APPROACH TO CLARIFY THE CAUSE OF HANDLING DEFECTS IN SILICON HETERO JUNCTION CELL PRODUCTION THROUGH THE INTERPLAY OF DIFFERENT IMAGING TECHNIQUES

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ABSTRACT: Within this paper, a systematic approach will be presented to clarify the origin of locally reduced carrier lifetime caused by conveyor belts and vacuum grippers used in current photovoltaic mass production. The most sensitive handling step in silicon heterojunction production is between wet-chemical cleaning and amorphous-Silicon (a-Si) layer deposition by plasma enhanced chemical vapor deposition (PECVD). In this state the wafer surface should be clean, defect-free and H-terminated what should not be altered by the automation. The handling takes place at room temperature before first side a-Si layer deposition and at elevated temperatures, resulting from residual heat of the previous deposition, before second side deposition. This paper focuses on the interplay of different imaging techniques to identify the cause of conveyor belt and gripper induced locally reduced carrier lifetime. Photoluminescence imaging (PL) is used to display the electrical properties of the passivated silicon surface in a spatially resolved manner. In addition micro photoluminescence imaging (µ-PL) images were taken to examine details in a small area. These images are applied to navigate to the handling system induced defects on the wafer surface by image navigation in a scanning electron microscope (SEM). At the end of the investigation chain, electron dispersive X-ray spectroscopy (EDX) is used to analyze the found irregularities concerning their chemical composition.
Keywords: a-Si, Silicon Heterojunction, Automation, Handling Induced Defects

1 INTRODUCTION

Surface sensitive cell concepts based on passivated selective contacts are expected to gain significantly in market share within the next decade, in parallel, the throughput of common industrial production equipment will further increase to values above 7000 wafers per hour [1]. Hence, it is necessary to thoroughly analyze and optimize the automated transfer of wafers between process steps. So far, the major challenge of wafer handling in photovoltaic mass production is the gentle transport, in terms of yield losses, at very high speed [2]. For highly surface sensitive cell concepts like silicon heterojunction the requirements increase concerning the purity and nature of the silicon surface, which becomes later the interface between the silicon base substrate and the passivation layer. As a starting point, a clean, defect-free and specifically H-terminated silicon surface is necessary prior passivation [3]. To maintain these interface requirements, a new challenge in handling photovoltaic substrates is added: the handling system, mostly consisting of vacuum- or Bernoulli-grippers and conveyor belts, must not affect the sensitive cleaned wafer surface. This applies not only for wafers handled at room temperature (RT) before first side deposition but also at elevated temperatures, resulting from residual heat of the previous deposition, before second side deposition. In order to avoid such affections, contamination and surface defects induced by the handling system should be traced back to their origin.

This paper presents a method to assign the causes of the influence of grippers and conveyor belts under different conditions, including temperature and grasping pressure variations, towards a-Si(i) passivation quality through the interplay of different imaging techniques.

2 EXPERIMENTAL AND METHODS

2.1 Experimental

A minimum of four textured n-type Cz-Si wafers per group with a thickness of approximately 160 µm were handled at RT or at elevated temperatures below 200 °C between wet chemical treatment and the passivation with intrinsic amorphous silicon (a-Si(i)). For wafers from Group A (Figure 1) and Group B (Figure 2) handling took place at an industrial handling system for the loading and unloading of trays. In Figure 3 a scheme that indicates how and at which position the wafers are handled by vacuum grippers and conveyor belts inside an industrial handling system is depicted. Before passivation the wafer gets unloaded from a chemical carrier, transported by conveyor belts, picked by suction cups and placed onto a tray. For Group A automated handling was only done before first a-Si deposition. For Group B wafers have been handled cold before first a-Si deposition at the first side and with residual heat after a-Si deposition of the first side before a-Si deposition of the second side.

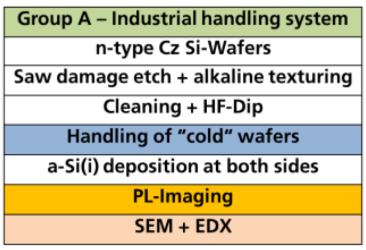

Figure 1: Experimental procedure group A.

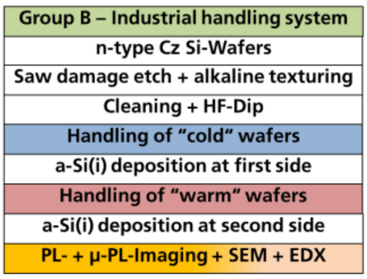

Figure 2: Experimental procedure group B.

