



Hydrogen induced contact resistance in PERC solar cells

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ABSTRACT

The origins of an increase in the series resistance of PERC multicrystalline silicon solar cells due to post-firing thermal processes are investigated. This effect has been shown to be capable of reducing the fill factor of finished cells by up to 20%_{ABS}, severely degrading their performance. It is observed that electric currents applied either during or after these thermal processes can greatly alter the series resistance, either causing it to increase by more than an order of magnitude or suppressing the effect entirely. It is demonstrated that this behavior is in good agreement with the expected interactions of hydrogen with dopants and electric fields within silicon wafers. It is therefore speculated that at least part of the observed increase in resistance is due to the motion of hydrogen within the cell itself.

1. Introduction

There has been significant recent interest in post co-firing processes for silicon solar cells. These processes are often intended to getter or improve passivation of defects [1–4], or to mitigate degradation effects [5–8]. While these approaches have proven to be effective in improving the bulk lifetime and long-term stability of devices, an unintended consequence has been a reported increase in device series resistance (R_S) [5,9,10]. Further investigation has revealed that this increase in R_S is almost exclusively due to an increase in the contact resistance at the interface between the screen-printed silver fingers and the silicon surface [9,10].

Initial observations of this effect on heavily diffused emitters concluded that the increased R_S was the result of a thickening of the glass layer surrounding silver crystallites at the Ag-Si interface [9]. However, more recently the authors have reported an unstable component to the R_S increase that appears to be related to the motion of charged particles [10]. This unstable component has been shown to be most significant at temperatures between 450 and 500 °C, while a more permanent increase in R_S is observed at higher temperatures.

It has been suggested that this unstable increase in contact resistance is related to the motion of hydrogen [10]. This is in good agreement with recent simulations on the re-distribution of hydrogen at similar temperatures [11] which predicts that there will be a significant build-up of hydrogen at the metal contacts. The mechanism by which hydrogen might act to increase contact resistance is currently unknown,

although possibilities include alteration of the glass between the screen printed silver and the silicon or through interaction with defects and silver crystallites underlying this glass layer [12–15].

This paper will further explore the phenomenon of increased contact resistance due to post-firing thermal processes. It is demonstrated how electric fields within the cells can be used to enhance or suppress this change in R_S . The observed changes in R_S and the expected behavior of hydrogen in solar cells is then compared [11]. It is found that there is a strong correlation between the experimentally observed increase in R_S and the simulated build-up of hydrogen at the surface.

2. Methods and materials

Full size 156 × 156 mm PERC cells were fabricated on an industrial manufacturing line. The wafers used were p-type boron-doped 1.2 Ω cm high-performance (HP) mc-Si wafers. The wafers underwent the following standard treatments: acidic texturing (final thickness 180 μm), cleaning, POCl₃ diffusion (90 Ω sq⁻¹), rear-side etch, and finally plasma-enhanced chemical vapor deposition (PECVD). The layers deposited by PECVD were hydrogenated silicon nitride (SiN_x:H) with a thickness of 75 nm and refractive index of 2.1 on the front n-type diffused side and a hydrogenated aluminium oxide (AlO_x:H)/SiN_x:H stack with thicknesses of 10 and 100 nm, respectively, on the rear p-type side. Point openings in this stack were formed using laser ablation, and the wafers were then screen printed with aluminium paste over the entire rear surface, and silver paste on the front in a grid pattern. This was

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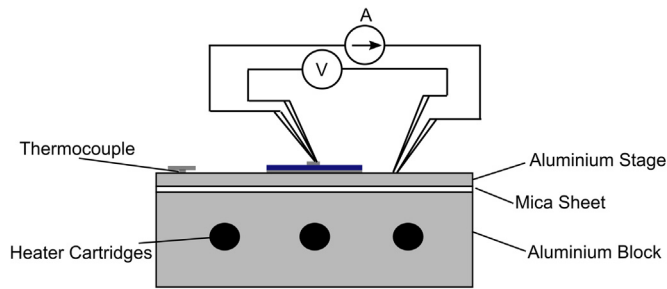


Fig. 1. Experimental set-up for thermal processing and in-situ monitoring of I-V characteristics for solar cell samples.

followed by a standard drying and co-firing step in an industrial belt-furnace to form the metal contacts and release hydrogen from the dielectric layers for bulk and surface passivation [10]. The wafers were then cleaved into smaller samples for further processing.

Whereas in previous work [10] samples have been re-fired using a belt furnace, in this work samples were annealed on a heated stage in the dark as shown in Fig. 1. The aluminium stage was PID temperature controlled via Labview and a mechanically affixed thermocouple as shown in Fig. 1. The probes were connected to a Keithley 2401 source measuring unit (SMU) to allow for the application of external bias to the samples and for in-situ observation of I-V characteristics. The samples were I-V tested at room temperature using the same equipment.

