Comparison of Cleaning Processes for Enabling Solderability of LFC-PERC Silicon Solar Cells with Evaporated Al as Rear Side Metallization

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ABSTRACT: Silicon solar cells with evaporated aluminum rear metallization suffer from incompatibility with common soldering processes. In this paper we present a way of making industrially processed passivated emitter and rear cells (PERC) with evaporated Al rear side and laser fired contacts (LFC) subsequently solderable and module capable. Solderability is enabled by sputtering a solderable stack on the Al metallization, but it becomes apparent that the deposited stack lacks of adhesion due to dust originating from the LFC process. Therefore prior to the deposition of the solderable stack, cleaning of the rear side is essential. Therefore, test samples and PERC solar cells with evaporated Al rear side and LFC are fabricated and four cleaning methods are introduced and applied with varying influence on adhesion and cell efficiency. We show that proper cleaning processes enable a well-adhering solderable rear side metallization which permits cell interconnection and encapsulation into mini-modules.

Keywords: Solderability, PERC, evaporated aluminum, PVD metallization, LFC

1 INTRODUCTION

PERC solar cells with physical vapor deposited (PVD) Al rear metallization show a high efficiency potential in research [1] and are industrially feasible as described in [2,3] with the Thermal Oxide Passivated All Sides (TOPAS) design. Efficiencies up to 19.4% are shown using industrial process equipment, an evaporated Al rear metallization and LFC for contact formation. PVD Al metallization is known for being incompatible with established soldering processes which is a major drawback regarding module integration and commercialization. Kumm et al. [4] solves this issue by complementing the evaporated Al with a temperature-stable, solderable stack of TiN/Ti/Ag before the cell undergoes laser fired contacts (LFC) and annealing which allows the passivated emitter and rear cells (PERC) concept to be industrially produced with a solderable rear side. Lehr et al. [5] deposit a solderable stack of NiV/Ag on fully-processed PERC cells to enable solderability, but long-term stability and compatibility with LFC are not addressed.

The aim of this work is to find solutions for fully-processed solar cells with PVD Al metallization and LFC to subsequently enable soldering of cell interconnectors with sufficient adhesion and long term stability of the solder joint.

2 SOLDERING ON PVD METALLIZATION WITH AND WITHOUT LFC

2.1 Preparation of PERC like test samples

PERC like samples with PVD Al rear side are fabricated as depicted in the process flow in Figure 1. The samples receive all relevant processes of the TOPAS sequence according to [2]. P-type Cz-Si wafers are alkaline textured and subsequently rear side polished by single side wet chemical etching [6]. After wet chemical cleaning their rear side is passivated by a thin thermal oxide layer covered by a plasma enhanced chemical vapor deposited (PECVD) SiOx-film. After simulated contact firing, a 2 µm thick Al layer is evaporated on the rear side.

Wafers of group A are directly annealed, representing cell designs that do not use LFC, whereas the samples of group B and C receive LFC prior to annealing representing fully-processed TOPAS-LFC solar cells. Samples of group C then undergo a cleaning procedure which is described in detail in the next section. Subsequently, a solder stack of TiN/Ti/Ag is sputter deposited on the Al rear side of all samples to enable soldering of a 2 mm wide cell interconnector to the sample using conventional solder. The quality of solder-joint and adhesion is characterized by performing a 90°-peel-test according to standard DIN EN 50461, which requires 2 N peel force to peel a 2 mm wide cell interconnector.