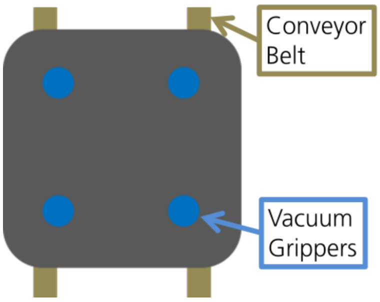

Figure 3: Scheme that indicates how and at which position the wafers are handled by vacuum grippers and conveyor belts inside an industrial handling system.

For wafers from Group C (Figure 4) handling took place at a test system built for the evaluation of different grasping devices.

Group C – Test system
n-type Cz Si-Wafers
Saw damage etch + alkaline texturing
Cleaning + HF-Dip
Handling of wafers at RT, 100°C, 150°C and 200°C
a-Si(i) deposition at both sides
PL-Imaging
SEM + EDX

Figure 4: Experimental procedure group C.

Within the test system (Figure 5) a wafer can be automatically picked with a defined air pressure, be moved in x- and z-direction and be heated precisely to a desired temperature. To avoid scratches or particles from an underlay, the wafer gets picked off a frame in which only the substrate edges are in contact with the underlay. The picking is done by four suction cups with inlays fabricated out of Polyetheretherketone (PEEK), which is a standard material in the semiconductor industry where a low surface contamination is especially important. In previous work [4] it was shown that a-Si passivation defects resulting from grippers are mainly caused by particle transfer and a clean gripper surface is indispensable. Therefore the inlays have been carefully cleaned before the experiments.

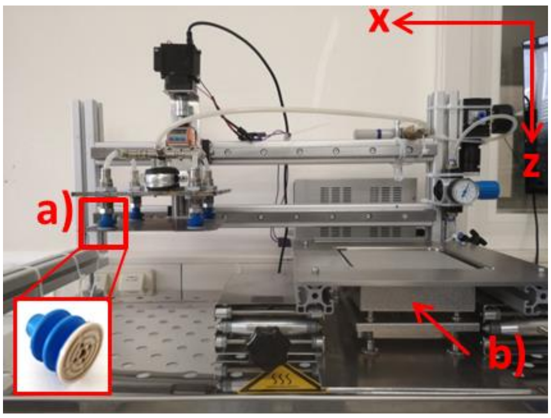

Figure 5: Photograph of the test system for different grasping devices. a) Four suction cups with PEEK inlays grasp the wafer. b) Precision hotplate for exact, regulated temperatures and evenly distributed heat, including corners and edges.

2.2 Methods

Photoluminescence imaging (PL) is used to display the electrical properties of the passivated silicon surface in a spatially resolved manner. The passivation quality of wafers which have undergone the same process sequence, however, are subject to certain fluctuations, such as e.g. waiting times or slightly changed process conditions during cleaning or depositions. Nevertheless, in order to be able to qualitatively compare these wafers, it is advisable to standardize the obtained PL images. In this work, the luminescence intensity assigned to the individual image pixels is normalized to a range between in each case 10% of the global maximum and minimum values. After the first PL measurement, the investigated wafer gets marked (Figure 6) by manual scraping and a second PL measurement is applied.

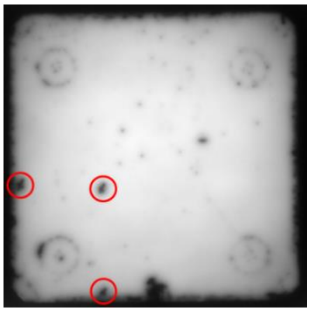

Figure 6: PL image of a marked wafer, with circled marks as a guide to the eye

These obtained images with the manual marks are used to navigate to the handling system induced defects on the wafer surface by image navigation in a scanning electron microscope (SEM). At the end of the investigation chain, electron dispersive X-ray spectroscopy is used to analyze the found local irregularities concerning their chemical composition. To examine details in a small area and to overcome the navigation limiting lifetime smear micro photoluminescence imaging (µ-PL) images were taken. The obtained images have been measured with a focused laser excitation at a wavelength of 905 nm at a spatial lateral resolution of 20 µm and have a size of 7.5 mm x 20 mm.

