Effects of Soldering Flux on the Reliability of TOPCon and HJT Solar Cells: A Comparative Study Under Low Humidity and Varied Illumination Conditions

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Abstract

Silicon heterojunction technology (HJT) and tunnel oxide passivated contacts (TOPCon) solar cell technologies are expected to gain significant market share in the coming years. There are, however, still some questions about the long-term stability of these technologies. This work examines the effects of two different soldering fluxes on the stability of tunnel oxide passivated contacts (TOPCon) and heterojunction technology (HJT) n-type solar cells, both in the dark and under illumination, in an environment with low humidity. TOPCon cells are found to be stable under low humidity irrespective of the illumination conditions, while HJT cells show severe degradation after testing. The series resistance (R_s) of HJT cells contaminated with flux substantially increased by approximately $700\%_{rel}$, leading to an efficiency drop of around $30\%_{rel}$ after only 50 hours of light soaking testing. After 50 hours of dark annealing, the efficiency of HJT cells decreased by up to $\sim70\%_{rel}$ because of a considerable increase in R_s of $\sim1500\%_{rel}$. The degradation is likely caused by the corrosion of the silver electrodes. This finding is vital for the PV industry as it suggests that under low humidity conditions, the metal contact of TOPCon cells appears to be corrosion resistant to soldering flux residue, while the metalisation of HJT cells appear to corrode easily. Additional efforts are required to enhance the reliability of HJT cells against degradation induced by soldering flux.

Introduction

Silicon heterojunction technology (HJT) and tunnel oxide passivated contacts (TOPCon) solar cell technologies have garnered significant attention as cutting-edge trends within the solar industry. Their exceptional performance has positioned them prominently, with projections pointing towards their dominance in the solar market within approximately five years [1]. However, these solar cells still encounter reliability issues that cause substantial power loss when subjected to high humidity [2] [3] [4] [5]. One of the most frequently observed causes of performance deterioration is metal contact corrosion, which increases series resistance (R_s) over time [6]. The underlying cause of this corrosion is believed to be electrochemical reactions occurring between moisture, metal contact of the solar cells and various contaminants, including acetic acid, sodium, and residue of soldering flux [2] [3] [4] [5]. Soldering flux is commonly used to facilitate the soldering process of connecting ribbon wires to the busbars of solar cells. Several research groups have highlighted a significant concern regarding the influence of soldering flux residue on solar cells under standard damp heat conditions of 85 ^oC and relative humidity of 85% [5]. Yet, uncertainties persist regarding the potential impact of soldering flux on solar cells under conditions of reduced humidity. Additionally, the potential impact of illumination conditions on the extend of degradation remains unexplored. Therefore, this study aims to determine the impact of soldering flux on the failure mode in TOPCon and HJT solar cells under low humidity conditions, both in the absence and presence of light.

