The role of Na^+ contamination in humidity-induced degradation in silicon HJT cells

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Abstract

This work investigates the role of sodium ion (Na^+) contamination in humidity-induced degradation in bifacial n-type silicon heterojunction (HJT) solar cells. It is found that Na^+ ions are highly detrimental to the HJT cell architecture. When the front side is exposed to Na^+, the series resistance (R_s) increases, likely due to corrosion of the finger electrode and the transparent conductive oxide (TCO) layer. This resulted in a maximum power (P_{max}) and fill factor (FF) loss up to ~40%$_{rel}$ after only 20 h at 85 °C and 85 % relative humidity (damp-heat test). When the rear side is exposed to Na^+, an increase in recombination issue is detected in addition to contact degradation, possibly caused by Na^+ penetration into the cells. Consequentially, V_{OC} and FF drop after the damp-heat test, resulting in a P_{max} loss of ~25%$_{rel}$. With both sides contaminated with Na^+, the P_{max} degraded up to ~50%$_{rel}$ after 20 h of damp-heat testing. This work is crucial for HJT manufacturers as it highlights the possible failure modes that could occur in both glass-glass and glass- backsheet HJT modules when Na^+ ions diffuse from the solar glass as a result of the potential difference between the glass and the solar cell in field conditions. Therefore, attention should be paid to this contamination, and suppression methods should be applied at the cell or module level to prevent its detrimental impact.

1. Introduction

Silicon heterojunction (HJT) solar cells are recognized as one of the most promising technologies to improve silicon solar cell power generation. Currently, they hold the world efficiency record of 26.7% for silicon solar cells in an interdigitated back-contact (IBC) architecture [1]. However, HJT solar cells can suffer from reliability issues such as damp-heat (DH) or humidity-induced degradation (HID) and potential-induced degradation (PID), resulting in severe power loss [2]. Although the efficiency of HJT cells exceeds other cell technologies, these failure modes have slowed the deployment of this technology to the market. Therefore, more studies on these failure modes are required to pinpoint the root cause and develop mitigation approaches. Conventional soda-lime glass is commonly used as a cover glass in solar modules, mainly due to the low cost of this material. However, this glass contains a high amount of Na^+, potentially released into the cells under high voltage operating conditions [3]. The impact of Na^+ contamination on other cell technologies, such as passivated emitter and rear cells (PERC), has been broadly studied [4]–[6]; however, there have only been limited studies on HJT solar cells.

2. Experiment

Bifacial n-type silicon HJT solar cells sourced from industry were used in this work. The solar cells featured intrinsic hydrogenated amorphous silicon (i-a-Si:H) passivation layers on both sides, and phosphorus-doped (n-a-Si:H) and boron-doped (p-a-Si:H) hydrogenated amorphous silicon layers on the front and rear sides, respectively. Both sides had an indium-doped tin oxide (ITO) layer with a screen-printed H-pattern silver grid. Subsequently, a 0.9 %wt. NaCl solution (medical grade) was applied to the 1) front side, 2) rear side, and 3) both sides of the cells, and one cell was kept as a control (no Na^+ contamination exposure). All cells then underwent a damp heat test at 85 °C and 85% relative humidity (RH) for up to 20 h to study the role of Na^+ ion contamination in humidity-induced failures. See Figure 1 for the detailed experimental flow diagram. The current-voltage (I-V) measurements were performed for all samples at standard testing conditions at the initial state and after incremental steps during the ageing test using the LOANA tool from PV Measurements. The

photoluminescence (PL), electroluminescence (EL), and series resistance (PL-R_s) images were captured using a BTi (LIS-R3) luminescence imaging system before and after the ageing test.