3 RESULTS AND DISCUSSION

3.1 Handling of wafers at RT (Group A)

A resulting PL image of a wafer handled at RT by the industrial handling system is shown in Figure 7.

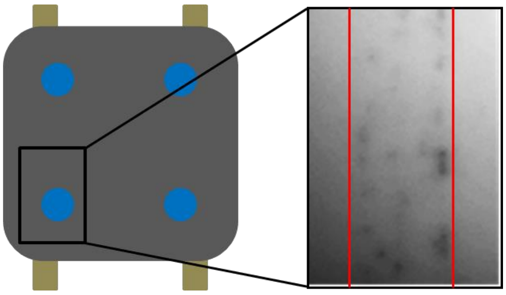

Figure 7: Position of PL image (left); PL image of the handled region with red lines, framing the conveyor belt location (right).

For all wafers characteristic traces in the form of reduced PL intensity were found. The observed position of the reduced PL intensity aligns well with the position where the wafers are handled by the conveyor belts and can therefore be assigned to result from them. An influence of the vacuum grippers has not been observed. Investigations of the defects by SEM revealed broken pyramid tips and accumulations of particles (Figure 8).

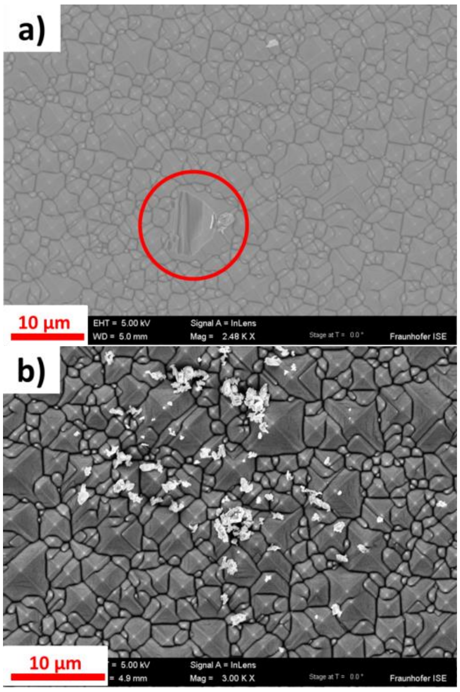

Figure 8: a) Exemplary SEM image of a broken pyramid tip found at the handled area; b) Accumulation of particles in handled area with particles analyzed by EDX (see Figure 9).

Analyzing the found particles by EDX showed a spectrum consisting of only the characteristic silicon peak (Figure 9).

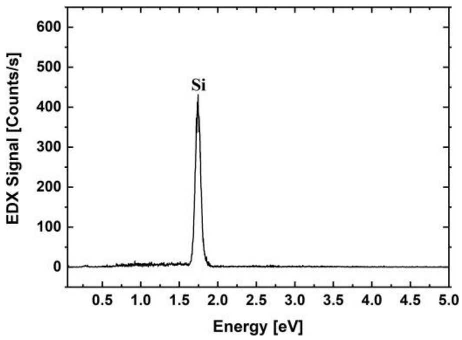

Figure 9: Exemplary EDX spectrum of particles which consists of pure silicon found in handled area of a Group A wafer.

It can be concluded that the high accelerations acting during the transport lead to micro movements between the wafer and the conveyor belt. The caused forces result into breaking off of pyramid tips, which are picked up as particles from the conveyor belt and return to the same or next wafer. At the area contaminated by silicon particles the wafer surface can’t be passivated sufficiently, which can be seen as areas of reduced intensity in the PL images.

3.2 Handling of wafers at elevated temperatures (Group B)

A PL image resulting from a wafer handled with residual heat in the industrial handling system is depicted in Figure 10.

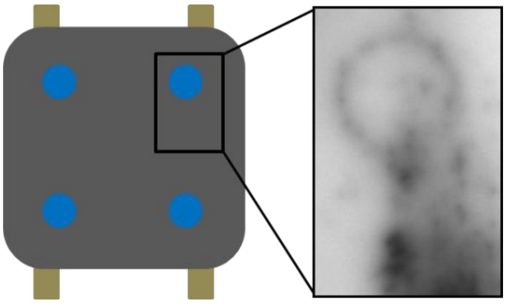

Figure 10: Position of PL image (left); PL image of the handled region in elevated temperature environment (right).

