by calibrating quasi-steady-state photoconductance (QSSPC) measurements to photoluminescence (PL) images. We find that using grippers which distribute their exerted force on a larger area of the wafer surface provides better optical and electrical properties than using grippers with smaller, locally defined contact areas.
Keywords: Wafer, Handling, Random Pyramids, Alkaline Texturing, a-Si, Passivation

1 INTRODUCTION

Pick and place operations are an integral part of industrial solar cell manufacturing lines. The brittle solar wafers need to be handled with high speed to achieve a high throughput, but at the same time with the least mechanical stress possible. Especially on mono-crystalline silicon material another requirement becomes important: a low contamination rate of the wafer surface. Alkaline surface texturing of monocrystalline wafers as well as the growth of passivation layers, especially of a-Si layers for hetero junction solar cells, highly depend on a clean wafer surface [1, 2]. In this work we investigate the influence of different wafer grippers on the homogeneity of alkaline textured surfaces as well as their influence on the passivation quality of a-Si layers.

2 EXPERIMENTAL

For the characterization of the impact of wafer grippers on silicon surfaces, wafers are handled with four different gripping principles as shown in Fig. 1**.**

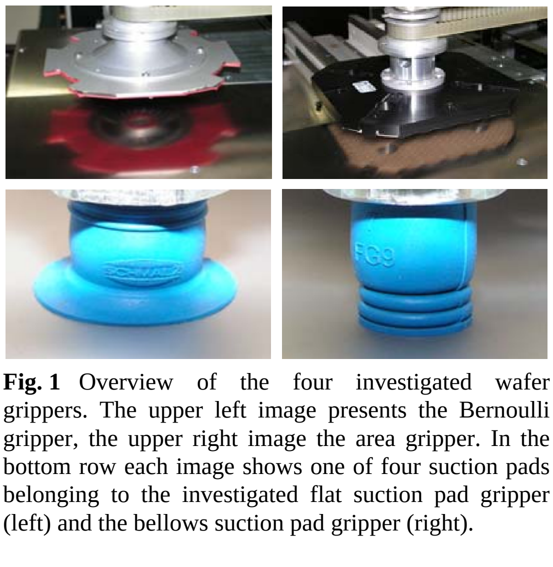

Fig. 1 Overview of the four investigated wafer grippers. The upper left image presents the Bernoulli gripper, the upper right image the area gripper. In the bottom row each image shows one of four suction pads belonging to the investigated flat suction pad gripper (left) and the bellows suction pad gripper (right).

One of the grippers is employing Bernoulli's principle; another one is an area gripper with the contact surface material PEEK (Polyetheretherketone), which is a standard material in the semiconductor industry where a low surface contamination is especially important. Furthermore, two elastomeric suction pad grippers were evaluated, a flat suction pad gripper with a supporting structure as well as a bellows suction pad gripper. Fig. 2 shows the two different experiments carried out to investigate the impact of the four different handling devices presented in Fig. 1 on the optical and electrical properties of monocrystalline silicon solar wafers.

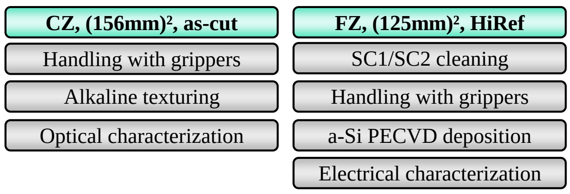

Fig. 2 Schematic overview of the performed process sequences for the optical and the electrical investigation of the influence from handling operations to wafer surfaces.

For the optical investigation as-cut p-Type czochralski (CZ) grown silicon wafers with a thickness of 180 µm were handled with each gripper before alkaline texturing. The handling was carried out within an industrial wafer handling machine. There the gripper takes the wafers, which are stacked on each other in an automation wafer box, and positions them on a conveyer band where each wafer is laser marked. An identical gripper takes the wafers and loads them into a wet chemistry automation carrier to be textured in an alkaline bath of KOH/IPA. Then the influence of the handling device on the homogeneity of the random pyramid growth during alkaline texturing was characterized optically.

