PROGRESS IN THE CHARACTERISATION OF LASER-FIRED CONTACTS

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ABSTRACT: To extend the field of application for the laser-fired contacts (LFC), a more detailed knowledge of the contact formation and property is needed. Therefore several examinations have been carried out including secondary ion mass spectroscopy (SIMS), scanning and transmission electron microscopy (SEM and TEM) as well as energy dispersive x-ray analysis (EDX). The results show in continuation to previous results the reduced metal semiconductor contact area compared to the area threatened by laser influence. A depth analysis of the aluminium alloyed into the silicon increase the insight of the alloying process of aluminium during laser firing.
Keywords: Laser Processing, Back Contact, Characterisation

1 INTRODUCTION

The ‘laser-fired contact’ technology (LFC) developed at Fraunhofer ISE [1] is a process scheme for fast and reliable production of passivated emitter and rear cells (PERC) back sides. It has proven to be capable of reaching solar cell efficiencies of up to 21.9 % on high efficiency cell structures [2] in a fast and industrially transferable process [3]. Despite the superior quality of the LFC contact formation compared to standard ohmic contacts for passivated emitter and rear cells (PERC) [4] a fundamental examination of the contact properties now is necessary to transfer the process to other structures or process equipment. This examination includes the diffusion depth of the aluminium into silicon, the contact properties themselves as well as the laser-induced recast of the material. They have been carried out by secondary ion mass spectroscopy (SIMS), scanning and transmission electron microscopy (SEM and TEM) as well as energy dispersive x-ray analysis (EDX).

2 MEASUREMENT SAMPLE STRUCTURE

The measurements have been performed on PERC rear side structures on either wafers or transfer layer monocrystalline silicon [5]see Fig. 1).

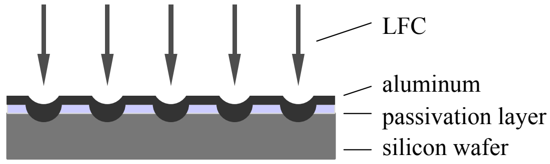


Fig. 1: Measurement sample structure.

The structure features a dielectric passivation layer with approximately 100 nm thickness consisting of thermally grown silicon oxide or PECVD silicon nitride. On top of this passivation layer 2 µm of aluminium are evaporated. The contact between the aluminium and the silicon bulk is established by LFC. This structure is consistent with the rear side of most high efficiency solar cells processed at Fraunhofer ISE.

As the structure usually is used for rear side contacting, we use the nomenclature to use “back side” when talking about the side when aluminium comes first and “front side” when coming from the silicon side.

3 LATERAL CONTACT PROPERTIES

3.1 Sample preparation

Encouraged by the electron beam induced current (EBIC) measurements performed in [4], detailed examinations by SEM and EDX were carried out. For a determination of the layer structure, samples prepared as shown in Fig. 1 including silicon oxide as passivation layer and being penetrated with standard LFC conditions were broken directly though one contact. The pictures then were taken under an angle of 15° between the surface and a vertical horizon for better visibility.

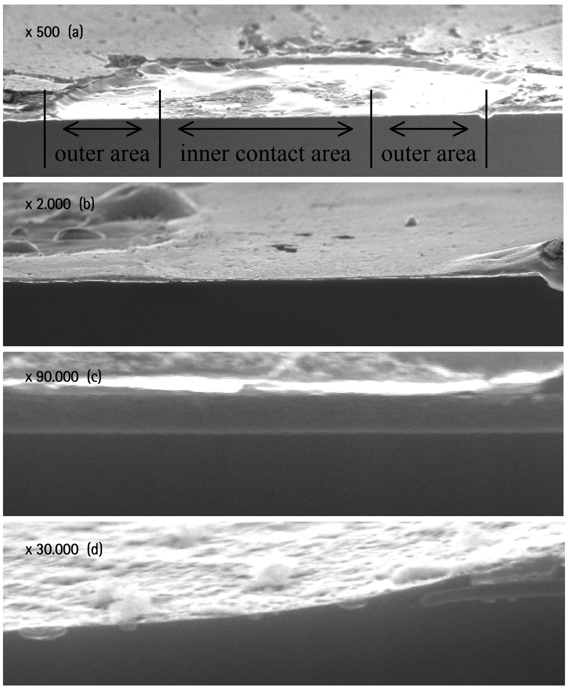
3.2 Determination of layer structure using SEM

Figs. 2a-d show a sequence of SEM pictures with increasing magnification. In Fig. 4a a survey of the LFC crater with a magnification of 500 is given. For navigation purpose, we divide it into five parts coming from left to right: non-contacted area, outer contact area, inner contact area, outer contact area and finally non-contacted area again. To examine the contact formation in more detail those single areas need to be analysed more deeply.