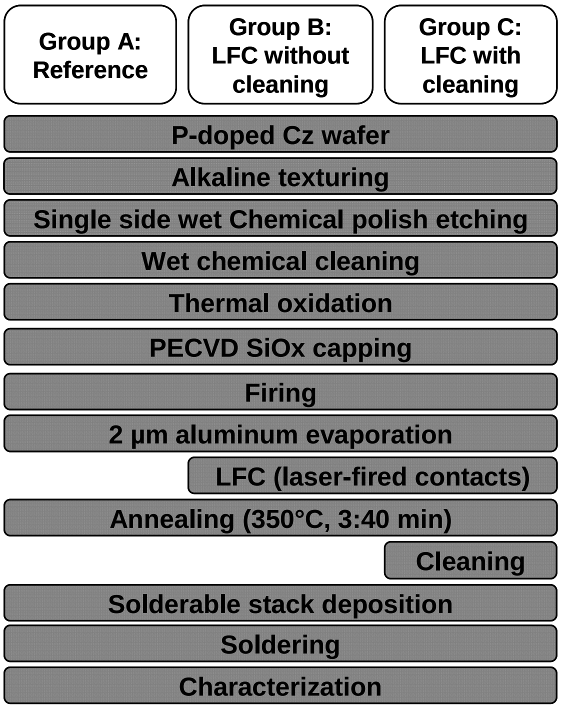

Figure 1: Process flow for fabrication of PERC like samples.

2.2 Results of soldering attempt and adhesion test

The samples without LFC are successfully soldered and pass the peel-test as exemplarily seen in Figure 2. This is similar to the results Lehr [5] have shown using a NiV/Ag layer as solder stack. It is anticipated that deposition of the introduced solder stack on solar cells with Al metallization without LFC enables subsequent cell interconnection by soldering. Combining the PVD processes of the Al layer and the solder stack in one deposition, as shown by Kumm et al. [4], even enables soldering after an annealing step and thereby in an industrial process sequence.

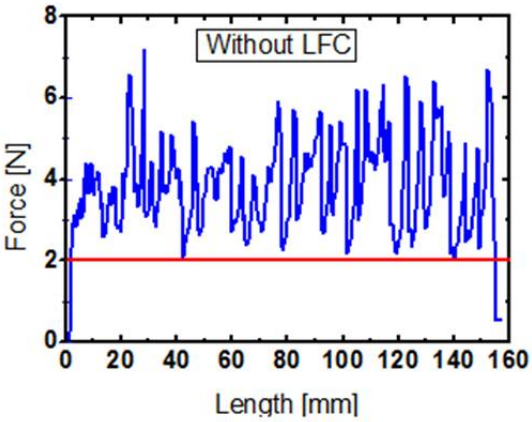

Figure 2: Peel-test diagram of PERC like sample without LFC (group A: reference)

On the samples of group B that have received LFC, no stable solder-joint can be established and a considerable lack of adhesion between solder stack and Al metallization is observed.

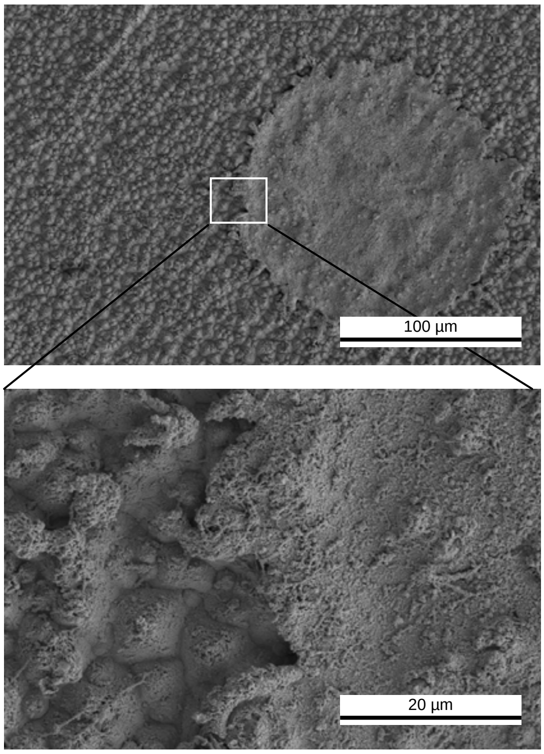

Figure 3: SEM images of the rear surface of a PERC like sample with LFC (top). Due to the LFC process dust particles cover the surface (bottom).

