Laser Fired Contacts for High Efficiency Solar Cells based on EFG Material

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ABSTRACT: In the past few years the quality of Edge-defined Film-fed Growth (EFG) silicon wafers has strongly improved and can now compete with most standard multicrystalline materials. As the wafer thickness decreases and meets the average diffusion length of the minority charge carriers, a dielectric rear side passivation can exceed the effectiveness of a standard aluminium Back Surface Field (BSF). To contact a dielectrically passivated rear side the concept of Laser Fired Contacts (LFC) is a very promising technique. Investigations for rear side passivation at the University of Konstanz (UKN) focus on a stack system of a thin thermal silicon oxide covered by a thick Plasma-Enhanced Chemical Vapor Deposited (PECVD) silicon nitride layer.
Keywords: Silicon Ribbon, Laser Processing, Passivation

1 INTRODUCTION

The maximum conversion efficiency of solar cells based on high quality Edge-defined Film-fed Growth material (EFG) is at the moment mostly limited by the applied solar cell processing steps [1]. This paper focuses on the application of dielectric passivation layers in combination with rear side contacting via Laser Fired Contacts (LFC) [2] on EFG silicon solar cells [3]. Besides the beneficial influences on the electrical performance of the solar cell, the application of LFCs also saves the - for this material due to the introduction of cracks critical - screen printing process for the back side metallization. This should lead to higher yield and also result in more planar solar cells because no bowing occurs during firing. The investigations made here aim for a deeper understanding of the modified photolithography based cell process at the University of Konstanz (UKN), especially concerning passivation of the rear surface and of bulk defects.

2 CELL PROCESS

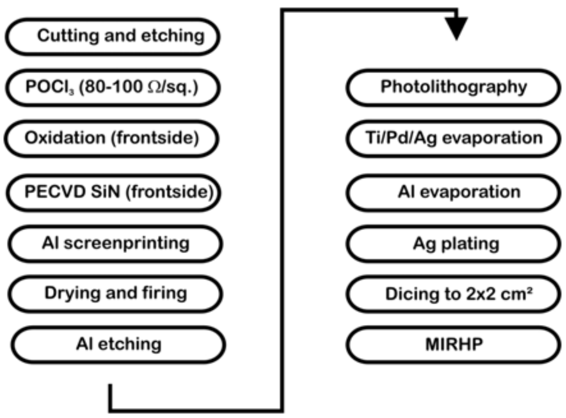

Figure 1: Standard photolithography based cell process at UKN.

Coming from the standard photolithography based cell process at UKN, (Figure 1) some rearrangements are made to establish a dielectrically passivated rear side and for the formation of local contacts with a laser firing process. In detail the process (Figure 2) is carried out as follows: The first step is a surface damage etch (chemical polishing etch based on HNO_3, HF and CH_3COOH). A thin (10-15 nm) thermal oxide layer is formed by a dry oxidation process. Subsequently the oxide on the rear side is covered by a PECVD silicon nitride layer and the oxide on the front is removed by a short HF-etching step. Emitter diffusion is carried out in a conventional $POCl_3$ open tube diffusion furnace before a second oxidation and PECVD silicon nitride deposition on the front side. The hydrogen rich PECVD silicon nitride is fired in a belt furnace with a peak temperature of around 800°C to passivate bulk defects. Metallization of the front grid is carried out using photolithography together with evaporation of contacts followed by silver plating. Aluminium is evaporated on the back side and contacted through the passivation layer with a Nd:YAG laser.

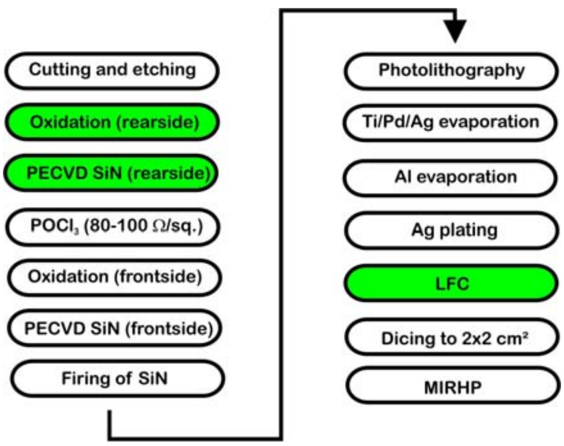

Figure 2: Rearranged photolithography based cell process with adaptations for the application of LFCs highlighted in green.