Room temperature characterization of R_S was done through profiling the dark I-V curve and subsequently fitting using a two diode model [16,17]. At elevated temperature, the change in series resistance ($\Delta R_{S,350}$) was evaluated by plotting the initial (lowest resistance) voltage as a function of current (V-I plot). This plot was then interpolated and subtracted from subsequent V-I measurements as shown in Fig. 2. The average values and standard deviation of the change in series resistance was then calculated using the positive current values of the resulting curves using:

$$\Delta R_{S,350} = \frac{V_{meas} - V_{initial}}{I}$$

It is important to note that in some instances $\Delta R_{S,350}$ changed so rapidly that there were alterations during the time interval (0.7 s) for the measurement to be carried out. This not only introduced errors into the measurements themselves but meant that altering the measurement frequency lead to slight changes in behavior over the entire process. In order to keep this effect manageable measurements were performed every 5 min during the process.

In order to illustrate the effect of the increase in series resistance simple simulations were carried out using PC1D [18], with the results for cell fill factor and efficiency presented in Fig. 3. The initial average

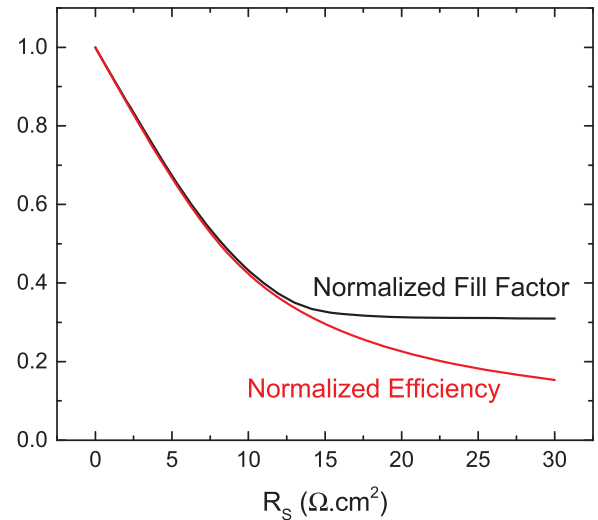


Fig. 3. Normalized Fill Factor and Power Conversion Efficiency as simulated using PC1D as a function of series resistance.

R_S value for our samples of $0.69 \Omega \text{ cm}^2$ reduces the fill factor and efficiency by less than 5%_{relative} compared to the case with no series resistance, while an increase of R_S to $2 \Omega \text{ cm}^2$ results in a 14%_{relative} reduction and an increase to $10 \Omega \text{ cm}^2$ results in a loss of more than 50%_{relative}. The parameters for these simulations may be found in Appendix A.

3. Results

3.1. Transmission line measurements

In order to accurately observe $\Delta R_{S,350}$ using in-situ measurements, temperatures close to 350°C were used in this work, resulting in a longer timescale for the $\Delta R_{S,350}$ increase than for samples re-fired at higher temperatures. It was therefore important to investigate whether the effects observed behaved in the same way as those reported in previous work [10]. In particular, it was necessary to check that increases in R_S were caused by a change in the contact resistance at the screen-printed metal fingers and that this increase was unstable under applied current at room temperature. This was done using transmission line measurements (TLM) [19] between the silver fingers of $30 \times 22 \text{ mm}$ samples cleaved from multi PERC cells without a busbar. As in previous work, in order to stabilize the readings, one of the contacts had its resistance minimized using a forward bias current prior to the measurement [10].

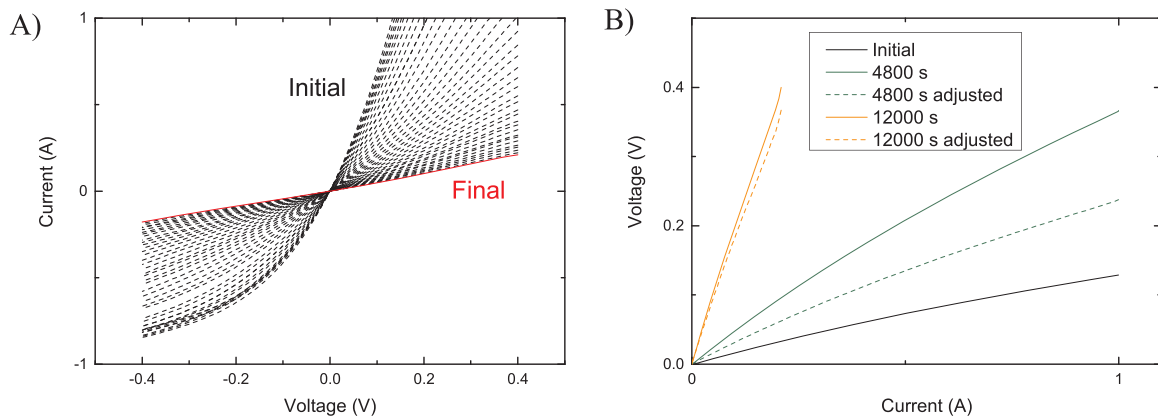


Fig. 2. A) In-situ I-V curves of a sample annealed at 350°C with a 0.2 V forward bias for 4 h sampled at 5 min intervals. B) V-I curves at the start of annealing, after 4800 s and 12000 s and curves adjusted by subtracting the initial curve.

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