SEM images of the surface before sputter deposition confirm that the weak adhesion can be attributed to dust originating from the LFC process, as shown in Figure 3 . Considerable amounts of dust result in a very rough surface, preventing a sufficient adhesion of solder stack and cell interconnector.

3 CLEANING PROCEDURES FOR IMPROVED ADHESION

3.1 Cleaning procedures

For a good adherence of the solderable stack it is essential to remove the dust prior to the sputter deposition. Therefore the test samples of group C are cleaned by one of four cleaning procedures, which are:

- **N2 cleaning**: Blowing the sample with nitrogen gas followed by manual wiping with dry tissue
- **Isopropanol cleaning**: Pouring isopropanol 99% on the sample followed by manual wiping with tissue. This is repeated 3-4 times until the tissue remains clean after wiping.
- **HF dip**: Dipping the sample in hydrofluoric acid 1% for 30 s, followed by rinsing in distilled water and drying it with nitrogen gas flow.
- **Al evaporation**: Additional depositing of 1-2 µm Al on the sample surface to cover the dust.

SEM images emable the characterization of the surface roughness after the different cleaning procedures. Additionally, their effectiveness on improving adhesion is characterized as before by a peel-test; possible effects on cell-performance by the cleaning procedures are addressed in the next section.

3.2 Effect of cleaning procedures on adhesion

Figure 4 shows the SEM images (left) and the corresponding peel-test diagrams (right) for the four different cleaning procedures. N2-cleaned samples, see Figure 4(a), show a reduced amount of dust compared to the uncleaned sample in Figure. 3, but the surface remains fairly dust covered and rough. This corresponds to an insufficient adhesion and low peel forces as shown in the peel-test diagram. Isopropanol-cleaned samples, see Figure 4(b), show fewer dust particles and a smoother surface than the air-cleaned samples. During the peel-test the wafer is observed to fracture under very high forces, the peel-test diagram shows several peaks of very high force. Therefore, sufficient adhesion is achieved by isopropanol cleaning. Samples that have been HF-dipped, see Figure 4(c), show practically no remaining dust or particles and a very smooth surface, which allows high adhesion of the subsequently deposited solder stack. The peel-test diagram confirms the high adhesion. Samples on which the dust has been covered by another evaporated Al layer, see Figure 4(d), show a smooth surface which enables strong adhesion of the stack The peel-test diagram shows forces that permanently exceed 2 N which certifies very good adhesion.

N2 cleaning shows not to be effective for sufficiently improving the adhesion of the solder stack and is not further investigated, while isopropanol cleaning, HF dipping and Al evaporation are suitable for removing LFC induced dust in regard of adhesion and therefore the effect on cell efficiency is investigated.