Finally four 2x2 cm^2 solar cells are cut out of the 5x5 cm^2 structure using a wafer dicing saw followed by a subsequent contact sintering and hydrogenation via Microwave Induced Remote Hydrogen Plasma (MIRHP).

3 REAR SURFACE PASSIVATION

The thickness of the fabricated cells was around 170 µm for cells from 3 Ωcm material and around 270 µm for cells from 1 Ωcm material. The effective minority carrier diffusion lengths L_{eff} determined from spectral response measurements using the Basore fitting method [4] also lie in the region of 150 µm to 300 µm and thus a better rear surface passivation should have a major impact on cell performance. For thin cells (thickness ~ 170 µm) LBIC measurements show the laser impact on the rear side (Figure 3). The dielectric passivation clearly exceeds the locally formed Al-BSF from the laser fired contacts.

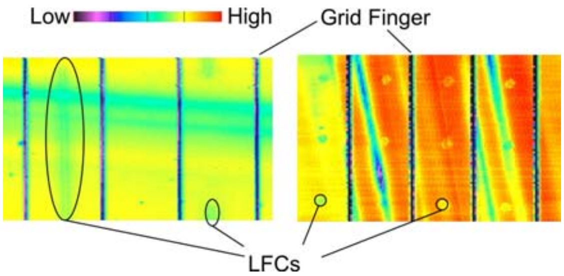

Figure 3: Internal quantum efficiency map at 980 nm on EFG solar cells with different LFC patterns (LBIC measurement). Dielectric passivation quality clearly exceeds the locally formed Al-BSF under the laser fired contacts.

4 BULK PASSIVATION

Like most multicrystalline wafer materials EFG is very sensitive to high temperature processing steps. Impurities which were gettered e.g. at grain boundaries during the crystallisation process can diffuse out of the gettering regions and contaminate formerly pure regions in the wafer. Normally this leads to a degradation of the bulk material.

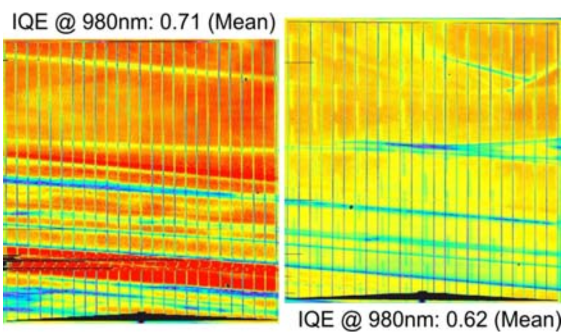

Figure 4: LBIC measurement on two adjacent solar cells from 1 Ωcm EFG material. Left: cell with standard Al-BSF, right: cell with LFCs.

Figure 4 shows LBIC measurements of two solar cells from adjacent wafers (compare grain structure). One is processed according to the standard process (Figure 1) the other one is processed according to the LFC process shown in Figure 2. The LFC cell shows less variation in the IQE and also a lower mean IQE value. This corresponds to the reduced cell parameters of this LFC cell (Table I, fifth row) compared to the neighbouring standard cell (Table I, sixth row). Measurements of the spectral response on the same cells (Figure 5) confirm the effect of diffusion of internally gettered impurities during high temperature steps.

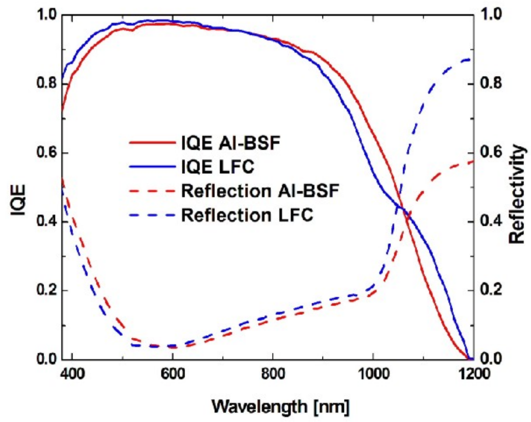

Figure 5: Measured hemispherical reflection and internal quantum efficiency on adjacent EFG solar cells from 1 Ωcm material. Red curve with common Al-BSF; blue curve with LFCs.

But also other observations were made: Figure 6 and 7 show the results of the same experiment on EFG material with lower bulk doping level (R_b = 3 Ωcm).