Experiment

This study used bifacial n-type silicon HJT and TOPCon solar cells sourced from an industrial production line. The HJT cells had intrinsic hydrogenated amorphous silicon (i-a-Si:H) passivation layers on both sides, along with phosphorous-doped hydrogenated amorphous silicon (n-a-Si:H) on the front side and boron-doped hydrogenated amorphous silicon (p-a-Si:H) on the rear side. Both sides had an indium-doped tin oxide (ITO) layer featuring a screen-printed H-pattern silver grid. The TOPCon cells featured a boron-doped emitter (p^+ emitter), silicon dioxide (SiO_2)/Al_2O_3/SiN_x:H stack, and a screen-printed H-pattern silver grid on the front. At the rear side, there was a SiO_2/phosphorusdoped poly silicon (n^+poly-Si)/SiN_x:H stack and a screen-printed H-pattern silver grid. Subsequently, both HJT and TOPCon cells were cleaned with deionised (DI) water and dried by blowing nitrogen (N_2) on both sides before the subsequent processes to minimise surface contamination (potentially introduced from contaminated gloves, placed on contaminated stages for characterisation, etc.). Afterwards, two types of soldering flux (SF180S and SF56) were sprayed onto the solar cells (one cell per flux type). Flux SF180S is composed of 96.0% - 99.0% isopropyl alcohol and 1.0% - 4.0% carboxylic acid. Flux SF56 contains 94.5% - 97.5% isopropyl alcohol, 1.50% l-malic acid, and 1.00% - 4.00% diethylene glycol monobutyl ether. The different types of flux were applied only to the front or rear side of TOPCon, and both sides of HJT solar cells. To eliminate any residual alcohol content, the cells were heated on a hot plate at 85°C for 10-15 minutes until they were completely dry, leaving behind only the acid residue. One cell in each group was left as a control without flux exposure. Afterwards, these cells were divided into two groups. One group underwent a light soaking (LS) test at 85 ºC and 1 sun for 50 hours, while another underwent dark annealing (DA) at 85 ºC for 50 hours. The humidity was set to 0% in both LS and DA testing, but the ambient humidity in the testing tool was higher than 0%. 1 shows the detailed experimental flow diagram in this work. The current-voltage (I-V) measurements were done at the initial state and after tests by a LOANA tool from PV Measurements. BTi (LIS-R3) luminescence imaging system was used for capturing series resistance (PL-R_s) images before and after the stability tests.

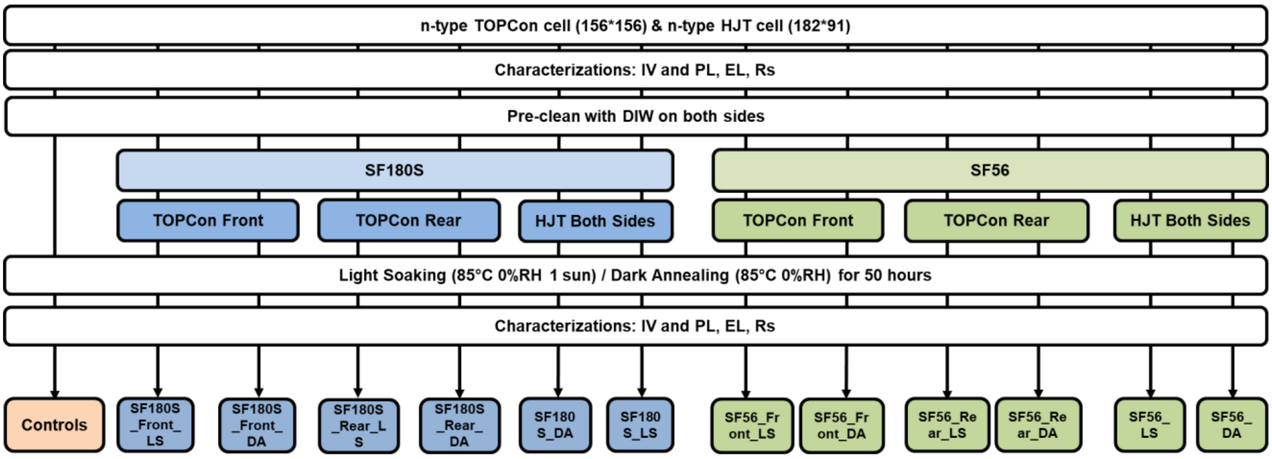

Figure 1. Detailed experimental flow diagram

Results and discussion

Table 1 shows the changes in I-V parameters in all cells after LS and DA testing. No substantial changes were observed in the HJT and TOPCon control groups. These results indicate that both LS and DA had no impact on the performance of HJT and TOPCon cells. The TOPCon samples that were subjected to flux either on the front or rear side prior to the stability test did not degrade after 50 hours of LS or DA testing. However, HJT samples with flux exposure on both surfaces degraded pronouncedly after both LS and DA testing. The R_s of HJT samples with flux exposure increased up to ~700%$_{rel}$ after 50 hours of LS testing, resulting in a decrease in efficiency (η) of ~30%$_{ref}$. There were no noticeable variations in the short circuit current (J_{sc}) and open circuit voltage (V_{oc}) of the HJT cell that underwent the LS test.