In comparison to wafers handled at RT, all wafers handled at elevated temperatures showed clearly more characteristic traces, in the form of reduced PL intensity. Beside damage associated with conveyor belts also an impact assigned to suction cups, which form circular structures, occur. As the defective area caused by the conveyor belt is large, individual local surface defects overlap due to lifetime smear. In order to obtain an improved resolution of the defective structures, µ-PL imaging was carried out. The resulting image is shown in Figure 11.

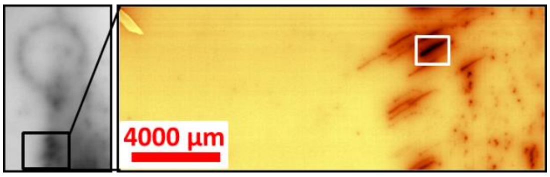

Figure 11: PL image of defective handled area. Marked position is analyzed by µ-PL (left). µ-PL image of defective handled area with marked area further investigated by SEM (Figure 12) and EDX (Figure 13) (right).

In addition to silicon particles and broken pyramids, black appearing residues could be found in SEM images (Figure 12) which appear as scratches in the µ-PL image (Figure 11).

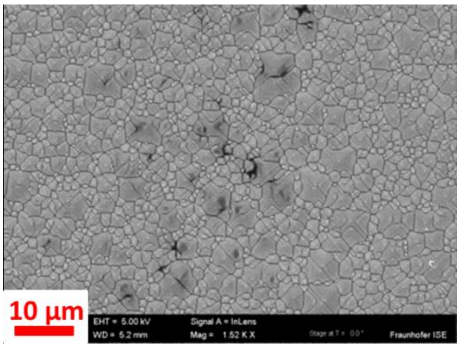

Figure 12: SEM images of marked area in Figure 11 with a1520x magnification.

Analyzing the dark residues with EDX reveals a spectrum consisting of carbon (C), nitrogen (N) and oxygen (O) peaks (Figure 13). The silicon peak occurs as well, because of the penetration depth of the x-rays used for the measurement into the silicon wafer by EDX.

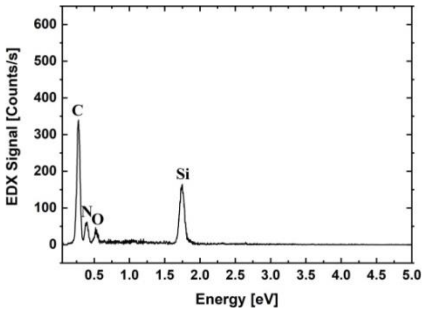

Figure 13: Exemplary EDX spectrum of found dark particles in Figure 13.

The combination of carbon, nitrogen and oxygen can be assigned to the material of the conveyor belts. Due to the influence of heat, the energy required is lower in order to release material from the conveyor belt. These circumstances apply also to the used suction cups.

3.3 Handling of wafers with test system (Group C)

To have a closer look on the impact of grasping at elevated temperatures, wafers have been handled by suction cups with PEEK inlays at RT, 100 °C, 150 °C and 200 °C. The grasping has been carried out with 2 bar and 4 bar grasping pressure for each set of wafer temperature. The resulting PL images of wafers handled at 2 bar grasping pressure are depicted in Figure 14. The handled wafers showed no pronounced defects at the suction cup locations for room temperature (RT) and a temperature of 100 °C. At 150 °C handling impact can be seen as dark areas in the form of circular defect pattern of the vacuum gripping surfaces, which are even more pronounced for a temperature of 200 °C.

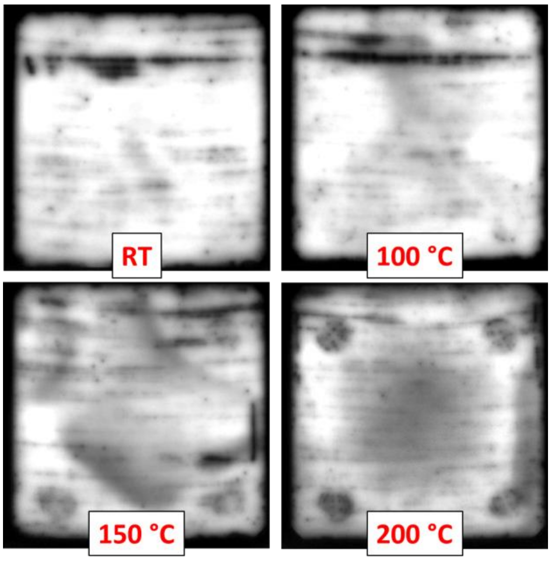

Figure 14: PL images of handled wafers with different temperatures and a low grasping pressure of 2 bar.