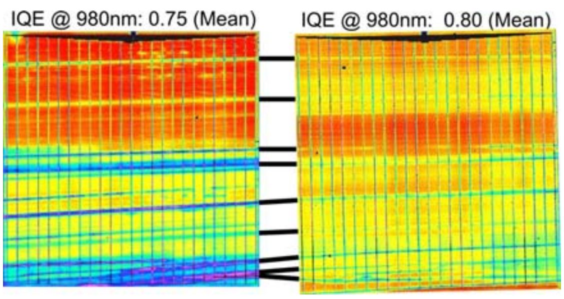

Figure 6: LBIC measurement on two adjacent solar cells from 3 Ωcm EFG material. Left: cell with standard Al-BSF, right: cell with LFCs.

Here the IQE variation for the LFC cell is also lower which can again be attributed to an out-diffusion of impurities, but anyhow the mean IQE for the LFC cell is higher than for the standard cell (see also Figure 7). Hence it can be concluded, that for very pure EFG material a wafer with a more homogeneous impurity distribution can be superior to a wafer with very good crystal areas alongside with areas of very poor quality.

Another point to be considered is the omission of the Al-gettering in the LFC process. This step is particularly crucial for material of low quality while high quality material (low impurity concentration) can bear the missing gettering step much better.

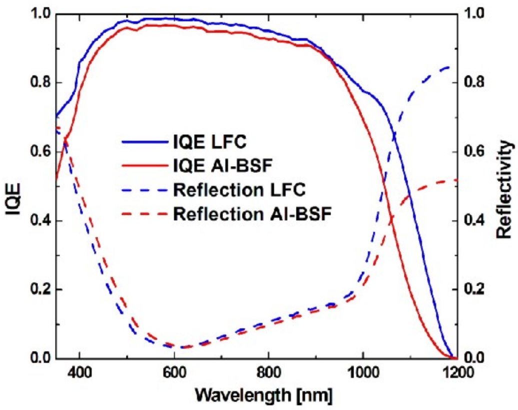

Figure 7: Measured hemispherical reflection and internal quantum efficiency on adjacent EFG solar cells from 3 Ωcm material. Red curve with common Al-BSF; blue curve with LFCs.

5 CELL RESULTS

IV measurements show very low fill factors for the FZ references and 3 Ωcm EFG solar cells with dielectrical passivation and LFCs (Table I). A fit of the IV curve according to the two diode model showed a more than twice as high series resistance for the LFC cells compared to their standard counterparts. This indicates a not yet optimized LFC pitch and/or laser parameters.

Table I: Measured IV data of the neighbouring solar cells discussed above. LFCs indicates dielectrically passivated cells; std indicates cells with Al-BSF.

Material	R_b [Ωcm]	FF [%]	J_{sc} [mA/cm²]	V_{oc} [mV]	η [%]
FZ LFC	0.8	75	34.6	658	17.1
FZ std	0.8	79.8	33.5	648	17.3
EFG LFC	~ 3	75.0	33.0	620	15.4
EFG std	~ 3	79.5	31.9	605	15.3
EFG LFC	~ 1	78.2	31.8	595	14.8
EFG std	~ 1	79.5	32.3	608	15.6

Assuming a fill factor of 80% for the two abovementioned solar cells, an efficiency of 16.4% for the 3 Ωcm EFG cell and of 18.2% for the Floatzone reference (both with only a single anti-reflection layer) can be expected. Application of a double anti-reflection coating (DARC) as is designated (but not yet applied) in the process, an increase in J_{sc} should boost the maximum efficiency up to 17.4% and 19.5% for EFG and Floatzone material respectively.

6 CONCLUSION

The application of a dielectric rear side passivation via SiO_2/SiN_x-stack turns out to be a difficult but feasible task if very pure EFG material is used. The additional high temperature step to form the thermal oxide on the rear side may lead to diffusion of impurities from the grain boundaries into the grains. This results in a reduced IQE in the bulk on the one hand, but on the other hand the recombination activity of grain boundaries is reduced and so the IQE of grain boundaries is increased. In total this effect can either lead to degradation or improvement of the whole solar cell. This effect seems to depend strongly on the quality of the material. The low fill factors of solar cells presented in this work indicate that pitch and pattern of the laser fired contacts as well as laser parameters are not yet optimized. But in principle efficiencies of 16.4% EFG and 18.2% for EFG and FZ material respectively can be reached (even more when applying a DARC).

7 OUTLOOK

Having determined the oxidation as the decisive processing step, further efforts will focus on the reduction of the thermal load on the wafers during processing. Another task will be the optimization of the laser parameters as well as pitch and pattern of the LFC contacts. Regarding the high reflectivity of the evaporated rear side aluminium contact, a combination with a front side texturisation to enhance the optical path in the solar cell seems very promising (optical confinement).

8 AKNOWLEDGEMENTS

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