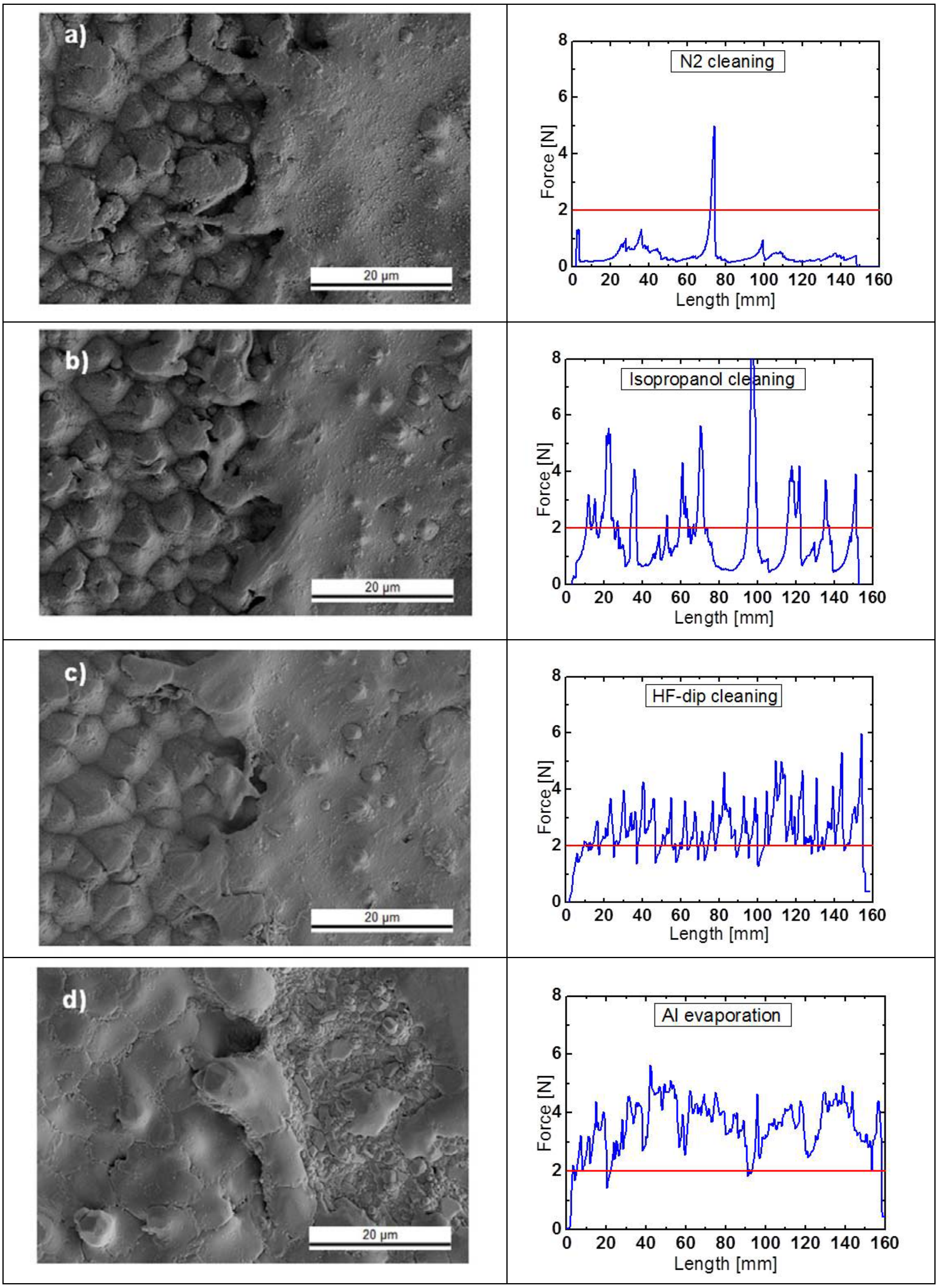

Figure 4: SEM image of the cleaned sample surfaces on the left and the corresponding peel-test diagrams on the right. (a) Air cleaned sample, (b) Isopropanol cleaned sample, (c) HF-dipped sample and (d) sample covered with evaporated Al. The peel force of 2 N, which is required to fulfill the adhesion standard, is indicated in red in the peel-test diagrams.

4 INFLUENCE OF THE CLEANING PROCEDURES ON CELL PERFORMANCE

4.1 Cell fabrication process

To investigate how the cleaning procedures affect cell performance, 14 PERC cells, with a TOPAS [2] and Al2O3/SiNx-passivation [7] with PVD Al and LFC are processed. They are front side screen-printed, and rear side metallized by evaporation of 2 µm of Al; as last steps the cells are laser-fired contacted, forming gas annealed and IV measured. Then the three different cleaning procedures are applied on three cells each, whereby the cells that are HF-dipped are covered with an HF resistant layer on the front side during the dip. Then, the solder stack is sputter deposited. Subsequently, the cell efficiency of all cells, including the untreated reference cells, is again measured.

4.2 Influence on cell efficiency

The cells show an initial median efficiency of 19.2%. To investigate to what extent cell performance is affected by enabling solderability in the proposed way, the change of efficiency in absolute percentage before and after cleaning procedures and solder stack deposition is depicted in Figure 5.