Fig. 2b shows the right outer contact area (magnification 2.000) as indication for the position. At a magnification of 90.000 this area is shown with a better resolution in Fig. 2c, where the layer structure clearly can be seen.

The inner contact area is shown in a magnification of 30.000 in Fig. 2d. Contrary to Fig. 2c no continuous passivation layer can be seen any more.

These pictures show that the outer area does not contribute to the electrical contact of LFC to silicon. Therefore we assume a reduced contact area which correlates to the inner contact diameter of about 50-60 µm. The outer ring around this contact area exhibits a surface passivation layer as well as a thin aluminium layer which means that in this region a structural modification is not visible place during laser firing.



Figs 2a-d: SEM pictures of the LFC contact area with varying magnifications. (a) shows the complete LFC, while (b) and (c) are zoomed further into the right outer area. (d) shows a spot from the inner contact area.

3.3 EDX analysis

To support the SEM results EDX measurements have been carried out (see Fig. 3).

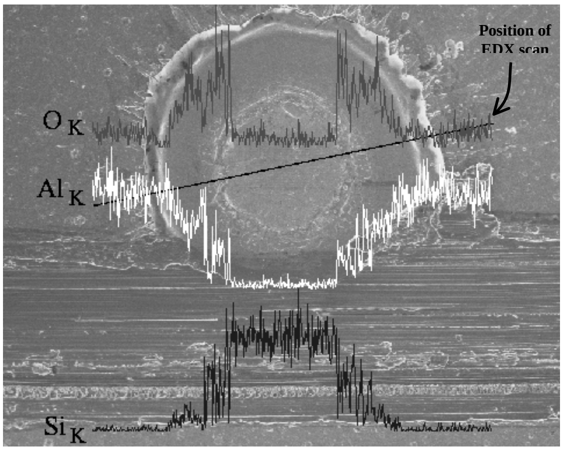


Fig. 3: SEM picture as guide for the position of the EDX measurement indicated by a line through the LFC. The signals of oxygen, aluminium and silicon along the scan are shown as superposition.

The measurement graphs support the previous results. Coming from left to right along the scan line the aluminium signal starts at a high level indicating the undamaged surface and then decays when reaching the contact middle. In the outer contact area the oxygen signal rises significantly. In conjunction with a slightly risen silicon signal this indicates an existing silicon oxide layer. The middle of the contact is dominated by the silicon signal due to the higher detection probability of silicon compared with aluminium.

4 ALUMINIUM DIFFUSION DEPTH PROFILING

4.1 Sample structure and setup

To investigate the usability for thin film devices, we need to know the penetration depth of the aluminium into the silicon. Two different ways of sample preparation have been used: on one hand the active LFC area was analysed in depth applying taylored sputter erosion at the back (contacted) side, on the other hand transfer layers provided by *ipe* in Stuttgart, Germany were used as wafer material for depth profile analysis starting at the front side of the sample.

4.2 Back side SIMS analysis of single LFC

To avoid measurement artefacts induced by disadvantageous material removal and/or the aluminium metallisation surrounding the analysed area the LFC centre was isolated using the O_2^+ ion gun of the SIMS device. The principle of sample preparation is shown in Fig. 4a.

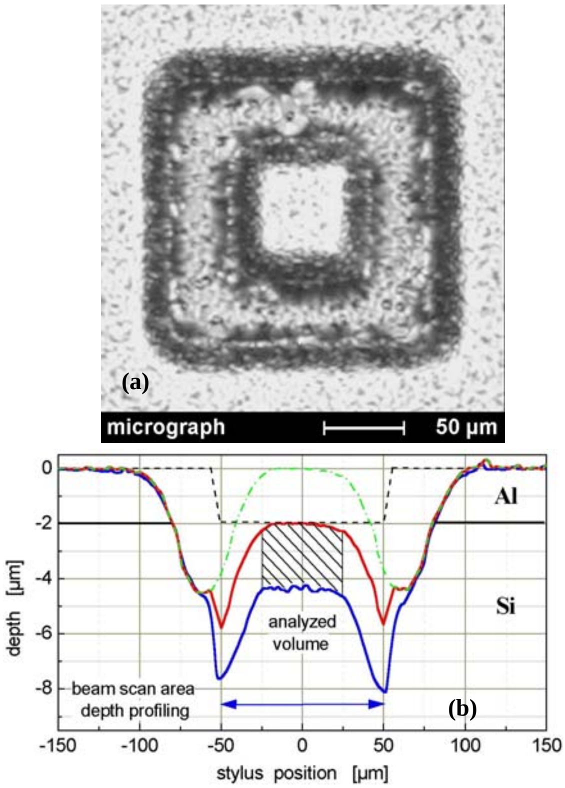


Fig. 4a-b: Microscope picture of the ion beam etch pattern for isolation of the contact area and trench pattern (top). Surface profiles (bottom) of sputtered trench pattern (dash-dot), assumed LFC profile (dash), calculated topography of the LFC after trench sputtering before SIMS (full line, middle) and measured surface profile after SIMS analysis (full line, lower). The analysed volume is shown dashed.