For the electrical investigation 1.9 Ωcm p-Type float-zone (FZ) wafers with a HiRef surface and a thickness of 250 µm were used for the fabrication of symmetrical lifetime samples. First, the wafers were labelled and underwent a SC1/SC2 cleaning to diminish possible surface contamination. Shortly after the cleaning step each wafer was handled with one of the four investigated wafer grippers. In contrast to the CZ wafers the FZ wafers were held by the gripper and are directly placed back into the carrier. They were not placed on the conveyer band of the handling machine, as possible contamination of the band would have an unwanted influence on the surface recombination velocity. After handling, both sides of the wafers were covered with a 20 nm thin layer of a-Si within an industrial-type PECVD machine. In contrast to surface passivation with typical silicon nitride layers, a-Si layers do not feature a large amount of fixed charges. Hence, the wafer surface is more sensitive to contamination or exerted forces.

Both process sequences represent industrially relevant handling operations. Alkaline texturing is usually carried out in wet-chemical batch etching machines where handling is needed to load the wafers into a carrier. Influences of the handling on the homogeneity of the textured surface of the wafer need to be avoided. Likewise, before the deposition of passivation layers, wafers need to be handled and loaded onto the tray which is supporting the wafers during the deposition process. This work also takes a look on the influence of handling operations on the a-Si passivation quality.

3 OPTICAL CHARACTERIZATION

After the handled wafers were alkaline textured the morphology of the wafers' surface was evaluated with optical characterization methods. Fig. 3 is showing images of four wafers taken with a camera based inline vision system.

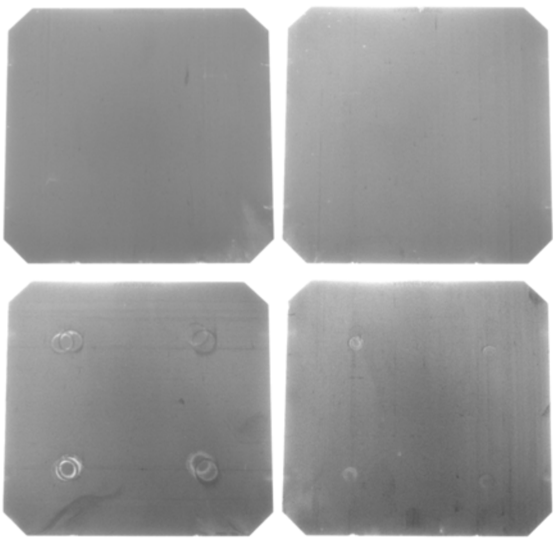

Fig. 3 Surfaces of the handled CZ wafers after alkaline texturing. The upper left image is showing the wafer handled with the Bernoulli Gripper, the image on the upper right the wafer handled with the area gripper. In the bottom row the left wafer was handled with a flat suction pad gripper, the right wafer with a bellows suction pad gripper.

The wafers which were handled with a Bernoulli gripper or an area gripper do not show any visible influence on the homogeneity of the alkaline texture. No handling-induced pattern can be seen with the naked eye. In contrast, on the wafers handled with a suction pad gripper distinct circles can be observed. These marks (shown in Fig. 3 on the bottom left) are not visible before the texturing process. When the wafer is handled with the bellows suction pad gripper, marks of the grippers can be seen as well, but not as pronounced as with the flat suction pad gripper. Fig. 4 and Fig. 5 take a closer look on the area where the flat suction pad gripper touched the wafer surface with the SEM.