The HTJ cells with flux exposure degraded more severely under the DA compared to the LS test. After 50 hours of DA testing, the R_s of the HJT cells exposed to soldering flux increased by ~1500%$_{rel}$. Unlike LS testing, both J_{sc} and V_{oc} degraded sustainably after DA testing, especially the sample with SF180S, which had a considerable drop in J_{sc}. The loss in J_{sc} was likely attributed to the significant increase in R_s, which hindered the efficient collection of carriers.

Table 1. Changes in I-V parameters after light soaking testing and dark annealing

Test	Sample	∆ Efficiency	∆ Jsc	∆ Voc	∆ FF	∆ Rs

Light soaking	TOPCon	SF56-front	0.3%	-0.1%	0.2%	0.2%	-28.7%
		SF56-rear	0.2%	0.0%	0.1%	0.2%	-46.0%
		SF180S-front	0.6%	0.1%	0.2%	0.4%	-51.4%
		SF180S-rear	0.6%	0.1%	0.1%	0.5%	-41.2%
		Control	0.9%	0.1%	0.2%	0.4%	-40.6%
	HJT	SF56	-27.3%	0.0%	0.1%	-27.1%	559.6%
		SF180S	-28.6%	0.3%	0.0%	-28.6%	679.1%
		control	0.4%	0.0%	0.0%	0.1%	2.2%
Dark Annealing	TOPCon	SF56-front	0.6%	-0.1%	0.0%	0.8%	-89.5%
		SF56-rear	0.2%	-0.1%	0.1%	0.4%	-68.5%
		SF180S-front	0.1%	0.2%	0.0%	0.0%	0.5%
		SF180S-rear	0.6%	0.1%	0.1%	0.5%	-64.9%
		Control	0.2%	0.1%	0.0%	0.1%	-26.4%
	HJT	SF56	-54.2%	1.8%	-0.9%	-54.4%	967.9%
		SF180S	-66.9%	-13.0%	-0.8%	-61.5%	1523.8%
		control	0.4%	-0.3%	-0.1%	1.0%	-30.4%

Figure 2 displays the PL-R_s images of HJT samples before and after LS and DA testing. The control sample exhibited relatively consistent R_s values before and after both LS and DA testing. However, a severe increase in R_s of HJT cells with flux spray was observed across the entire cell area in samples after LS testing, in line with results from the I-V measurements. The samples with flux spray almost degraded completely after 50 hours of DA testing, as shown in Figure 2 (b). It is likely that the increase in R_s was caused by the corrosion of the finger electrodes and/or ITO layers due to an electrochemical reaction between the organic acid (which is a residue of soldering flux), moisture, and the metallisation and/or ITO of the HJT cells [5]. Based on these findings, it seems that some types of soldering flux may negatively affect the metallisation and/or ITO of HJT solar cells, even when exposed to low levels of moisture. However, it is still unclear why HJT cells that are exposed to soldering flux tend to experience more significant degradation in the dark; more work is ongoing to identify the underlying cause of this problem. Moreover, it is also essential to determine whether the flux impacts the front or the rear surface of the HJT cells.

Figure 3 shows the PL-R_s images of TOPCon solar cells. Unlike HJT solar cells, the R_s of TOPCon solar cells did not change obviously after LS and DA testing, which is aligned well with the I-V results.

