IN-LINE HIGH-RATE DEPOSITION OF ALUMINUM ONTO RISE SOLAR CELLS BY ELECTRON BEAM TECHNOLOGY

Fraunhofer FEP

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PURPOSE OF WORK

The concept of RISE-EWT solar cells includes the cost effective opportunity to establish a plane metallization technique. The electron beam high-rate deposition with aluminum should be tested under conditions of an inline coating equipment. The technical challenge consists in maximizing the deposition rate and keeping a temperature limit of 400°C during deposition of 20 µm aluminum onto silicon wafers.

Different types of evaporation crucibles (water cooled copper crucible, ceramic crucibles) were proved in stationary deposition experiments for a preselection in relation to power efforts and layer properties.

The inline metallization step by keeping the temperature limit of 400°C with an industrial relevant deposition rate (3.6 µm m/min) was realized in pilot scale equipment without any solar cell efficiency loss in comparison to lab coating. The cell efficiencies were evaluated with 18.4%.

STATIONARY ALUMINUM DEPOSITIONS

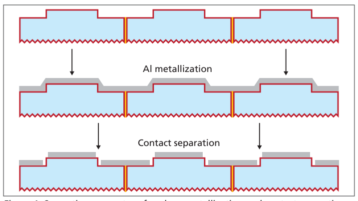

Figure 1: Scematic process steps for plane metallization and contact separation for RISE-EWT solar cells (compare [1])

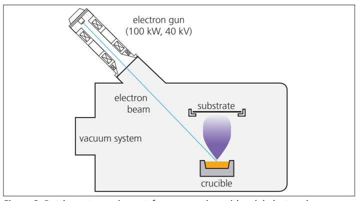

Figure 2: Batch coater equipment for evaporation with axial electron beam gun

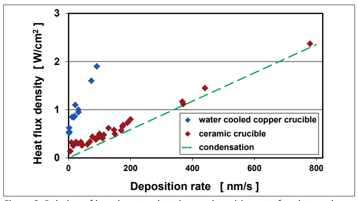

Figure 3: Relation of heat input and stationary deposition rate for electron beam evaporation of aluminum from different types of crucibles

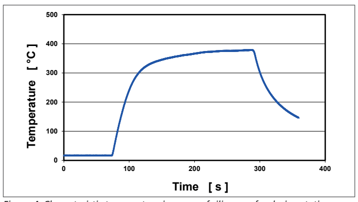

Figure 4: Characteristic temperature increase of silicon wafer during stationary aluminum deposition (100 nm/s)

Back contacted solar cells offer the opportunity to establish new metallization techniques like plane depositions using electron beam high-rate evaporation. One technical challenge is maintaining the temperature limit of about 400°C to prevent locally spikes into the silicon surface creating short-circuits the p-n junction. The metallization of the RISE-EWT (Rear Interdigitated Single Evaporation-Emitter Wrap Through) solar cell was designed in the lab as two layer structure consisting of 10 ... 25 µm of aluminum and a quite thin additional layer serving as etch protection for the contact separation process (figure 1) (compare [1]).

Stationary depositions of thick aluminum layers using axial electron beam gun were realized in a batch coater (figure 2) for pretests of different types of evaporation crucibles: water cooled copper crucible, so called “hot” ceramic crucibles manufactured from aluminum oxide and from boron nitride.

Figure 3 demonstrates that for both types of ceramic crucibles the heat input is lower in comparison with water cooled copper crucible. The “energetic efficiency” is close to the theoretical limit by heat of condensation. Low specific electrical resistances about 10% above the value for bulk material were achieved with water cooled copper crucible but also with boron nitride crucible.

According to heat capacity of the used 180 µm silicon wafer and the heat input of the coating process the wafer temperature during deposition increases rapidly in the first ten seconds, after then the temperature converges a steady state of heat input and heat radiation (figure 4).