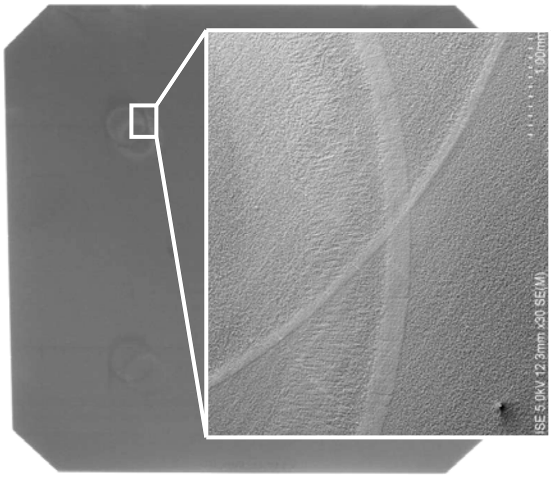

Fig. 4 SEM image of a 30x-magnified section of the wafer surface where the crossing marks of two handling operations with the flat suction pad grippers are observed. The brighter areas indicate a difference in pyramid growth and a higher reflection compared to the unhandled areas.

The magnified image in Fig. 4 shows the cross section of two marks caused by handling with a suction pad gripper. The marks appear brighter than the untouched wafer surface, which indicates a difference in pyramid growth and a higher reflection. Fig. 5 displays a 4000x-magnification of two areas on the same wafer. The top image represents random pyramids on an untouched wafer surface, the bottom image shows the wafer surface where the suction pad gripper left a mark.

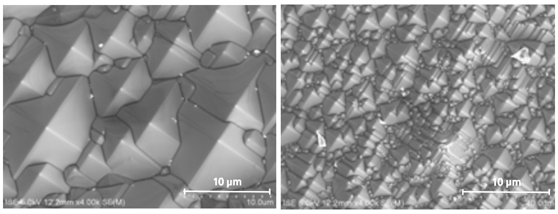

Fig. 5 SEM pictures of the surface of the same alkaline textured wafer at 4000x-magnification. The left image shows an unhandled wafer area. The right image shows an area where the flat suction pad gripper touched the wafer surface before alkaline texturing and smaller random pyramids can be observed.

Fig. 5 reveals a substantial difference in pyramid growth in the wafer area where the gripper touched the wafer before alkaline texturing. A homogeneous alkaline textured wafer surface features random pyramids with a typical edge length of 4 to 6 µm as shown on the upper image. In previously handled areas the biggest pyramids do not exceed an edge length of 2 µm. It can also be seen that many more, even smaller pyramids evolve between the 2-µm-sized pyramids leading to high distribution in pyramid size. This effect results in a higher weighted reflection on these areas. To quantify the influence of different pyramid growth, spectrally weighted reflection measurements from 250 to 1200 nm with an extra-polation from 900 nm [3] were carried out on handled as well as on unhandled areas of the investigated wafer surfaces.

Table 1: Spectrally weighted reflection of differently handled wafer areas

Wafer gripper	Measuring position	Weighted reflection
Bernoulli gripper	Handled area, wafer centre	12,2 %
Area gripper	Handled area, wafer centre	12,3 %
Flat suction pad gripper	Unhandled area	12,0 %
	Handled area	12,7 %
Bellows suction pad gripper	Unhandled area	12,0 %
	Handled area	12,8 %

The reflection measurements confirm that wafer areas being exposed to a gripper before alkaline texturing show an increase in reflectivity.

4 ELECTRICAL CHARACTERIZATION

The characterization of the influence from the wafer grippers on the electrical properties of the wafers was carried out by a PL imaging [4] setup, which is described in Ref. [5]. To calibrate PL images to minority carrier lifetime the procedure presented in [5, 6] is used. A generalized QSSPC [7] measurement was carried out on a homogeneous sample area on one of the 250 µm thick FZ wafers with a base resistivity of 1.9 Ωcm. The centre area from the bottom left wafer in Fig. 6 is used as calibration area, where a minority carrier lifetime of 2530 µs is measured. The spatial averaged PL intensity of the same area is calibrated to carrier lifetime using a scaling factor. Applying a linear fit of minority carrier lifetime to PL intensity, all samples are scaled to lifetime. This procedure is feasible as all wafers are uniform in doping level and surface morphology. If this was not the case more sophisticated approaches [8, 9] are to be applied. The calculated spatially resolved carrier lifetime maps are show in Fig. 6.