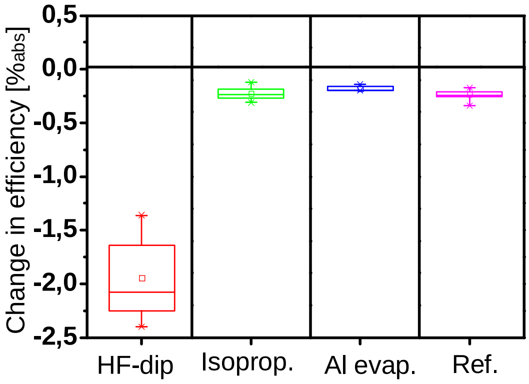

Figure 5: Influence of cleaning before PVD deposition of the solder stack on cell efficiency of PERC solar cells

Cells that are HF-dipped show a significant loss of $\Delta\eta$=-2%$_{abs}$ in efficiency. By external quantum efficiency measurements the decrease can be attributed to increased rear surface recombination, which suggests that the rear passivation might be damaged during the HF-dip. Although HF-dipping results in a very good adhesion, it proves to be an unsuitable procedure in terms of cell performance.

Those cells that are cleaned with isopropanol or evaporated with Al show an average change in efficiency of $\Delta\eta$=-0.2%$_{abs}$. However, the reference cells that are not handled show also a change in efficiency of $\Delta\eta$=-0.2%$_{abs}$. The reason for the loss is not clear, but as it seems to be independent of the cleaning and sputtering procedure, we conclude that cleaning with isopropanol or evaporation of Al are suitable cleaning procedures.

5 MODULE INTEGRATION AND LONG-TERM STABILITY

Cells on which solderability is successfully established by isopropanol cleaning or Al evaporation and solder stack deposition are integrated into six mini modules of one or four cells each by a conventional soldering process.

To investigate the long-term stability of the realized solder connection the modules undergo a humidity-freeze test and thermal cycling. Three mini modules undergo a humidity-freeze test of 10 cycles between 85°C and -40°C at 85% relative humidity. With a maximal degradation of -3.5%$_{rel}$ all modules pass the test according to standard IEC 61215. Additionally, three mini modules undergo a reduced thermal cycling test with 80 thermal cycles between 85°C and -40°C, showing a maximal loss in efficiency of -0.7%$_{rel}$. Testing the modules in a full thermal cycling test and a damp heat test according to the IEC standards needs yet to be done.

We conclude that the proposed cell interconnection method - which bases on the cleaning methods of isopropanol cleaning or Al evaporation, a sputter deposited solder stack of TiN/Ti/Ag and a common soldering process - is a promising method for enabling cell-interconnection of fully-processed PERC solar cells with PVD Al metallization and LFC.

6 SUMMARY

In this work, we demonstrate a method for enabling soldering of cell interconnectors onto fully-processed PERC solar cells with evaporated Al rear side metallization interconnect them into mini modules. Sputter deposition of a solder stack on the Al metallization allows high adhesion of the solder joint. However, if the LFC technology is used for contact formation, residual particles prevent the sputtered solder stack from adhering sufficiently. Prior cleaning of the surface is therefore essential and four cleaning methods are introduced and evaluated in respect of their effect on adhesion improvement and cell efficiency. N_2-cleaning is not capable of removing the LFC dust whereas an HF dip causes a major decrease in cell efficiency, which makes these both cleaning procedures unsuitable. Cleaning with isopropanol or an additional Al evaporation step however, result in a smooth rear surface on which the solderable stack adheres well. These cleaning methods combined with the solder stack can be used to establish solderability of PVD Al metallization with LFC, which is also demonstrated on PERC cells. These cells show no significant change of efficiency compared to the reference cells and they are successfully interconnected by soldering and encapsulated into mini modules. The modules withstand a humidity-freeze and a reduced thermal cycling test.

7 ACKNOWLEDGEMENT

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