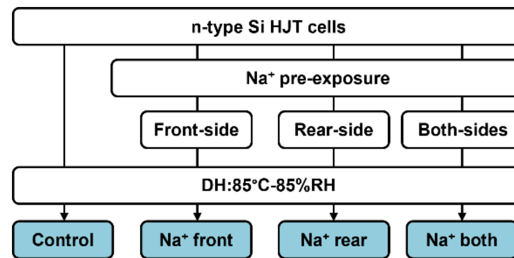

Figure 1. Experimental flow diagram

3. Results and discussion

Figure 2 shows the changes in I-V parameters of the control and cells that were exposed to Na^+ contamination on the front, rear and both sides before the damp heat testing. After 20 h of damp-heat testing, the control sample did not show any change in the I-V parameters. However, the cells that were pre-contaminated with Na^+ showed a significant decrease in all I-V parameters. The P_{max} and FF of cells with both sides pre-Na^+ exposure degraded up to ~50%$_{rel}$, while the reduction in open circuit voltage (V_{OC}) and short circuit current density (J_{SC}) was only ~2-3%$_{rel}$ as shown in Figure 2 (a, b, d, e). These losses were mainly driven by the failures occurring on both the front and rear sides of the cells. For the front side, the presence of Na^+ contamination during the damp-heat test primarily led to a substantial increase in series resistance (R_s), as shown in Figure 2(c), red curve. For the rear sides, the Na^+ ion contamination was observed to cause a more significant recombination loss in addition to the R_s increase, leading to a substantial drop in V_{OC} (~2%$_{rel}$), as shown in Figure 2 (d). Figure 2 (f) shows the evolution in saturation current density for the n=2 diode model (J_{02}) of the control and Na^+ contaminated samples after humidity testing. The J_{02} of the control and front side Na^+ contaminated samples remained relatively constant after 20 h of damp-heat testing. On the other hand, a considerable increase in J_{02} was seen on cells with the rear and both sides contaminated with Na^+, suggesting that more localized recombination issues occurred in these groups [7]. This recombination is likely caused by Na^+ ion penetrating the interface and into the silicon bulk leading to an increase in recombination. Note that saturation current density for the n=1 diode model (J_{01}) was also observed to increase for these samples (data not shown but will be presented in the final paper), implying that there is also a recombination increase in both the surface and bulk silicon due to Na^+ ion penetration during damp-heat.

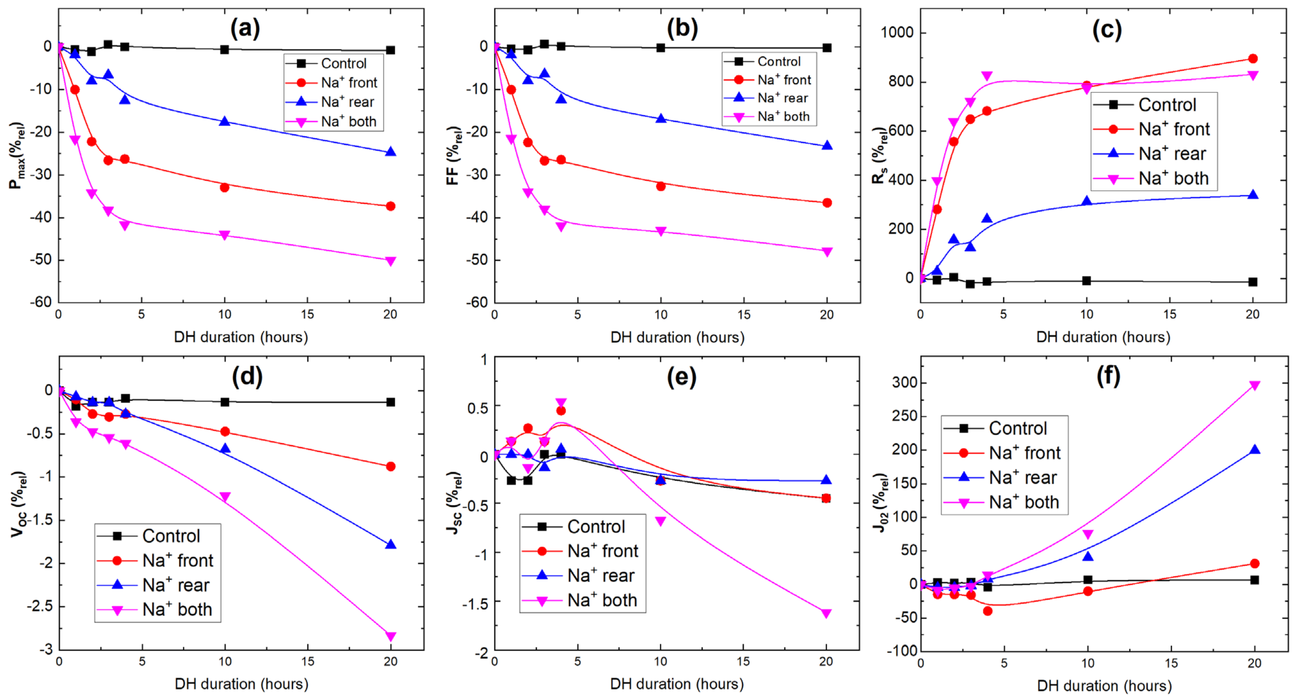

Figure 2: Changes in I-V parameters after damp-heat testing (a) P_{max}, (b) FF, (c) R_s, (d) V_{OC}, (e) J_{SC}, and (f) J_{02}.

Changes in PL images [Figure 3 (a)] further demonstrate the impact of damp-heat testing. No significant differences in PL counts were observed on the control and front Na^+ contaminated samples, implying no significant additional recombination loss on these samples. However, the PL intensity of samples with rear and both sides Na^+ contaminated dropped markedly, inferring an increase in recombination in these groups. This data aligns well with the change in V_{OC} shown in Figure 2 (d), where V_{OC} loss was mainly realized on the cells pre-contaminated with Na^+ on the rear and both sides. The explanation as to why no notable recombination loss occurred on the samples with front Na^+ contamination remains unclear; a more detailed study is ongoing to pinpoint the precise root cause and will be presented in the final paper.