For PL images of wafers handled at 4 bar these circular defect patterns can be seen as dark areas in the form of the vacuum gripping surface already at a temperature of 100 °C (Figure 15). The PL signal in the handled area gets more reduced for wafers handled at temperatures of 150 °C and 200 °C.

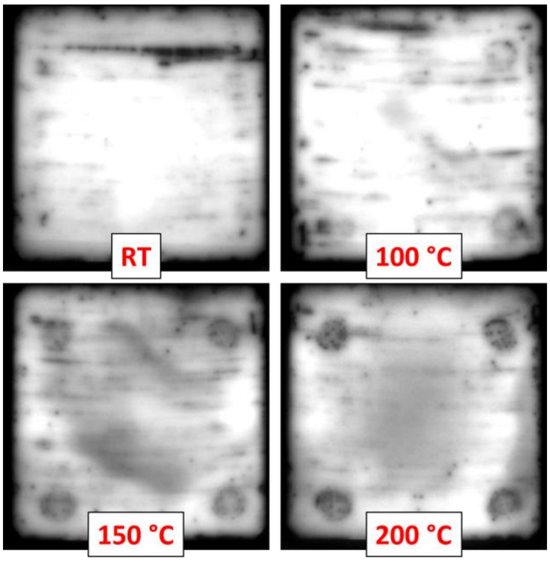

Figure 15: PL images of handled wafers with different temperatures and a high grasping pressure of 4 bar

SEM analysis of defective areas of wafers handled at 200 °C reveal a high amount of particle accumulations (Figure 16).

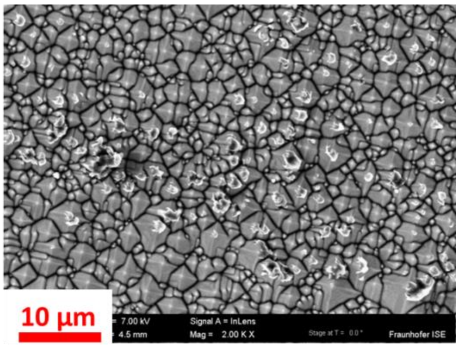

Figure 16: SEM image of wafer area handled by suction cups with PEEK inlays at 200 °C wafer temperature.

EDX analysis of the particle composition indicates element peaks of carbon and oxygen, which are two of three elements PEEK consists of (Figure 17). The third element is hydrogen, which can\`t be detected with the applied method.

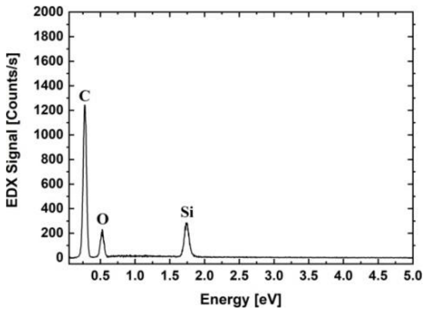

Figure 17: Exemplary EDX spectrum of found particles in Figure 16.

For Wafers handled at elevated temperatures an interaction between temperature and acting forces can lead to a release of particles from the end effectors onto the wafer surface. The released material covers the surface so that insufficient passivation occurs in this area, resulting in a reduced PL intensity.

4 SUMMARY

In conclusion, we can assign the causes of conveyor belt and vacuum gripper induced defects towards a-Si passivation under different temperature and grasping pressure conditions through the interplay of the analysis methods used. PL imaging is used to display handling induced local surface defects and contamination and serves as a basis for subsequent characterizations. The image of a PL measurement is used as a map to navigate to each individual surface defect on the wafer inside a SEM, where the surface is further analyzed by EDX to reveal the material composition and possible contamination. With this approach we were able to clarify that a-Si passivation defects resulting from conveyor belts and vacuum grippers used in automation are caused by particle transfer. The particles are generated by acting forces and/or heat transfer. For wafers handled at RT the acceleration of the wafer carrying conveyor belt leads to broken pyramid tips, which are taken up as particles from the same or following wafer. For wafers handled at elevated temperatures, a release of particles out of the conveyor belt material, as well as the vacuum gripper material, is added and/or increased. The released and transferred material results in surface areas with insufficient passivation.

ACKNOWLEDGMENT

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