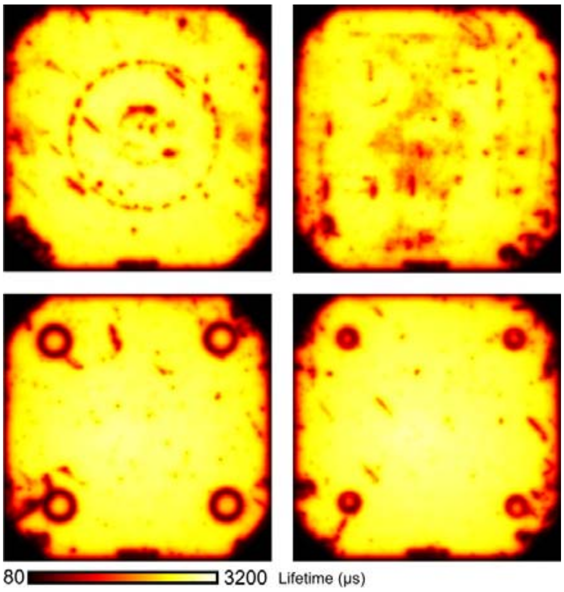

Fig. 6 Lifetime-calibrated PL images of handled FZ wafers with a-Si coating. After SC1/SC2 cleaning, the wafers were handled by the grippers and then coated with a-Si on both sides before PL measurement. The wafers are arranged in the same order as in Fig. 3.

The images in Fig. 6 show a carrier lifetime reduction at the positions where the wafers' surface has been touched by the handling devices. Similar to the observation of optical characterization, the most prominent effects are found at the contact areas of the flat suction pad and the bellows pad gripper. Even with the usage of a conceptually non-contact handling device like the Bernoulli gripper, clearly visible marks appear at the contact points, where accelerative forces were exerted. The area gripper shows a slight lifetime reduction over the whole contact area. On all images small spots and scratches with reduced carrier lifetimes can be observed in addition to the gripper related imprints. These areas with reduced lifetime are caused by manual handling or by small dust particles on the wafer surface which can hardly be avoided during processing. This becomes very obvious on the edges and the corners of the wafers, where the influences of carriers and tweezers used during handling can be observed. Because of the the influence of manual handling as well as to possibly varying passivation quality of the a-Si layer deposition between the different wafers it is not feasible to simply compare the absolute lifetime values of the samples. Thus, to extract the influence of the wafer grippers on the area-weighted average minority carrier lifetime τ_{avg}, the lifetime of areas with gripper induced damage is analyzed in relation to the lifetime of an untouched reference area on the same wafer. To calculate of the average lifetime values τ_{avg} Eq. 1.is used

$$\tau_{avg} = \left(\frac{1}{A} \cdot \sum_{N} A_i \cdot \frac{1}{\tau_i} \right)^{-1} \qquad \textbf{Eq. 1}$$

with A being the total investigated area and A_i being the area (of a pixel) having the lifetime τ_i.

The green rectangle on the left image in Fig. 7 displays the used reference area for the investigated PL image of the wafer handled with the Bernoulli gripper.

The blue circle in the right image in Fig. 7 shows the area where the Bernoulli gripper was holding the wafer. The marked areas within the circle are neglected because we assume that the lowered PL signal of these areas is not induced by the handling device itself but by manual handling for instance. The same procedure is performed with all images shown in Fig. 6.