The evolution of PL-R_s mapping images before and after 6 h of damp-heat testing of the control and pre-Na^+ contamination can be seen in Figure 3 (b). The R_s of the control sample remained relatively constant after the damp-heat test. High R_s increase throughout the whole cell area was seen on the samples with front and both sides pre-contaminated with Na^+. The R_s of the sample with rear side Na^+ contamination also slightly increased, with a more severe increase at the edge of the cell. These data are consistent with the R_s changes determined from the I-V measurement shown in Figure 2(c). The increase in R_s is possibly caused by corrosion of finger electrodes due to the electrochemical reaction between sodium, moisture, and silver, leading to contact oxidation, and reducing the conductivity of the finger electrode[8]. In addition, Na^+ ion may also electrochemically react with the ITO layers, leading to corrosion or ion exchanges between Na^+ ions and $(In_2O_3)_x(SnO_2)_{1-x}$, reducing lateral conductance and reducing carrier collection[9]. The reason why R_s on the front side increased more significantly and rapidly than on the rear side after a humidity test with Na^+ contaminated is still unclear and is an ongoing investigation. However, it is potentially related to the different properties of the ITO layers at the front and rear sides. Typically, the ITO layer on the front side is well optimized to reduce optical absorption losses, while the ITO layer on the rear side is optimized for good ohmic contact at the contact interfaces and high lateral conductance [10]. The rear ITO is possibly more resistant to corrosion induced by Na^+ and moisture, and as a result, the rear side R_s did not increase as rapidly.

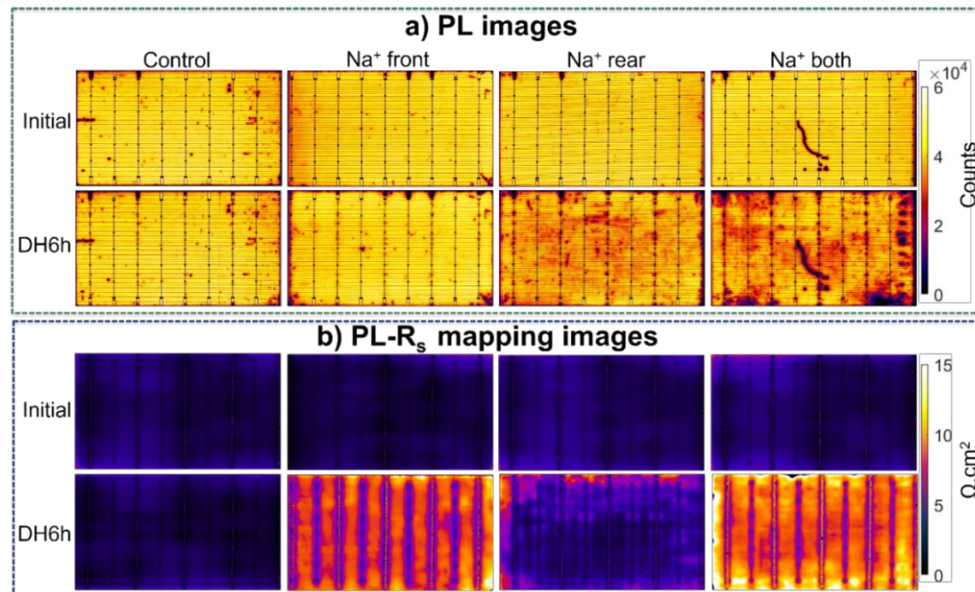

Figure 3 (a) Photoluminescence and (b) series resistance images of control, front side Na^+ contamination (Na^+ front), rear- Na^+ contamination (Na^+ rear), and both sides Na^+ contamination (Na^+ both) before and after 6 h damp-heat testing.

It is also important to note that no shunting-related issues were observed on the dark I-V measurements for the control and Na^+ contaminated samples after the damp-heat testing. These results are consistent with the results of the PID test on the HJT modules, where there was no shunting-related failure mode detected on the modules after ~400 h of PID test with/without bias voltage (data not shown). This suggests that HJT cells/modules may not suffer from this shunting-related failure mode in the field, but careful attention should be paid to the contact/ITO corrosion and recombination issues.

4. Conclusion

In summary, the impact of Na^+ ion contamination in humidity-induced degradation in bifacial n-type silicon HJT solar cells without encapsulation was investigated. It was found that Na^+ contamination is very harmful to HJT cells. On the front side, it was shown to quickly degrade the finger electrode and ITO layer, leading to a rapid increase in R_s on the front side. However, if Na^+ contamination was introduced to the rear side, in addition to the finger electrode and ITO layer corroding, it also caused an increase in recombination, resulting in a significant V_{OC} loss. It should be noted that these results are also relevant for HJT modules. PV module glass typically contains a significant amount of Na^+, which can diffuse to the solar cell due to the high potential difference between the glass and solar cell in the field. This may necessitate a solar cell level solution to protect the HJT solar cell from this failure mode.

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