A sputtered trench within the regular $Al/SiO_2/Si$ layer stack is positioned in square shape around the area of interest. Adjusted on the LFC this geometry allows a separate examination of the central contact formation by subsequent depth profiling. The trench pattern surface profile is used in Fig. 4b to reconstruct the volume of the analysed material.

In Fig. 4b the surface profiles after several steps of sputter removal are plotted. In the centre of the picture three qualitative almost identical curves can be seen. The upper one (dash-dot line) indicates the surface profile after trench sputtering. The middle curve is calculated from the upper one by superposing the assumed LFC shape (square profile, dash line) into account. The lowest profile was determined after SIMS depth profiling. Therefore the analysed volume (dashed square) is clearly identified.

The lateral variation of aluminium concentration on the contact surface (see inlet in Fig. 5) is coupled with various Al depth distributions (Fig. 5). Profile A indicates the averaged aluminium concentration over the complete analysed 50 × 50 µm² area, profiles B and C indicate the aluminium concentration within different areas of ~12 × 9 µm² as indicated in the inlet in Fig. 5. Clearly a variation of the aluminium depth distribution within the LFC can be identified. This is probably caused by non-linearity during the ablation / melting process as well as by a non uniformly distributed laser beam intensity.

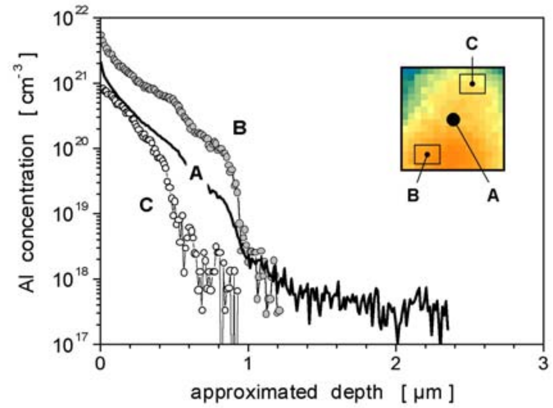


Fig. 5: Aluminium depth profiles at different areas within the centre of the LFC. The lateral positions of the areas are shown in the small inlet.

The local aluminium concentration decreases continuously until a depth of approximately 0.5 – 1 µm, then it drops to values of ≤ 10^{19} cm^{-3}. This behaviour can be explained by local melting processes causing a mixture of aluminium and silicon crystals within the surface layer. A less steep gradient in the Al-distribution follows which reaches at a depth of approximately 1.5 µm the SIMS resolution limit of approximately 5×10^{17} cm^{-3}. We assume diffusion of aluminium into the substantially undisturbed silicon lattice to be responsible for the latter decay in the Al-concentration. This assumption is in consistency with literature values of max. solubility and expectable diffusion length of aluminium in silicon.

4.3 Front side SIMS profiling

A second approach was to examine the usability of LFC for very thin substrates. Therefore transfer layers produced by *ipe* [5] were used as sample material. Due to their low thickness of 25 µm it is possible to perform SIMS measurements from the front side of the sample. As solar cell back side structure a stack system consisting of amorphous silicon, amorphous silicon nitride, aluminium and LFC is used. This system shows a different behaviour when penetrated with a laser. Fig. 6 shows a cross-section SEM picture of a raw transfer layer as described without the back side stack system.

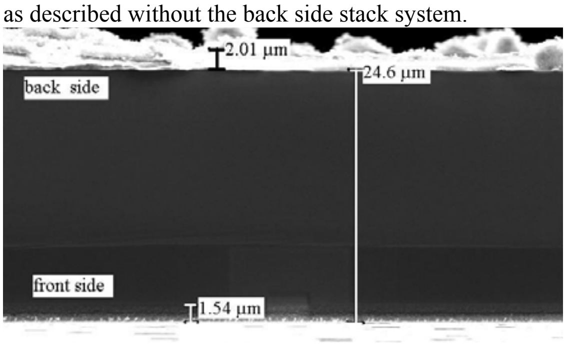


Fig. 6: Cross-section SEM picture of a transfer layer as used for the SIMS measurements of LFC. The back side of the silicon epitaxial film with a thickness of 24.6 µm is directed upwards, where the evaporation of 2 µm aluminium leads to the overall sample thickness of 26.6 µm.