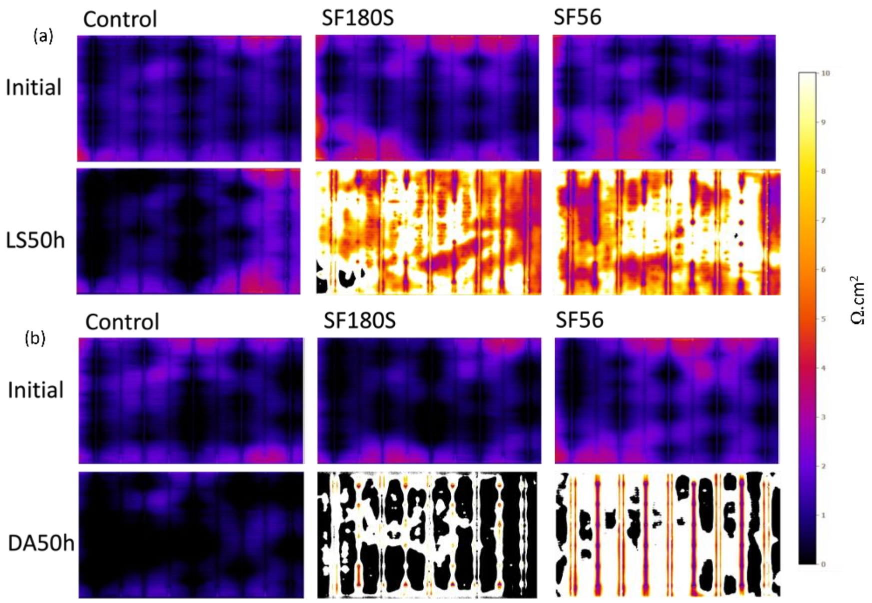

Figure 2. Changes in PL-R_s images of HJT solar cells (a) after light soaking testing (b) after dark annealing testing

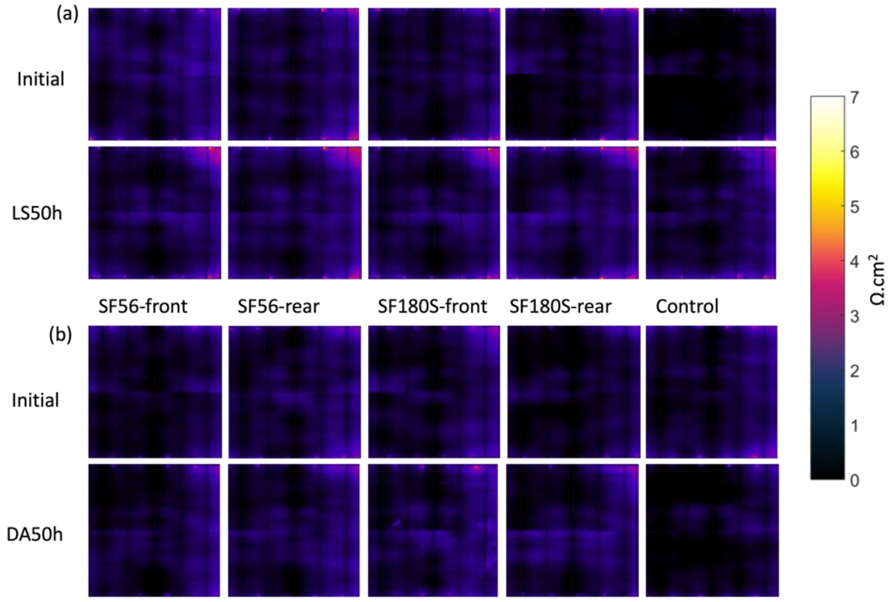

Figure 3. Changes in PL-R_s images of TOPCon solar cells (a) after light soaking testing (b) after dark annealing testing

Conclusion

In conclusion, this study investigates the impact of two different fluxes on the failure in HJT and TOPCon solar cells under dark and light with low humidity. TOPcon solar cells were proven to be insensitive to soldering flux under low humidity conditions. However, our study shows that both tested types of soldering flux can cause substantial failure to HJT solar cells in the presence of light and during dark annealing, even under low humidity conditions. This suggests that the metallisation and/or ITO layer of HJT solar cells are susceptible to corrosion caused by the soldering flux. The chemical reaction between the soldering flux and the metalisation and/or ITO layers of HJT cells can significantly increase R_s, particularly during dark testing. The results of this study have important consequences for the photovoltaic industry. It highlights the need for increased focus on the soldering flux aspect during production and improving the corrosion resistance of the metallisation and/or ITO layers in HJT cells.

Acknowledgements:

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