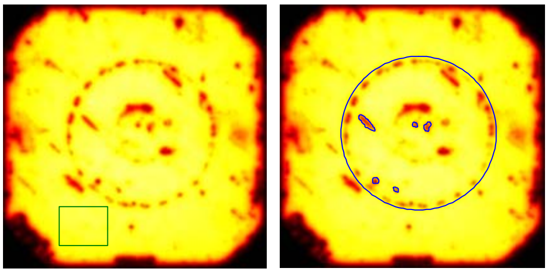

Fig. 7 Two PL images of the same FZ wafer after handling with a Bernoulli gripper. The green rectangle on the left indicates the unhandled reference area and the blue circle on the right indicates the gripper-handled area on the wafer surface. These areas are used for the calculation of the area-weighted average minority carrier lifetime τ_{avg}.

After determining the position for the reference area and the area with gripper-induced damage, Eq. 1 is used to calculate the average lifetime τ_{avg} for each area. The results are shown in Table 2.

Table 2: Calculated area-weighted average minority carrier lifetimes τ_{avg} of the unhandled and handled wafer areas

Wafer gripper	**τ_{avg} of unhandled reference area**	**τ_{avg} of handled area**
Bernoulli gripper	2280 µs	2170 µs
Area gripper	2180 µs	2090 µs
Flat suction pad gripper	2350 µs	1150 µs
Bellows suction pad gripper	2460 µs	1220 µs

The results reveal that areas touched by a flat suction pad or a bellows suction pad cup gripper suffer from a significant lifetime drop of approximately 50 % in contrast to the reference area on the same wafer. The lifetime drop in areas touched by a Bernoulli or an area gripper is only around 5 %. It is to note that for flat suction pad and bellows pad grippers the total area with reduced lifetimes is considerably smaller compared to Bernoulli and area grippers and the remaining area without gripper-induced damage is much larger. To analyse the impact of handling on the average lifetime value of the whole wafer, τ_{avg} of the reference area is scaled to the whole wafer area where no gripper influence is found. Fig. 8 displays two histograms with the normalized lifetime distributions.

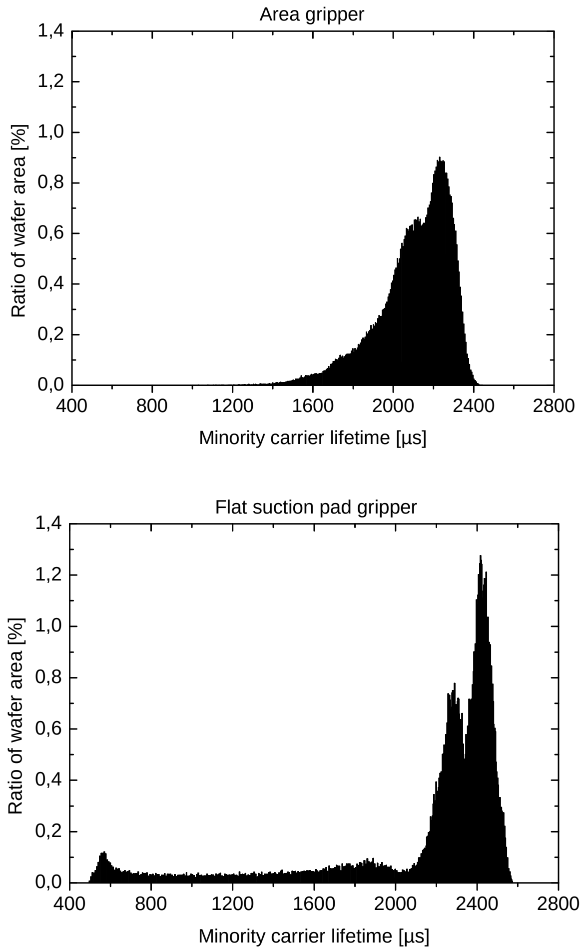

Fig. 8 Lifetime-distribution of the wafers of area gripper and flat suction pad gripper. The distributions are calculated using the original gripper-handled area and the remaining wafer area, for which the lifetime τ_{avg} of the unhandled reference area is assumed to correct for dust and scratches.