By using thin sample material it is possible to prevent the SIMS ion beam from pushing the aluminium deeper into the silicon. Furthermore, since the sample surface facing the ion beam of the SIMS measurement is silicon material only, the first detection of an aluminium signal means the detection of an LFC.

To enhance the probability of hitting a laser-fired contact we pattern LFC close to each other without overlapping. Fig. 7 shows a microscope scan of the sample back side with the exit opening of the SIMS sputtering crater and some inserted LFC as guide to the eye.

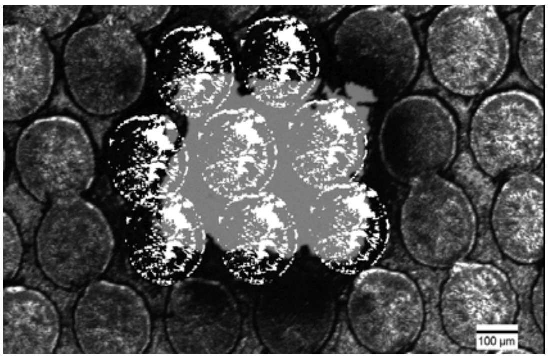


Fig. 7: Back side picture of the measurement position with some LFC inserted as guide to the eye.

Fig. 8 presents the resulting depth profile. Here the aluminium detection signal starts to rise after approximately 19 µm. Taking into account the overall sample thickness of 26.6 µm derived from Fig. 6 this results in a contact depth of around 7.5 µm from the first aluminium count to the aluminium surface of the sample back side.

In order to compare this result with the SIMS measurement from Fig. 5 we have to match the reference surfaces. The LFC crater depth due to laser penetration can be determined to a range of 2.5 to 3.5 µm from the aluminium surface. Therefore the aluminium reaches to 4 to 5 µm into the silicon with respect to the crater surface, which results in an overall depth of the laser fired contact of 4.5 to 5.5 µm with based on the former silicon surface.

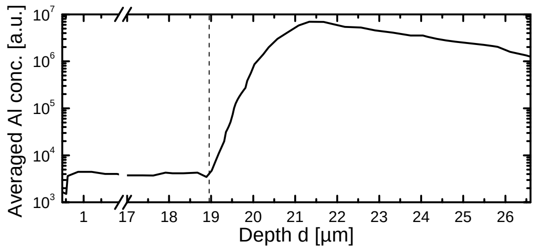


Figure 8: Depth profile obtained by SIMS from the front side of the samples. The aluminium concentration is given in arbitrary units.

Comparing this result to the data obtained in subsection 4.2 a difference of up to 3.5 µm in the obtained aluminium penetration depths can be found. This difference can be explained by the lasers interaction with the sample composition. As thermal silicon oxide behaves different than an stack system consisting of amorphous silicon and amorphous silicon nitride the remaining pulse energy usable for the melting / diffusion process might differ resulting in a variation of penetration depths of aluminium into silicon. Nevertheless, the result of a maximum penetration depth of 5.5 µm enables the use of LFC in thin film devices.

Additional variations can be caused by different LFC crater depths due to different optical coupling between the laser and the sample surface due to varying optical properties of the material. These variations should be less than 0.5 µm though.

5 LASER-INDUCED MATERIAL RECAST

Having evaluated the different depths of aluminium diffusion the question about the laser-induced crystalline defects [6] still is unmeasured. Although very high efficiencies can be reached using LFC in it is shown that the LFC rear side structure can be described using a model with an additional damage area and therefore reduced minority carrier lifetime surrounding the contact. The strong thermal gradient due to the laser heating influence might cause crystal defects not detectable by SIMS. Therefore further characterisations are underway utilising TEM to gain information about the structural composition of the contact area.

6 CONCLUSIONS

The geometrical contact properties have been evaluated more deeply. As a result it can be stated that the contact expands solely over the inner contact area, whereas the outer LFC area is still completely isolated with a continuous passivation and a thinned aluminium layer. Therefore when determining the contact area fraction solely the inner contact area has to be considered.

The SIMS measurements come to the conclusion of an aluminium penetration depth ranging between 1.5 and approximately 5 µm depending on the used layer system. The shallow penetration shows that LFC is excellently suited for processing thin sample substrates.

Acknowledgements

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