[1] S. Hermann, A. Merkle, C. Ulzhöfer, S. Dorn, I. Feilhaber, M. Berger, T. Friedrich, T. Brendemühl, N.P. Harder, L. Ehlers, K. Weise, R. Meyer, R. Brendel, Solar Energy Materials & Solar Cells 95 (2011) 1069–1075

DYNAMIC ALUMINUM DEPOSITIONS

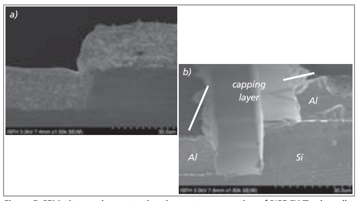

Figure 5: SEM pictures demonstrating the contact separation of RISE EWT solar cells a) cross section before b) tilted view after contact separation.

Figure 6: “MAXI” inline high-rate coating equipment at Fraunhofer FEP Dresden

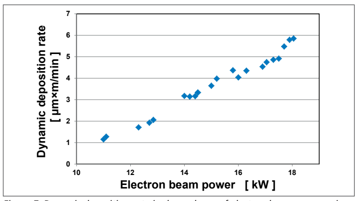

Figure 7: Dynamic deposition rate in dependency of electron beam power using a boron nitride crucible

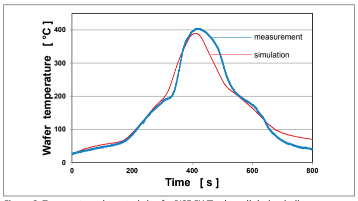

Figure 8: Temperature characteristic of a RISE EWT solar cell during in-line evaporation using a boron nitride crucible (dynamic deposition rate: 3.6 µm m/min)

In figure 5 are shown SEM pictures demonstrating deposited 20 µm aluminum coating and the cross section after contact separation of RISE EWT solar cells. For the separation it is advantageously that in opposite to sputtering by electron beam evaporation deposited aluminum layer is thinner and more porously in flank regions.

The dynamic aluminum depositions using electron beam high-rate evaporation were carried out in Fraunhofer FEP inline coating equipment “MAXI” (figure 6).

Operating ceramic crucibles the dynamic deposition rate was adjusted to industrial relevant size of “several µm m/min” (figure 7) at relatively low energy efforts. Coating width of 400 mm was realized with one EB-source.

The 400°C temperature limit during deposition – preventing electrical p-n short circuits at silicon wafers – was kept at deposition rates of 3.6 µm m/min. The relatively broad vapor distribution and connected the input heat distribution result in temperature dependencies according to figure 8. The wafer temperature during deposition was simulated using two-dimensional finite-element simulations [2]. The calculations allow detailed analysis of local and time depending temperature patterns during wafer metallization.

[2] C. Mader, M. Kessler, U. Eitner, R. Brendel, Solar Energy Materials and Solar Cells 95 (2011) 3047-3053

CELL RESULTS

Lifetime measurements at samples passivated with silicon nitride and silicon oxide, respectively, did not show any observable degradation due to the high energy electron beam used during the coating experiments.

The table shows solar cell parameters in comparison between a reference cell, metallized with deposition rate 5 nm/s and a cell, metallized in an inline equipment (dynamic rate: 3.6 µm m/min, corresponds to stationary rate: 210 nm/s).

parameter	reference	high-rate deposition
V_{OC} (mV)	630	629
J_{SC} (mA/cm²)	39.9	39.6
FF (%)	74	74
η (%)	18.5	18.4

It can be noticed that all cell parameters correspond within deviations lower than one percent with the parameters of the reference cells. This demonstrates that the aluminum metallization with high rates in a running in-line plant offers same solar cell efficiency of 18.4%.

SUMMARY

Electron beam high-rate deposition with aluminum was tested for plane metallization of RISE-EWT solar cells. According to heat load, power input and layer properties ceramic crucibles were chosen for dynamic coatings.

In an inline coating plant the metallizations with 20 µm aluminum layers were realized at dynamic deposition rates of 3.6 µm m/min maintaining the temperature limit of 400°C.

Processed solar cells present efficiencies up to 18.4%. The solar cell parameters reveal identical values in comparison to the laboratory metallization step which was solved at remarkably lower deposition rates. The developed electron beam evaporation process under pilot equipment dimensions and conditions was realized with industrial comparable deposition rates without solar cell efficiency loss.

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