The upper histogram illustrates that there are almost no areas with lifetimes below 1400 µm when using the area gripper. The Bernoulli gripper shows a similar lifetime distribution (not shown). In contrast, the flat suction pad gripper causes reduced lifetimes at the contact points down to approximately 600 µs. The areas with lifetimes larger then 2200 µs are more abundant though, which is seen as a narrower distribution and higher counts compared to the histogram of the area gripper.

Here, the important question is: What is having a stronger influence on the carrier lifetime, a small lifetime reduction on a large area or a substantial lifetime reduction on a small area? To answer this question, we calculate the average lifetime τ_{avg} with Eq. 1 of the whole wafer by using the corrected lifetime distributions presented in Fig. 8 and compare it to the lifetime of the reference area of the concerned wafer. Table 3 displays the relative lifetime loss of the handled wafers.

Table 3: Calculated relative lifetime reduction using different grippers.

Wafer gripper	**τ_{avg} of unhandled reference area**	**Corrected τ_{avg} of full wafer**	**Lifetime loss**
Bernoulli gripper	2280 µs	2250 µs	-1.3 %
Area gripper	2180 µs	2130 µs	-2.3 %
Flat suction pad gripper	2350 µs	2110 µs	-10.2 %
Bellows suction pad gripper	2460 µs	2350 µs	-4.5 %

The results in Table 3 indicate that the investigated handling devices which exert their holding force on locally defined areas induce more damage to the wafer surface than the handling grippers that exert their holding force on a larger wafer area and thus lead to a higher relative lifetime loss regarding the full wafer area.

We must note that with the technique applied here the results in lifetime loss can vary depending on the manually picked reference area and the subtracted non-gripper induced damaged zones within the gripper area, which possess lowered lifetimes due to other influences. But a clear tendency for the advantage of Bernoulli and area gripper is noticeable. Additionally it is to remark that the diffusion length of free carriers is depending on the carrier lifetime and thus on the silicon material quality and doping. Hence, the overall influence of a localized relatively poor area increases for lowly doped and high-quality material.

5 SUMMARY

We investigated the influence of four different wafer grippers on the pyramid growth during alkaline texturing as well as their impact on a-Si surface passivation quality. One of the grippers is employing Bernoulli's principle; another one is an area gripper with the contact surface material PEEK. Furthermore, two elastomeric suction pad grippers were evaluated, a flat suction pad gripper with a supporting structure and a bellows suction pad gripper.

In contrast to the other two models Bernoulli and area grippers apply the pressure more evenly over a wafers surface and contact contamination is reduced, which causes a more homogeneous pyramid growth when applying alkaline texturization after handling. The application of flat suction pad and bellows pad gripper causes clearly visually observable marks of the grippers' suction pads after texturization. In the area of these marks the random pyramids grown by alkaline etching possess significantly smaller edge lengths and an increase in size distribution of the pyramids. This leads to a higher weighted reflection in handled areas compared to non-handled areas.

PL measurements were carried out for the electrical characterization of the influence of the handling devices on the passivation quality of a-Si layers on FZ wafers. The PL signal intensity was lifetime calibrated by means of QSSPC measurements on the same wafer area. Area-weighted average minority carrier lifetimes were calculated for handled and unhandled areas. The electrical characterization of the influence caused by the handling devices on the a-Si passivation quality reveals areas with reduced minority carrier lifetimes for all investigated handling devices. The minority carrier lifetimes of the gripper handled areas were compared with areas where no handling damage occurred. The Bernoulli grippers and the area grippers which use a wide-spread contact zone showed a lifetime reduction of approximately 5 % within the gripper modified area. The wafer grippers with a relatively small and defined contact area reduce the carrier lifetime by more than 50 % within that small area. Considering the lifetime loss over the whole wafer area the results indicate an advantage using Bernoulli or area gripper.

6 ACKNOWLEDGEMENTS

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